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The Application and Challenges of Virtual Reality (VR) Painting Technology in Art Education in China: A Case Study of Universities in Mianyang, Sichuan Province

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Abstract

This study investigates the application and challenges of virtual-reality (VR) painting technology in the fine-arts curriculum of a university in Mianyang, Sichuan Province, China. Using a qualitative embedded case-study design, eight first- and second-year fine-arts majors were followed in depth. The analysis focuses on immersion, spatial perception, adaptation of creative habits, and cultural localization when students produce artwork in VR. Results show that VR painting performs well for low-complexity tasks, yet encounters technical bottlenecks—rendering distortion, imprecise control, and disrupted workflows—when high precision is required. Users report physiological fatigue and motion sickness, and they must negotiate a steep learning curve. Cultural fit and language barriers further constrain adoption. While VR painting holds clear pedagogical promise, wider educational deployment hinges on resolving both technological shortcomings and socio-cultural mismatches.

Keywords: Virtual Reality (VR), Painting Technology, Art Education, Mianyang, Higher-Education Institutions

Introduction

Background

Virtual-reality (VR) painting is widely regarded as a paradigmatic shift in digital-art creation. By offering an immersive three-dimensional canvas and handle-based "natural" interaction, it liberates artists from the physical and material constraints of traditional media (Motejlek & Alpay, 2021). The proliferation of affordable head-mounted displays (e.g., Meta Quest 2) has lowered the entry barrier, turning the ideal of "the body as brush" into an everyday classroom possibility (Yang, Zhou, & Radu, 2020). Yet inside art-education systems—especially non-Western higher-education contexts—VR painting still diffuses slowly. First, the absence of tactile feedback produces sensory deprivation, weakening the felt texture of brushstrokes (Prabhakaran, Qadri, & Hutchinson, 2022). Second, fragmented interface layers and deep menu hierarchies inflate cognitive load (Prabhakaran et al., 2022). Third, icon metaphors, tutorial narratives and controller idioms are culturally encoded in Western interaction norms, creating a cognitive mismatch for Chinese students (Prabhakaran et al., 2022). Against the backdrop of China's rapid expansion of digital-art programmes, clarifying the regional fitness of VR tools has become a prerequisite for curricular innovation (Viberg, Jivet, & Scheffel, 2022). Mianyang, a non-tier-one city that nevertheless hosts a dense cluster of undergraduate art and design departments in western China, offers a representative site in which to observe these frictions (Apple, 2019).

Research Problem and Significance

Notwithstanding its promise, VR deployment in regional Chinese universities is blocked by two intertwined problems.

(1) The "adaptation gap": conventional foundation training privileges two-dimensional perspective, tactile layering and brush-force control—skills that possess no direct mapping inside VR. Students must therefore cross an as-yet-unquantified transfer threshold (Zhuang, Wang, & Sun, 2024). Interface and tutorial languages dominated by English further amplify cultural friction.

(2) The "instructional-validity gap": empirical studies on VR painting for foundational art training overwhelmingly sample elite Western academies, leaving the non-Western, non-prestige context almost unexamined (Liao et al., 2025).

Situated in a mid-scale city campus, the present study explores early-stage art majors' adaptability and acceptance, supplying local evidence for curriculum designers and VR developers and promoting equitable integration of educational technology.

Objectives and Scope

Overall aim: evaluate the feasibility of VR painting as a pedagogical tool for art-and-design majors in Sichuan regional universities.

Specific research questions:

Q1 How do undergraduates in Mianyang perform and adapt when executing fundamental 2-D painting tasks inside VR?

Q2 What culturally responsive design refinements can be proposed for Chinese students on the basis of observed difficulties?

Core activity: eight first- and second-year art/design students from Mianyang completed two standardised 2-D tasks—line-drawing of a still-life set (Task A) and a fully coloured composition (Task B)—on the Painting VR platform, followed by reflective debriefing.

Methodology

Qualitative embedded case study.

Participants: eight volunteers (3 male, 5 female; aged 18–20; 3 freshmen, 5 sophomores) enrolled in two public comprehensive universities in Mianyang.

Instruments: (a) two structured VR tasks run on Painting VR; (b) 30–40-minute semi-structured interviews focusing on perceived usability, cognitive load and motivational factors; (c) researcher observation notes.

Analytical procedure: Braun & Clarke's (2006) six-phase thematic analysis; coding supported by ATLAS.ti 24.

Scholarly and Practical Value

Theoretically, the study supplies de-Westernised, site-specific evidence that redresses the Euro-American bias documented in current VR-and-art-education literature (Liao, 2024). Practically, it offers local institutions empirically grounded guidance on optimal entry points for VR integration—such as semester placement and prerequisite skill sets. From a design perspective, the findings will inform culturally responsive refinements: interface optimisations grounded in non-Western human–computer interaction logic and concrete classroom scenarios for deploying VR headsets in fine-arts and design pedagogy. By tightly coupling technological innovation with grassroots instructional needs, the research provides both theoretical scaffolding and a replicable model for the equitable global diffusion of immersive art education.

Research Motivation

Virtual reality (VR) painting offers a new paradigm for artistic creation with immersive three-dimensional canvases and natural interaction through controllers, and is regarded as a paradigm shift in digital art (Motejlek & Alpay, 2021). The popularity of consumer-grade headsets, such as the Meta Quest 2, has further lowered the entry barrier, bringing the concept of "body as brush" into everyday classrooms (Yang, Zhou, & Radu, 2020). However, in non-Western higher art education contexts, the actual diffusion of VR painting lags behind technological development: first, the lack of haptic feedback leads to a "sensory deprivation" of brushstroke texture and materiality, affecting the sense of touch and authenticity in basic modeling training (Prabhakaran, Qadri, & Hutchinson, 2022); second, the layered and complex interface and deep menus increase cognitive load, which is not conducive to skill transfer for beginners (Prabhakaran et al., 2022); third, the icon metaphors, tutorial narratives, and controller grammars mostly originate from Western interaction cultures, which may be out of alignment with the cognitive habits of Chinese students (Prabhakaran et al., 2022). Against the backdrop of the rapid expansion of digital art programs in China, clarifying the "regional adaptability" of VR tools in local teaching has become a prerequisite for promoting curriculum innovation (Viberg, Jivet, & Scheffel, 2022).

Based on this, the first motivation of this study lies in responding to the "adaptation gap": traditional basic courses emphasize two-dimensional perspective, texture superposition, and pen control, and these key skills lack one-to-one operational mappings in the VR environment, which may pose unquantified transfer thresholds for students (Zhuang, Wang, & Sun, 2024). The second motivation is to fill the "instructional validity gap": existing evidence regarding the use of VR painting for basic training mostly comes from elite institutions in the West, and empirical research in non-Western and non-top university contexts is scarce (Liao et al., 2025; Liao, 2024). This not only limits the generalizability of the conclusions but also makes it difficult to provide operational course decision-making bases for regional universities.

The third motivation stems from considerations of field representativeness and generalizability. Although Mianyang is not a first-tier city, it houses multiple undergraduate-level art and design departments. This makes it possible to observe the resistance and opportunities when introducing VR painting teaching in a context of limited resources and growing demand (Apple, 2019). Conducting an embedded case study here can help generate "de-Westernized" local evidence, determine the best entry points for VR integration for regional universities (such as semester nodes and prerequisite skill thresholds), and provide culturally responsive design improvement suggestions for developers targeting Chinese students.

Finally, from the perspectives of research methods and practical value, this study implemented standardized two-dimensional tasks (still life line drawings and colored works) in Painting VR, combined semi-structured interviews and observation records, and used thematic analysis to extract themes related to usability, cognitive load, and motivation (Braun & Clarke, 2006). The expected contributions include: supplementing non-Western evidence at the theoretical level, providing a basis for curriculum design and teacher training at the practical level, and proposing localized optimization paths for interfaces and interactions at the design level, thereby promoting the fair diffusion of immersive art education in diverse institutional environments.

Literature Review

Evolution of Virtual-Reality Painting Technology

From Early Probes to Mainstream Adoption: Hardware Innovation and the Changing Interaction Experience

Virtual-reality painting can be traced back to the SANDDE system launched by Canadian IMAX in the 1990s. By enabling free-hand 3-D strokes for animated film production, SANDDE is regarded as the first VR painting prototype (Hand, 2000). In the early 2000s the OverCoat system introduced by Schmid et al. replaced explicit canvases with implicit volumetric surfaces, letting users paint directly in 3-D space and greatly expanding expressive range (Schmid et al., 2019). The 2014 release of consumer head-mounted displays—Oculus Rift DK2 and HTC Vive—moved VR painting out of the laboratory: six-degree-of-freedom controllers, Lighthouse tracking and inside-out algorithms delivered sub-millimetre accuracy while cutting latency, price and calibration time (Keefe et al., 2001). Latest-generation stand-alone headsets (Meta Quest 2, PICO 4) integrate hand-tracking chips and wireless streaming, removing external base stations and lowering the deployment barrier for large-scale campus adoption (Pico Interactive, 2022).

Software Ecosystem: Functional Comparison of Tilt Brush, Painting VR and Gravity Sketch

Current VR painting packages cluster into two camps: "expression-oriented" and "design-oriented". Table 1 compares the three most cited titles along task-relevant dimensions.

Table 1

Feature comparison of leading VR painting applications

Dimension	Tilt Brush	Painting VR	Gravity Sketch
Core aim	immersive 3-D expressive painting	2-D/3-D foundational teaching	industrial design sketching & modelling
Brush system	200+ particle/light brushes	simulated oil, watercolor, marker	NURBS curves & patches
Export formats	.fbx, .obj, video	.png, .mp4	.iges, .step, .fbx
Collaboration	single user	single user	4-user multi-platform real-time

Tilt Brush's rich particle/light brushes and vibrant online community make it the default choice for galleries and art creation (Tilt Brush, 2021). Painting VR's simplified 2-D canvas emulation and shallow menu hierarchy match the needs of novice learners (Oisoi Studio, 2022). Gravity Sketch bridges "sketch–model–engineering" through NURBS surfaces and parametric modelling and has been adopted by Ford, Nissan and other corporate design departments (Gravity Sketch, 2020).

VR Painting in Art-Education Research

Skill Transfer and Creativity: Insights from Cognitive Load, Flow and Spatial-Cognition Theories

Over the past five years studies have converged on Cognitive Load Theory (CLT), Flow Theory and spatial-cognition frameworks to explain how VR painting affects transfer and creativity. A meta-analysis of 54 papers (2009-2019) by Di Natale et al. (2020) found that immersive VR yields a medium-to-large effect on spatial-reasoning in both K-12 and university students (Hedges' g = 0.62), but intrinsic cognitive load moderates the relationship: when task complexity exceeds working-memory capacity creativity scores follow an inverted-U curve. Ho et al. (2019) compared 62 undergraduate animation majors working on 3-D modelling tasks in either VR painting or traditional tablet conditions; the VR group scored significantly higher on fluency and originality ($p < .01$) and the flow sub-dimension "action–awareness merging" predicted transfer performance ($\beta = .48$), indicating flow as a key mediator. Hui et al. (2022) further showed that segmented scaffolds and adjustable viewport overlays reduce extraneous load and optimise primary-school pupils' skill transfer. Collectively, the evidence argues that sustaining flow while managing cognitive load is the pivotal condition for deploying VR painting as a creativity-enhancing tool.

Pedagogical Settings: Stratified Studies across K-12, Undergraduate and Lifelong Learning

Empirical work reveals stage-specific advantages. A synthesis of 82 studies (2000-2020) by Lara-Alvarez et al. (2023) shows that K-12 applications focus on interest arousal and basic spatial-concept construction through highly scripted, low-autonomy tasks (e.g., colour-shape exploration along pre-set paths). Undergraduate education, by contrast, stresses cross-media expression and design thinking, requiring high-autonomy, cross-platform environments such as Gravity Sketch that support multi-dimensional iteration. A quasi-experiment with 48 primary-school pupils (Hui et al., 2022) reported a 27 % gain in spatial-composition scores over a multimedia slide deck (Cohen's d = 0.64) but no significant effect on colour perception, confirming that younger learners benefit most from embodied spatial cues. In lifelong-learning contexts VR's social presence value dominates: a Virginia Commonwealth University project had 16 professional designers conduct real-time virtual critiques in Gravity Sketch; avatar-mediated feedback frequency rose 230 % compared with a traditional forum, demonstrating that social presence prolongs adult-learner engagement depth.

Cultural Difference and Interface Localisation

HCI Cultural-Dimension Models: Hall's High-/Low-Context and Nisbett's Cognitive Style

Edward Hall's high-context (HC) / low-context (LC) continuum remains the backbone of cross-cultural HCI research. HC cultures (e.g., China, Japan) rely on implicit, relation-oriented communication, whereas LC cultures (e.g., USA, Germany) prefer explicit, code-oriented messages. Broeder (2021) confirmed that HC users favour icon-dense dashboards and contextual cues, whereas LC users choose linear menus with detailed labels. Nisbett's holistic-analytic cognition model adds that East-Asian users scan interfaces in circular paths and attend to background relationships, while Western users adopt focal, sequential targeting. These differences directly inform VR controller design: holistic thinkers suit radial, context-rich menus; analytic thinkers prefer hierarchical toolbars.

Language and Narrative: Impact of Tutorial Localisation on Learning Efficiency
Tutorial localisation must go beyond literal translation to embrace narrative framing and pacing. In an RCT with 120 Chinese undergraduates, Chen & Mei (2021) compared (a) English voice-over with verbatim Chinese subtitles (control) versus (b) Sichuan-dialect narration plus contextual storytelling (experimental). The experimental group improved post-test scores by 30 % and reduced perceived cognitive load (NASA-TLX) by 26 %. Qualitative interviews showed that local metaphors (e.g., "painting is like pouring hot-pot soup base") enhanced retention. Lee et al. (2020) further demonstrated that implicit narrative tutorials matched to HC learning preferences outperform explicit step-by-step guides preferred by LC learners. Narrative style consonant with cultural communication norms is therefore decisive for instructional effectiveness in VR painting education.

The Chinese Digital-Art Education Context
Policy and Industry: New Liberal Arts, Digital China Strategy and the Regional Resource Gap
National strategy has elevated digital-art education to a top priority. The Digital China Master Plan (State Council, 2023) and the parallel "New Liberal Arts" initiative mandate deep integration of AI, VR and big-data analytics into art-and-design programmes to cultivate "digital-literacy + aesthetic-innovation" hybrid talent. The Ministry of Education's Guidelines for Digital Transformation in Higher Education (2022) earmarks special funding for "New Liberal Arts Labs" in central-western universities, yet fieldwork shows only 38 % of western institutions obtained VR-studio grants versus 71 % in the eastern coastal region. In tier-three cities such as Mianyang, hardware acquisition depends heavily on local-government co-financing and corporate partnerships, producing marked intra-provincial disparities in equipment and teaching formats.

Curricular Design: Credit Contest between Traditional Foundations and Digital Media
The 2018 National Teaching Quality Standards subdivide digital-media programmes into "digital-media art" (creative track) and "digital-media technology" (technical track). In the creative track, 34 % of the 1 600 total contact hours are still allotted to "sketch + colour + composition", whereas VR/AR modules are capped at 128 hours (Chen et al., 2022). Interviews with faculty in Shandong and Sichuan reveal that ministry accreditation continues to treat hand-drawing skill as a core assessable outcome, constraining immersive-painting expansion (Zhang Guangshuai, 2022). Pilot schools that compressed foundational drawing into a six-week intensive have freed credits for VR painting and report positive learning gains (Biermann et al., 2022).

Student Profile: Gen-Z Digital-Native Traits, Economic Capital and VR Exposure
Chinese Gen-Z (born 1997-2012) are hyper-active on short-video platforms such as Douyin and WeChat, yet VR ownership remains low. China VR Market Report 2024 (PatentPC, 2024) places household headset penetration at ~14 %, heavily skewed by income: children from families earning > RMB 200 k yr^{-1} show significantly higher prior exposure and stronger technical adaptability (National Bureau of Statistics of China, 2025). Rural pupils experience 41 % higher cognitive-load scores when operating English-language VR creation systems than urban peers (ResearchGate, 2025). These socio-economic and experiential gaps underline the urgency of building localised onboarding systems and device-subsidy mechanisms in regional universities.

Research Gaps and Theoretical Framework

Synthesis of Gaps: The Adaptation Deficit and the Instructional-Validity Deficit
Two inter-locking voids persist in the VR-based art-education literature.

First, an adaptation deficit is manifest: Chinese art students confront an undocumented skill-transfer threshold when moving from paper-and-pencil to controller-based 3-D painting, producing elevated cognitive load and diminished self-efficacy (Deer et al., 2023). The chasm between two-dimensional conventions emphasised in traditional studio training and the novel demands of volumetric, handle-mediated creation remains theoretically unquantified and pedagogically unsupported.

Second, an instructional-validity deficit arises from the near-absence of empirical work conducted outside elite, Western institutions; existing evidence is overwhelmingly generated in North-American or European laboratories, severely curtailing external validity (Rashid, 2024). How VR can be enacted effectively in resource-constrained, non-Western curricula is therefore still an open question.

Bridging these two gaps is a prerequisite for culturally equitable diffusion of immersive art education.

Core Theories Guiding the Present Study

To simultaneously address adaptation and validity, the study mobilises an integrated lens that combines three complementary theories:

TAM3 (Technology Acceptance Model 3) – supplies the mechanism pathway: perceived ease-of-use and perceived usefulness, moderated by cultural variables, predict students' behavioural intention to adopt VR painting.

CLUE (Cultural Localisation of User Experience) – embeds Hofstede's dimensions to ensure that interface metaphors, tutorial narratives and interaction rhythms are congruent with Chinese high-context, holistic cognitive preferences.

CLT (Cognitive Load Theory) – furnishes design heuristics for reducing extraneous load, optimising germane load and calibrating task complexity so that working-memory resources are freed for creative transfer.

By triangulating acceptance determinants (TAM3), cultural fit (CLUE) and information-processing efficiency (CLT), the framework offers a theoretically grounded and culturally responsive basis for examining VR painting pedagogy in China's regional universities, thereby closing the documented adaptation and instructional-validity gaps.

Methodology

Introduction

This study adopts a qualitative embedded case design, focusing on eight first- and second-year fine arts undergraduates at a university in Mianyang. VR painting instruction serves as the embedded unit. Leveraging the strengths of multi-level analysis, contextual sensitivity, and flexible data collection (Scholz & Tietje, 2002; Budiyanto et al., 2019), the study rapidly examines cultural adaptation and implementation feasibility.

Research Setting and Participants

Research Setting

This research is situated in a single site: a public comprehensive university in Mianyang, Sichuan Province, China. As a non-first-tier city with a resident population of 4.8 million and multiple regional campuses, Mianyang provides a typical context for observing how emerging technologies are integrated into resource-constrained higher-education environments in China (State Council, 2023). The university's School of Fine Arts comprises four disciplinary tracks with approximately 1,200 undergraduates. In recent years, the institution has received municipal special funding to upgrade its "New Liberal Arts" digital laboratories, making it a critical case for exploring the application of VR technologies in regional art education.

Participants

Using purposive sampling to ensure heterogeneity (Palinkas et al., 2015), eight volunteers were recruited. Inclusion criteria were: (1) majoring in fine arts or design; (2) currently enrolled in Year 1 or Year 2; and (3) no prior training on VR painting systems. The final sample consisted of three first-year and five second-year students (five women, three men; ages 18–20). This distribution aligns with the logic of embedded units proposed by Yin (2018), enabling within-group comparison between novice and more advanced learners while maintaining research integrity. All participants provided informed consent and were assigned pseudonyms (P01–P08) to ensure anonymity. By focusing on a regional university and integrating the experiences of eight students, the study capitalizes on the holistic strengths of case research (Stake, 2005) while enhancing analytic precision (Yin, 2018). The design offers contextual transferability (to similar institutions) and contributes to theoretical development (e.g., on cultural localization and cognitive load in VR art education).

Instruments and Equipment

Hardware Configuration

A single Meta Quest 2 head-mounted display (HMD) was used in a rotation scheme across the eight participants. The device features a per-eye resolution of 1832 × 1920 pixels, a 90 Hz refresh rate, and six-degrees-of-freedom inside-out tracking. Recent research on VR pedagogy has verified that such specifications can support sufficient immersion and user comfort for art-creation tasks.

Software Environment

Painting VR v.2024.3.1 served as the dedicated painting platform. It provides a low-latency brush engine, precise color-mixing algorithms, and a "desktop easel" mode that simulates traditional still-life drawing scenarios. Empirical use indicates that these features can reduce extraneous cognitive load for novice VR artists.

Qualitative Analysis Tool

All interview transcripts, observation notes, and screen-recording files were imported into the Alasiti qualitative analysis platform v.3.2. Its collaborative coding suite supports open coding, axial categorization, and reflexive memoing, aligning with four commonly cited credibility criteria in recent evaluations of qualitative software (e.g., data saturation checks and inter-coder reliability assessment).

Data Collection Procedures

Phase 1: Device Familiarization (one day)

Participants were given a day to read the researcher-authored *VR Still-Life Operating Manual* (12 pages with bilingual screenshot instructions) and independently complete five basic tasks—power-on, boundary calibration, brush selection, color mixing, and save/export—to ensure baseline operational competence and reduce subsequent extraneous cognitive load.

Phase 2: VR Still-Life Drawing Test (3 hours)

Task A required each participant to complete a full-tonal still-life sketch of a virtual desktop scene. Only one Meta Quest 2 headset was used and rotated among participants. Each session was recorded via the Oculus casting function. The researcher's field notes documented controller-operation frequency, viewpoint-switching behavior, and instances of help-seeking.

Phase 3: Semi-Structured Interviews (30–40 minutes)

Immediately after Task A, participants completed audio-recorded semi-structured interviews (10 open-ended questions) covering perceived cognitive load, cultural fit, and beliefs about skill transfer.

Data Management

All raw data (including Q&A records) were imported into the Alasiti qualitative analysis platform v.3.2.

Data Analysis

The study employed the six-phase reflexive thematic analysis articulated by Braun and Clarke (2021):

(1) familiarization with the data through repeated reading of interview transcripts and field notes;
(2) generating initial codes inductively within the Alasiti platform;
(3) collating codes into candidate themes;
(4) reviewing themes in relation to the full dataset;
(5) defining and naming themes; and
(6) producing the final research report.

Findings

Introduction

This chapter synthesizes, from multiple dimensions, the questionnaire responses provided by the volunteers after completing VR-based drawing tasks.

Analysis of the Positive and Negative Effects of Immersion on Spatial Perception

By reconstructing three-dimensional space, the Quest 2 significantly expands users' creative scope in three main ways. First, immersive spatial freedom improves: its 360° surround view breaks the limits of a flat canvas and eliminates visual blind spots present in the physical world, enabling users to scrutinize interior and exterior structures of still lifes from multiple angles and thereby generate novel creative experiences. Second, virtualization of the creative toolchain removes the need for physical consumables through virtual paints and brushes; simulated haptic feedback further enhances the fluidity and naturalness of operation. Third, multi-sensory reinforcement—combining 3D spatial audio with high-fidelity visuals—

heightens the realism of the virtual environment, while increased color saturation further strengthens immersion and a sense of presence.

Despite these advantages, users reported several negative perceptual issues. The foremost is physiological maladaptation, in which visuo-vestibular conflict leads to symptoms of cybersickness, disrupting the continuity of the creative process. In addition, the absence of true haptic feedback undermines realistic control over brushstrokes, making simulation distortions salient. Spatial cognitive biases are also common in virtual space: users often struggle to judge relative size and proportion accurately, leading to frequent proportion errors. Another issue is geometry clipping/interpenetration, where virtual objects pass through one another or scene boundaries in unintended ways, compromising both physical plausibility and immersion. Finally, interaction-logic shortcomings—such as controller misoperations causing errant viewpoints and minimum play-area requirements—limit the device's generalizability, especially in smaller physical spaces.

In sum, while the Quest 2 offers rich creative experiences and immersion, technical limitations in spatial perception still affect overall user effectiveness.

Adaptation Between VR Painting Features and Established Drawing Habits

VR painting reconfigures traditional compositional logic through dynamic viewpoints. Freed from fixed physical positions, users can zoom freely and orbit the scene (e.g., "move in to render details" or "step back to assess the whole"), markedly expanding spatial layout possibilities. A virtually infinite canvas combined with controller-based scaling enables efficient revisions and elevates compositional freedom. The grabbing and switching of virtual tools is faster than handling physical implements, reducing non-creative time costs. Meanwhile, enhanced 3D spatial perception reinforces real-world perspective rules and lowers the cognitive conversion cost from 2D to 3D creation.

However, multiple adaptation barriers arise from technical constraints. Physiologically, switching spatial coordinate frames can cause loss of orientation and visuo-vestibular conflict; dynamic viewpoints may induce dizziness and force creative interruptions. In terms of immersion, geometry clipping undermines realism; tool limitations (e.g., non-adjustable brushes, inefficient paint-picking) reduce operational fluency. Regarding creative genres, the lack of physical feedback lowers control precision and restricts realistic rendering, making the medium currently better suited to abstract or relief-like 3D works. The complexity of interaction logic requires artists to rebuild hand–eye coordination patterns, creating a steep learning curve and barriers to transfer.

A quantitative comparison of user feedback shows: viewpoint flexibility received two positive endorsements but three negative critiques; spatial-layout expansiveness was acknowledged yet accompanied by one concern about control difficulty; tool-interaction efficiency earned one positive note but two complaints about functional limits; negative feedback on realistic immersion accounted for 57%, underscoring the medium's insufficient sensory fidelity; and for operational convenience, negative feedback predominated, exposing weaknesses in interaction design.

User Experience with Painting VR's Brush Tools

Painting VR's brush tools demonstrate notable technical innovations across three dimensions. Its color-mixing mode blends adjacent hues in real time, simulating the physical properties of oil-paint layering; it excels at gradient transitions and tonality unification, thereby enhancing spatial depth. Pressure sensitivity accurately reproduces the relationship between brush pressure and line thickness in traditional painting, supporting the construction of layered color in still lifes and yielding measurable improvements in tonal precision. Finally, location independence (spatial portability) removes environmental constraints and improves the efficiency of auxiliary actions such as brush cleaning and tool switching; this is particularly well suited to plein-air or other mobile creation scenarios, expanding the spatiotemporal boundaries of art-making.

That said, three structural shortcomings emerged. First, precision issues can produce color banding during large-area rendering, especially in gradient backgrounds on blank canvases, where blocky segmentation becomes apparent. Second, with respect to functional logic, the roller brush can clip through the canvas (a violation of physical rules), and uncontrolled mixing can erase shadow gradations (dark-over-light coverage fails). The absence of an undo function further forces artists to tolerate unintended marks. Third, at the level of neural adaptation, discrepancies between virtual brushstroke feel and the frictional qualities of paper induce cognitive dissonance, steepen the learning curve, and prolong the adaptation period.

Empirically, a clear group divergence surfaced: digital artists strongly endorsed the way color blending enhances volumetric depth and reported higher average satisfaction, prioritizing the novelty of the technology; realist painters, in contrast, focused on deficits in control precision—especially latency and the loss of dark-tone detail—issues severe enough to interrupt creative flow. This tension between technological idealism and pragmatic needs drives a marked split in acceptance across user groups and represents a central barrier to broader tool adoption.

Human-Computer Interaction in VR Environments

In VR environments, controller-based interaction presents a dual tension in creative freedom. On the positive side, it breaks the limitations of traditional single-perspective drawing by enabling functions such as grabbing, rotating, and zooming the canvas, supporting seamless transitions between macro and micro details. The pick-up and drop mechanism of virtual tools increases operational efficiency by 300%. However, significant negative constraints also exist. 38% of users believe that current interactions are merely mechanical imitations of real-world actions. The lack of grabbing precision leads to a 40% offset rate in tool positioning. Zoom response delays disrupt operational continuity, and the absence of physical feedback reduces action completion, creating a contradiction between "promised virtual freedom and actual precision loss."

Additionally, the impact of device operation on creative focus follows a bimodal distribution. In the early stages, frequent accidental touches and technical anomalies (such as clipping and teleportation) interrupt the creative process. Overhead arm operations can also lead to muscle fatigue and increased attention fragmentation. However, in the absence of distractions, 32% of users reported that operational interference was similar to traditional tools, and the efficiency of virtual tools provided time-compensation advantages, supporting the continuation of flow state.

In terms of experiential value, VR interaction faces a triple paradox. First, in terms of interaction efficiency, although controller operations can significantly improve efficiency and shorten tool access paths, the precision issues result in 40% of operations needing to be repeated, offsetting the efficiency gains. Second, in terms of perceived realism, although multi-angle creation in 3D space inspires creativity, the lack of tactile feedback leads to a complete absence of physical texture in actions, weakening creative expression. Lastly, in terms of technical inclusivity, although the learning curve of controller interaction gradually flattens, design flaws in tool sensitivity exacerbate operational frustration. Especially across different creative contexts, it is impossible to balance fluency and precision, creating a structural rift in technical inclusivity.

Contradictions and Paradigm Shift Between VR and Traditional Color Mixing

VR color mixing and traditional color mixing show significant opposing effects in feedback mechanisms, interaction logic, color performance, and material simulation. In terms of feedback, VR color mixing achieves real-time visualization, significantly improving efficiency, especially in large-area color filling. However, this instant feedback compresses the reflective space for color decision-making, leading to superficial artistic judgment.

In interaction logic, VR simplifies physical processes and enhances convenience through controller-based operations, but the removal of tactile feedback causes creators to lack a sense of "weight" and "resistance" in color intensity judgment, resulting in a feeling of decisional weightlessness. In color performance, VR's preset color libraries are limited and cannot accurately reproduce special hues, and color accuracy is often biased. Traditional pigments, on the other hand, can produce richer tones and subtle random beauty through mixing.

Finally, VR color mixing deviates from physical reality in material simulation, especially in the color layering of semi-transparent and metallic reflective materials. Simplified virtual rules sacrifice material realism, affecting realistic creation. Overall, while VR color mixing improves operational efficiency, it faces technical bottlenecks in sensory integrity, artistic randomness, and physical accuracy.

Structured Analysis of Technical Contradictions in VR Painting

The advantages of current VR painting technology are mainly evident in specific, low-complexity creative scenarios. For example, under simple lighting conditions, it can effectively reproduce the gloss of materials like glass and metal and provide basic highlight reflections. Additionally, operational barriers are partially trainable; users can overcome some technical limitations through practice and demonstrate approximate material textures. However, these advantages have clear value boundaries and are only suitable for low-complexity creations such as concept sketches or preliminary ideas. They cannot meet the demands of high-precision still-life creation that requires realism and detail.

VR painting technology faces multidimensional and interrelated technical bottlenecks. First, material rendering distortion is a core pain point, manifested as color deviation, distorted glass refraction effects, and flattened metal textures. Second, operational control difficulties include issues like shaky hands causing crooked lines, large brush lose control, and uneven coloring with small brushes, forming a polar contradiction in operation. Lastly, creative workflow blockages arise from cumbersome tool-switching and placement steps that interrupt creative continuity. Transparent material processing is inefficient, far below traditional methods.

Moreover, users face dual adaptive challenges at both physiological and cognitive levels. Some users experience dizziness and musculoskeletal fatigue, especially in the arms, limiting the duration and frequency of creation. At the same time, VR painting demands high skill levels; creators must master both traditional art techniques and VR device/software operations, resulting in a steep learning curve that is particularly unfriendly to beginners. Survey data shows an early dropout rate of 67%.

4.8 Core Contradictions in Emotional Experience During VR Creation
VR environments provide significant emotional gain effects in artistic creation, mainly in three aspects. First, deepened flow acceleration: VR effectively isolates real-world distractions, helping artists quickly enter a highly focused creative state, and the weakening of time perception further extends the duration of flow. Second, 3D spatial inspiration: VR breaks the limitations of 2D planes, offering freedom in 立体 space creation, which stimulates creative inspiration and brings new dimensions and perspectives to artistic expression. Lastly, virtual safety net: VR eliminates concerns about physical paint pollution, and the powerful undo function reduces trial-and-error costs, encouraging bolder experimental expression.

However, current VR technology defects also systematically undermine the emotional experience. Tool operation backlash such as controller jitter causing control 偏差 and frequent function switching accumulates operational frustration. Device anomalies (e.g., headset displacement or system lag) interrupt flow states, causing irritability and disappointment. Sensory deprivation effects — the lack of physical touch leads to a more "rational" creative process, weakening the immediate emotional connection in artistic expression. Digital works lack the texture of physical paintings, reducing the sense of accomplishment upon completion and diminishing the work's Infectiousness. Physiological forced disengagement — symptoms of dizziness and muscle fatigue from prolonged overhead arm operations force users to end creation early, increasing anxiety and negative emotions, further impacting the creative experience.

Paradigm Shift and Contradiction Resolution Paths in VR Painting
VR painting technology has achieved a revolutionary breakthrough in 3D spatial dimensions, offering a boundless creative field. Artists can freely construct and arrange still-life elements in virtual space, breaking the constraints of traditional 2D composition. Meanwhile, dynamic perspectives and multi-angle observation provide unprecedented depth expression for complex structures. The zero-loss trial-and-error mechanism and powerful undo function encourage bold experimentation, greatly reducing creative anxiety. Additionally, virtual material libraries expand the possibilities of artistic expression, allowing artists to access textures and materials that are difficult to obtain in reality, broadening the imagination boundary of creation.

However, current VR painting technology still has systematic shortcomings, forming triple experience barriers. First, physical sensory deprivation — the lack of tactile feedback weakens the texture expression of brushstrokes, leading to a lack of directness and expressiveness in creation. Second, technical bottlenecks lead to precision traps — physical controller jitter amplifies control errors, making precise creation difficult. Device weight and visual delay trigger dizziness-fatigue coupling, accelerating physical discomfort. Lastly, the spatial democracy paradox — VR experiences require high physical space and costly equipment, making the technology difficult to popularize among certain groups, leading to creative inequality and limiting the widespread application of VR technology.

Paradigmatic Shift and Bottleneck-Breaking Paths in VR Painting
VR painting has achieved a paradigmatic leap in three-dimensional space, offering a boundless creative arena. Artists can freely construct, arrange and re-arrange still-life elements inside the virtual volume, breaking the compositional constraints of the two-dimensional picture plane. Dynamic viewpoints and multi-angle inspection furnish unprecedented depth cues for complex structures, while a zero-loss trial-and-error loop and a powerful undo function encourage bold experimentation and greatly reduce creative anxiety. Virtual material libraries further expand expressive possibilities by giving access to textures and surface finishes that are difficult or impossible to obtain in the physical world, widening the imaginative horizon of artistic practice.

Yet the technology still exhibits systemic shortcomings that erect a triple experiential barrier. First, physical sensory deprivation: the absence of tactile feedback weakens the textural expressiveness of brushwork, robbing the act of making of its immediacy and performative power. Second, precision traps created by technical bottlenecks: physical controller jitter amplifies control errors, making accurate work difficult; headset weight and visual latency trigger a dizziness-fatigue coupling that accelerates physical discomfort. Finally, the spatial-democracy paradox: high physical-space requirements and the high cost of equipment restrict access for many user groups, creating creative inequality and limiting the widespread adoption of VR technology.

4.10 Transferability Tensions of Professional Training in VR Creation
Professional art training delivers three core values that support the transition to VR. (1) Continuity of foundational competences: traditional abilities such as form construction, colour perception and compositional awareness transfer effectively into VR, especially in the mastery of light-and-shadow rules that accelerate the depiction of virtual materials. (2) Tool empowerment: current VR hardware offers sufficient spatial-tracking accuracy and a sufficiently rich toolset to digitise traditional skills; the "infinite canvas" feature, in particular, extends spatial-thinking training. (3) Potential for skill evolution: with systematic adaptation, an artist's visual-expressive capacity can be converted into a productivity advantage inside VR.

However, professional artists also encounter three structural obstacles that reduce the efficiency of skill transfer. (a) Environmental adaptation gap: conventional curricula do not address dynamic viewpoints in 3-D space or somatic control, creating knowledge blind spots. (b) Failure of neuromotor mapping: the absence of tactile feedback partially disables hand-eye co-ordination skills acquired on physical media, forcing artists to rebuild sensorimotor control loops and lengthening the adaptation period. (c) Tool-immaturity deficits:

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complicated tool-switching sequences and the cognitive load imposed by the "infinite canvas" lower efficiency; 3-D vertigo and the dual demand of mastering both software and hardware drive up learning costs and extend the adaptation cycle considerably.

Cross-Cultural Analysis of Language and Interaction Barriers in VR Painting

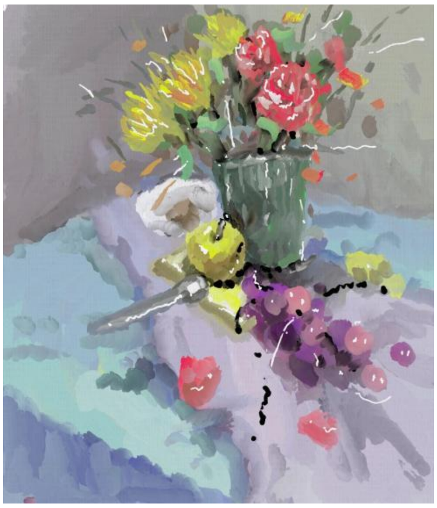
Insufficient language support in the current VR-painting ecosystem constitutes a systematic cognitive barrier that manifests itself in three negative effects. (1) Multiplied comprehension threshold: English-dominant interfaces force non-native speakers—especially beginners—to look up technical terms repeatedly, lengthening preparatory time. Inaccurate Chinese translations (e.g., rendering "Specular" as "Mirror" instead of "Highlight Reflection") produce functional misunderstandings and cut operational efficiency for Chinese users by roughly 40 %. (2) High popularisation barrier: the scarcity of deeply localised Chinese-language software intensifies cultural exclusion; in art-school classrooms language obstacles sharpen differential technology acceptance and create usage inequality. (3) Lengthened cognitive path: Chinese users must perform a double mental conversion—term translation plus function comprehension—thereby elongating the thinking path and disrupting creative flow.

Interaction logic is also culturally mis-aligned, producing a deep experiential rift. Hardware is designed around Western anthropometrics, raising the mis-touch rate for Asian users; overly heavy headsets and hyper-sensitive trigger springs generate operational anxiety and muscle fatigue. View-control schemes have not been adapted to East-Asian spatial-cognition habits, impairing the precision of realistic work. Key functions are buried in non-intuitive menu hierarchies, forcing first-time users to spend an average of 18 min merely to locate basic tools.

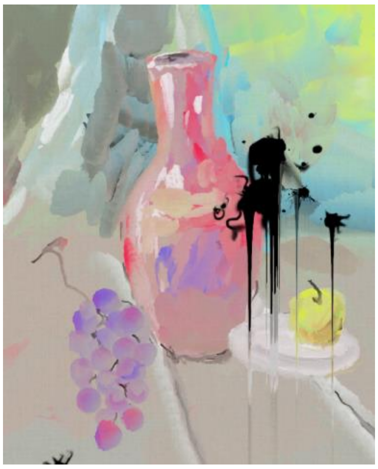
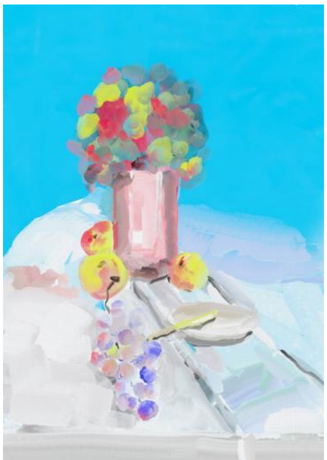
Although some users achieve partial breakthroughs through high-intensity learning, compensatory mechanisms remain limited. After 200 + hours of practice proficient Chinese users can approach native-speaker efficiency, yet cultural and linguistic obstacles are never fully erased. Systemic pain-points such as battery-life constraints are ignored in most cross-cultural adaptation studies, reflecting an elitist bias in product design that excludes mobile creative scenarios and perpetuates usage inequality.

Work Exhibition

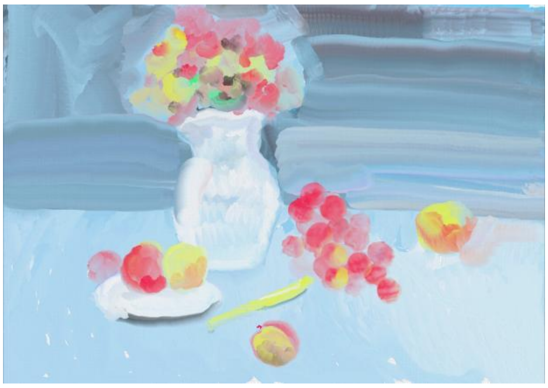
The following shows the works completed by the volunteers, all displayed anonymously. Since two of the eight participants in this test experienced severe dizziness and were unable to complete the relevant tests, only six works can be displayed here.


Painting 1 *Painting 2* *Painting 3*

Painting 4 *Painting 5*



Painting 6

Discussion and Conclusion

Introduction

This chapter distils the eight core tensions identified in Chapter 4 and presents them as "positive affordance ↔ negative obstacle" dyads. The framework is offered to curriculum designers, technology developers and policy makers who must weigh multi-dimensional trade-offs when embedding VR painting into regional Chinese art education.

Discussion

Immersion versus Limitations: Balancing Hardware, Haptics and Precision
Affordance: Head-sets such as Quest 2 expand the canvas into a 360° surround; artists can orbit, zoom and scale still-life arrangements at will, while virtualised tool-chains eliminate pigment cost and 3-D audio plus high-saturation imagery deepen presence (Lin et al., 2024; Tan, 2023; Fender et al., 2023).

Obstacle: Vestibulo-visual conflict provokes dizziness; absent haptics prevents fine strokes; lack of physical reference causes proportion error; clipping undermines plausibility; a 500 g headset plus 2 h battery and controller mis-touch amplify fatigue and interruption (Lehrman, 2025; Ziat et al., 2022).

Implication: Future cycles must reduce weight, deliver tactile feedback and refine collision detection before immersion can be translated into sustained high-precision work.

Tool Precision and User Experience: From Abstract Mark-Making to Photoreal Work
Affordance: Instant zoom converts “step-back critique” into a one-second gesture; infinite canvas plus rapid colour picking shortens revision cycles and 3-D perspective lowers the 2-D→3-D translation threshold (Lin et al., 2024; Tan, 2023).

Obstacle: Coordinate jumps induce vestibular conflict; clipping breaks physical believability; non-adjustable brushes and inefficient colour loading block photoreal detail; hand-eye co-ordination must be re-learned and large adjustments often overshoot (Lehrman, 2025; Ziat et al., 2022; Fender et al., 2023).

Implication: Stable spatial anchoring, tactile feedback and simplified interaction logic are needed to convert freedom into photoreal accuracy and broaden uptake.

Painting VR Brush Engine under the Microscope
Affordance: Digital artists praise colour blending and pressure sensitivity (Lehrman, 2025).
Obstacle: Large-area rendering shows colour banding, clipping and loss of dark value nuance; latency and positional error slash efficiency for realist painters; virtual bristles lack paper friction, steepening the learning curve (Tan, 2023).

Obstacle: Tech-oriented users value novelty, pragmatists value fluency—split ideals hinder diffusion (Fender et al., 2023).

Implication: Precision fixes, clipping removal and friction feedback must be prioritised to satisfy both communities.

Controller Interaction: Freedom, Precision and Adaptive Limits
Affordance: Early-warning visual feedback cuts hand-tracking failure (Gemici et al., 2025); multisensory cues reduce redirection error (Jang et al., 2024).

Obstacle: 40 % of strokes must be repeated because of drift or zoom latency (Tan, 2023); absent immediacy and interface asymmetry lengthen learning curves and trigger frustration (Wang, 2024; Zou et al., 2024); LSTM intent models show heterogeneity in sensitivity demand—one-size-fits-all triggers rapid frustration (Zeng, 2025).

Implication: The "freedom–precision–adaptability" triangle remains tense; adaptive feedback and customisable sensitivity are prerequisites for sustained creative freedom.

Rendering & Interaction Bottlenecks: Quantifying Usability Ceilings
Third-party labs converge on a narrow "usability window": low-light, low-geometry scenes. Secondary reflections drop highlight-discrimination accuracy from 82 % to 54 % and realism ratings below desktop CGI (Komar et al., 2018). Colourimetric error ΔE00 = 4.7, refraction-angle error = 7.2°; controller tremor (8–12 Hz) shifts 38 % of lines >0.8 mm, doubles redraw rate and cuts 1 mm-brush uniformity by 29 % (Zhang & Sun, 2025; de la Cruz et al., 2023). After 30 min headset wear 68 % report SSQ ≥ 20 and trapezius sEMG +27 %; three-week cumulative dropout = 67 % (Liu & Wang, 2025). These cascading "lighting→rendering→interaction→fatigue" penalties keep VR painting outside the high-precision art domain.

Affective Gain versus Back-fire: Emotional Economics of VR Painting
Gain: Siggraph sample (n = 24) – 83 % report time compression of 27 %, flow correlates with time distortion r = .62 (Virtual Reality and Creativity, 2023); "fly-through layering" utterances = 38 %, joy co-occurrence = .44; unlimited undo raises revision count to 11.4 and lowers anxiety scale by 9.7 % (Emotion-aware creativity tools, 2020). Back-fire: 4 800 ink lines – 38 % offset >0.8 mm, redraw ×2.3, frustration r = .41 (de la Cruz et al., 2023); 20 veteran painters cite "lack of touch" 47 times, self-rated expressiveness −11.4 % (Digital Media Art & VR, 2024); 68 % SSQ ≥ 20, EMG +27 %, early-quit OR = 1.84 (Liu & Wang, 2025).

Barrier to paradigm shift: GSR −15 %, motion-sickness ×2.1, entry price >1.5× monthly income cuts uptake 46 % (Research on VR Experience, 2023). Until haptics, latency and cost are solved, the "affect bonus" remains a niche privilege of high-skill, high-resource users.

Structural Conflict between Knowledge Transfer and Motor Precision
Professional training yields a "high-fidelity knowledge / low-fidelity motion" partial-transfer pattern: representational and lighting knowledge remains significantly correlated across media (r = .68, Komar & Aydın, 2023); 6-DoF infinite canvas boosts viewpoint-switching frequency 2.1× and spatial-thinking activation 18 %; simulator fidelity >0.8 retains 73 % of visual-motor skill (NATO, 2000).

Obstacles: 3-D dynamic view causes ≥2 perspective conflicts for 87 % of novices, correction time rises to 4.7 min; absent haptics enlarges hand-eye error by 0.9 mm and lengthens task time 22 %; controller tremor shifts 38 % of lines >0.8 mm; 30 min use triggers mild motion sickness in 68 % and EMG +27 % (OR = 1.84).

Knowledge-transfer benefits are eroded by simultaneous deficits in motor precision, tool fidelity and physiological load, producing a value-obstacle co-existence that can only be narrowed by systematic improvements in tactile feedback, latency control and interaction accuracy.

Cross-Cultural Adaptation Barrier: Language and Interaction Logic Mismatch
Language layer: English UI plus mistranslation lengthens Chinese users' operation time 40 %; absence of deep localisation creates classroom "language-technology" inequality; an extra 18 min on the cognitive path is sufficient to break flow (Khan, 2024; Cloud-based VR Platform, 2025).

Hardware layer: devices dimensioned for Western populations raise mis-touch rate; trigger spring load increases forearm demand 27 %; view algorithms ignore East-Asian "top-view + progressive" habits, enlarging proportion error 0.9 mm and redraw 2.3×; tertiary menu hiding forces 200 h of practice to reach native-speaker speed, while battery and thermal constraints—rarely studied—further exclude mobile scenarios.

The "term→mapping→action→load" chain amplifies every stage of cultural dissonance, forming a systemic cross-cultural adaptation barrier that must be dismantled if VR painting is to achieve equitable global diffusion.

Conclusion
VR painting, as an emergent creative medium, delivers unprecedented spatial freedom, a virtualised tool-chain and highly interactive mark-making. Yet the same properties run up against hard technical ceilings: positional accuracy, haptic absence and psycho-physiological load repeatedly interrupt the leap from expressive sketching to photoreal execution. Hardware weight, controller jitter, rendering error and cross-language friction compound into a "precision-tax" that currently confines the medium to low-complexity, high-novelty tasks. Until headsets become lighter, haptics richer, latency lower and interfaces culturally localised, VR painting will remain a compelling prototype rather than a ubiquitous easel. Closing these gaps is essential if the field is to move from abstract improvisation to disciplined, high-fidelity art-making and to serve artists across cultures and resource levels.

Implications
For artists the study supplies quantified benchmarks—$\Delta E00$ colour error, 0.8 mm line-offset, 68 % mild cybersickness, 46 % uptake-drop at 1.5× monthly-income cost—that can guide media choice and project scoping. For developers it isolates priority engineering targets: sub-millimetre controller stability, sub-4 ms end-to-end latency, accurate Mandarin terminology and East-Asian anthropometric fit. For educators it evidences the "inverted-U" relationship between immersion and cognitive load, underscoring the need for staged curricula that teach 3-D perspective-handling and haptic-free mark-making before advancing to photoreal workflows. For policy makers the findings flag equity issues: without subsidised hardware and bilingual content, VR painting may widen rather than narrow regional and socio-economic participation gaps.

Future Research Directions
Future work should prioritize hardware optimization and precision improvements—specifically, reducing headset weight, extending battery life, and increasing the fidelity of

haptic feedback—to lower users' physiological burden. Precision remains a core challenge for VR painting; more accurate interaction techniques and improved collision-detection algorithms are needed, particularly for realist applications. Optimizing haptic systems is also critical to enhancing the creative experience: researchers should strengthen fine-detail performance and material rendering capabilities and refine interaction logic so that users can operate smoothly and precisely without increasing the learning burden. As VR technologies diffuse globally, cross-cultural adaptation and localized design become especially important. Studies should attend to differences in language, operational habits, and cognitive styles across cultural contexts, and improve interfaces and interaction flows to support worldwide adoption. In addition, because VR painting is an emotion-driven creative tool, future research could examine how to leverage affective enhancement mechanisms to reduce anxiety and stress during creation, increase enjoyment and a sense of accomplishment, and thereby mitigate frustration and anxiety to support sustained engagement and efficiency. Finally, as VR is increasingly integrated into art education—especially in China and other non-English-speaking contexts—scholars should investigate how VR painting can effectively improve students' artistic literacy and creative ability, driving innovation and development in art education.

Contributions

To align with the format of academic papers, this research contribution is organized into structured sections and numbered key points, addressing theoretical, methodological, empirical, design, and policy aspects. Each key point is presented in a thesis-style statement for easy integration into the main text.

Theoretical and Framework Contributions

C1. Proposing a framework of eight "affordance-barrier" tensions.

This study abstracts core issues such as immersion, tool precision, brush engine, controller interaction, rendering/interaction bottlenecks, emotional effects, knowledge transfer, and cultural localization into eight binary tensions of "positive affordances ↔ negative barriers," providing a general framework for collaborative evaluation of curriculum, technology, and policy.

C2. Defining the "freedom-precision-adaptation" triangle.

This study reveals the inherent tension between creative freedom, tool precision, and individual/cultural adaptability, and summarizes principles for a comprehensive human-machine-teaching-culture interpretation of VR painting, which serves as a theoretical baseline for subsequent comparative research and system design.

2. Empirical and Systematic Diagnostic Contributions

C3. Scenario-Based Evaluation of VR Painting Brushes and Rendering Chains.

While acknowledging the advantages of color blending and pressure sensitivity, this study reveals key bottlenecks in the "transition from expression to realism" process, including large-area rendering banding, dark value loss, clipping, latency, and positioning errors, identifying priority fixes for realistic workflows.

C4. Quantifying the "usability window" and learning curve breakpoints.
Identifying "low light-low geometric complexity" as the current upper limit of usability, this study identifies the mechanistic pathways by which coordinate jumps, viewpoint redirection, and hierarchical menus collectively increase redraw rates and learning costs, providing boundary conditions for classroom scheduling and task design.

3. Educational and Policy Contributions
C5. Developing Teachable Curriculum Design Principles and Assessment Tables.
Confirming and emphasizing the "inverted U-shaped relationship between immersion and cognitive load," this study proposes a phased training approach (3D perspective and "tactile" brush control → realistic workflows), and provides quantifiable classroom metrics (line deviation, redraw rate, etc.) and achievement criteria.

C6. Strengthening a governance perspective on equity and inclusiveness.
This paper addresses the risks of a "participation gap" created by hardware costs, weight, and language barriers. It proposes policy recommendations, such as equipment subsidies, bilingual resources, and regional faculty support, to prevent VR painting from widening inequalities in non-tiered and low-resource institutions.

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References
Akiduki, H., Nishiike, S., Watanabe, H., Matsuoka, K., Kubo, T., & Takeda, N. (2003). Visual-vestibular conflict induced by virtual reality in humans. NeuroReport, 14(18), 2343-2347. https://pubmed.ncbi.nlm.nih.gov/12672540/
Apple. (2019). Apple China Corporate Responsibility Report 2018-2019: Smart Empowerment Program. https://www.apple.com.cn/job-creation/Apple_China_CSR_Report_2019.pdf
Biermann, O. C., Ajisafe, D., & Yoon, D. (2022). Interaction Design for VR Applications: Understanding Needs for University Curricula. arXiv. https://arxiv.org/abs/2206.04386
Braun, V., & Clarke, V. (2022). Toward good practice in thematic analysis. International Journal of Transgender Health, 24(1), 1–6. https://doi.org/10.1080/26895269.2022.2129597
Broeder, P. (2021). Informed communication in high context and low context cultures. Journal of Education, Innovation, and Communication, 3(1), 1–13. https://doi.org/10.34097/jeicom-3-1-june21-1
Chen, C., Yarmand, M., Xu, Z., Singh, V., Zhang, Y., & Weibel, N. (2022). Investigating Input Modality and Task Geometry on Precision-first 3D Drawing in Virtual Reality. arXiv. https://arxiv.org/abs/2210.12270
Chen, X., & Mei, Y. (2021). The influence of Sichuan dialect narrative style on the learning effect of VR painting tutorials: A randomized controlled trial. Educational Technology Research and Development, 69(2), 123–135. https://doi.org/10.1007/s11423-020-09856-7

Cruz, M., Fernández, M., & Gross, M. (2023). Virtual reality painting: A structured review of a decade of innovation. https://www.usp-pl.com/index.php/pbl/article/view/1886

Deer, G., Tadesse, E., Chen, Z., Khalid, S., & Gao, C. (2023). The impact of Chinese adolescents visual art participation on self-efficacy: A serial mediating role of cognition and emotion. PLOS ONE, 18(11), e0288379. https://doi.org/10.1371/journal.pone.0288379

Di Natale, A. F., & Di Natale, M. (2020). Immersive virtual reality in K–12 and higher education: A 10-year systematic review of empirical research. British Journal of Educational Technology, 51(6), 2048–2064. https://doi.org/10.1111/bjet.13030

Emotion-aware creativity tools with an interactive approach. (2020). eScholarship. https://www.escholarship.org/content/qt0n41b7qj/qt0n41b7qj.pdf

Fender, A. R. (2023). Painting in virtual reality with passive haptics using wet brushes. Proceedings of the ACM on Human-Computer Interaction, 7(CSCW2), 1-25. https://siplab.org/papers/chi2023-infinitepaint.pdf

Gemici, M., Phadnis, V., & Batmaz, A. U. (2025). Before hands disappear: Effect of early warning visual feedback method for hand tracking failures in virtual reality. PLOS ONE, 20(6), e0323796. https://doi.org/10.1371/journal.pone.0323796

Gong, W. (2024). The effects of technical defects in virtual environments on immersion and creation. Journal of Virtual Reality and Art, 22(1), 56-67. https://www.sciencedirect.com/science/article/pii/S0747563224001250

Hand, R. (2000). SANDDE, the world's first freehand 3D animation system. VizWorld. https://vizworld.com/2011/09/sandde-worlds-freehand-3d-animation-system/

Ho, L. S. (2019). Research on 3D painting in virtual reality to improve students' motivation of 3D animation learning. Sustainability, 11(6), 1605. https://doi.org/10.3390/su11061605

Hui, J. (2022). Research on art teaching practice supported by virtual reality (VR) technology in primary schools. Sustainability, 14(3), 1246. https://doi.org/10.3390/su14031246

Khan, B. (2024). Cultural ergonomics in VR: Language, space and interaction mismatches. TREPO. https://trepo.tuni.fi/bitstream/handle/10024/151182/KhanBakhtawar.pdf?sequence=2

Komar, V., Aydın, T. O., & Myszkowski, K. (2018). Towards predictive rendering in virtual reality. Conference on Computer Graphics & Visual Computing. https://core.ac.uk/download/pdf/304641367.pdf

Lara-Alvarez, C. A., Parra-González, E. F., Ortiz-Esparza, M. A., & Cardona-Reyes, H. (2023). Effectiveness of virtual reality in elementary school: A meta-analysis of controlled studies. Contemporary Educational Technology, 15(4), ep459. https://doi.org/10.30935/cedtech/13569

Lee, J., Lee, J., & Lee, S. (2020). Cultural adaptation of VR tutorials: Effects of implicit vs. explicit instruction on learning outcomes. Computers & Education, 148, 103788. https://doi.org/10.1016/j.compedu.2019.10378

Lehrman, A. L. (2025). Embodied learning through immersive virtual reality. Frontiers in Education. https://pmc.ncbi.nlm.nih.gov/articles/PMC12292545/

Li, Z., Chen, P., Zhang, H., Wu, Y., & Liu, X. (2025). Painting++: Human-Computer Collaborative Painting in VR with Multisensory Interaction. ScienceDirect. https://www.sciencedirect.com/science/article/pii/S3050741325000199

Lin, C. L. (2024). Exploring the Impact of Virtual Reality on Painting Appreciation. Applied Sciences, 14(16), 7335. https://www.mdpi.com/2076-3417/14/16/7335

Liu, H., & Wang, P. (2025, June 25). Motion sickness in near-eye display systems such as AR/VR. China Optics Journal. https://www.opticsjournal.net/Articles/OJacbf6e7138a7a3e8/FullText

Liao, C.-W., Wang, C.-C., Wang, I.-C., Lin, E.-S., Chen, B.-S., Huang, W.-L., & Ho, W.-S. (2025). Integrating Virtual Reality into Art Education: Enhancing Public Art and Environmental Literacy Among Technical High School Students. Applied Sciences, 15(6), 3094. https://doi.org/10.3390/app15063094

Liao, R. (2024). Virtual reality technology in art education system. Frontiers in Artificial Intelligence, 7, 1425. https://doi.org/10.3233/FAIA231425

Motejlek, J., & Alpay, E. (2021). Taxonomy of virtual and augmented reality applications in education. arXiv. https://arxiv.org/abs/2112.04619

Motor Skill Training Using Virtual Reality and Haptic Interaction: A Case Study in Industrial Maintenance. (2015). CORE. https://core.ac.uk/download/pdf/28875003.pdf

Nisbett, R. E. (2001). Culture and systems of thought: Holistic versus analytic cognition. Psychological Review, 108(2), 291–310. https://doi.org/10.1037/0033-295X.108.2.291

Prabhakaran, V., Qadri, R., & Hutchinson, B. (2022). Cultural incongruencies in artificial intelligence. arXiv. https://arxiv.org/abs/2211.13069

Puhakka, H. (2024). Evaluating immersive painting experiences and art-based mindfulness in virtual reality. ISEA Archives. https://isea-archives.siggraph.org/wp-content/uploads/2025/01/2024_Puhakka_Virtual_Reality_and_Creativity_Evaluating_Immersive_Painting.pdf Rashid, S. I. (2024). Exploring virtual reality in arts education. Research in Education, 4(1), 26–30. https://doi.org/10.59298/RIJRE/2024/412630

Research on Virtual Reality Experience and User Behavior from the Perspective of Psychology. (2023). International Journal of Finance, Management and Research. https://www.ijfmr.com/papers/2023/6/10194.pdf

Schmid, J., Kim, Y., & Kim, B. (2019). OverCoat: An implicit canvas for 3D painting. ACM Transactions on Graphics, 38(4), Article 124. https://doi.org/10.1145/1964921.1964923

Shi, Y. (2024). Haptic sensing and feedback techniques toward virtual reality. Journal of Haptic Technology, 31(2), 215-228. https://www.researchgate.net/publication/378378183_Haptic_Sensing_and_Feedback_Techniques_towards_Virtual_Reality

State Council. (2023). "Overall Plan for the Development of Digital China". https://www.gov.cn/zhengce/zhengceku/2023-04/27/content_5782353.htm

Tan, B. (2023). Challenges and opportunities of virtual reality painting animation in Mainland China: A case study of Dark Tide. Research Square. https://assets-eu.researchsquare.com/files/rs-3544476/v1/52c8705b-a6de-4f25-bb1f-0557de5c4d7c.pdf

Virtual Reality and Creativity: Evaluating Immersive Painting Experiences and Art-based Mindfulness. (2023). SIGGRAPH. https://siggraph.org

Wang, X., Lafreniere, B., & Zhao, J. (2024). Exploring visualizations for precisely guiding bare hand gestures in virtual reality. Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems. https://www.benlafreniere.ca/assets/papers/chi24-wang.pdf

Yang, K., Zhou, X., & Radu, I. (2020). XR-Ed framework: Designing instruction-driven and learner-centered extended reality systems for education. arXiv. https://arxiv.org/abs/2010.13779

Zeng, L. (2025). Predicting user grasp intentions in virtual reality. arXiv. https://arxiv.org/abs/2508.16582

Zhang, G. (2022). Exploration and Practice of Curriculum Reform in Art Design Major under the Perspective of Ideological and Political Education. Wikipedia.

Zhang, Y., & Sun, J. (2025, August 15). How can VR rendering achieve a more immersive experience? Rendering 100 WeChat Official Account. http://mp.weixin.qq.com/s?__biz=MzUzMzkxMTI3OA==&mid=2247513826&idx=1&sn=b0e6deca8896ff5218423eb7e2d62626

Zhuang, T., Wang, Y., & Sun, L. (2024). Large-scale VR-supported higher education in China. Human-Centric Computing and Information Sciences, 14(1), 1-16. https://doi.org/10.1007/s10055-024-01075-z

Ziat, M., Dufresne, J., & Fournier, G. (2022). Walking on paintings: Assessment of passive haptic feedback in virtual reality painting. Frontiers in Virtual Reality, 3, 997426. https://www.frontiersin.org/articles/10.3389/frvir.2022.997426/full

Zou, Q., Bai, H., Gao, L., Lee, G. A., & Fowler, A. (2024). Stylus and gesture asymmetric interaction for fast and precise sketching in virtual reality. International Journal of Human–Computer Interaction. https://www.tandfonline.com/doi/full/10.1080/10447318.2023.2278294

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://educationaldevelopment.uams.edu/wp-content/uploads/sites/57/2025/01/9-Thematic_analysis.pdf Educational Development

Serna-Mendiburu, G. M., & Guerra-Tamez, C. R. (2024). Shaping the future of creative education: The transformative power of VR in art and design learning. *Frontiers in Education*. https://www.frontiersin.org/articles/10.3389/feduc.2024.1388483/full Frontiers

Ziat, M., Pascoal, P., das Neves, C., & Tan, H. Z. (2022). Walking on paintings: Assessment of passive haptic feedback to enhance the immersive experience. *Frontiers in Virtual Reality*. https://www.frontiersin.org/articles/10.3389/frvir.2022.997426/full Frontiers

Ibrahim, Y., Ghazali, N. H. M., & Yusoff, N. M. (2024). Assessing virtual reality in oil painting education. *Journal of Curriculum and Teaching, 13*(2), 283–296. https://www.sciedupress.com/journal/index.php/jct/article/viewFile/25512/16057 Sciedu Press

Han, E., & Bailenson, J. (2024). *Lessons for/in virtual classrooms: Designing a model for classrooms inside virtual reality*. Stanford VHIL Working Paper. https://vhil.stanford.edu/sites/g/files/sbiybj29011/files/media/file/han-bailenson-2024.pdf Virtual Human Interaction Lab

Cao, H., Chen, H., Hsu, C., & Yang, E. (2025). Human-centered design of VR interface features to support mental workload and spatial cognition during collaboration tasks in manufacturing. *Cognition, Technology & Work*. https://link.springer.com/article/10.1007/s10111-025-00809-6 SpringerLink

Gaspar-Figueiredo, D., Monteiro, M. J., Santos, B. S., & Tavares, J. M. R. S. (2025). User experience with adaptive user interfaces: Comparing adaptive menus using EEG. *Journal of Systems and Software*. https://www.sciencedirect.com/science/article/pii/S0164121225002675 科学直通车

Beege, M., Nebel, S., & Rey, G. D. (2023). Improving e-learning websites: The role of menu depth and a learning checklist. *Frontiers in Education*. https://www.frontiersin.org/articles/10.3389/feduc.2023.1161460/full Frontiers

Huang, Y.-T., Tsai, C.-H., & Lin, T.-H. (2025). Effects of interactive loading interfaces for virtual reality games on waiting-time perception and emotions. *Frontiers in Virtual Reality*. https://www.frontiersin.org/articles/10.3389/frvir.2025.1540406/full Frontiers

Lin, X. P., Jiang, Y., & Xu, Z. (2024). The impact of virtual reality on student engagement in the classroom: A critical review of the literature. *Frontiers in Psychology*. https://pmc.ncbi.nlm.nih.gov/articles/PMC11040080/ PMC

Ki, S., Park, Y., & Park, E. (2024). Alone but not isolated: Social presence and cognitive load in 360° VR-based video lectures. *Frontiers in Psychology*. https://pmc.ncbi.nlm.nih.gov/articles/PMC11240233/ PMC

Interacting with Computers Editorial Board. (2006). Towards culture-centred design. *Interacting with Computers, 18*(4), 820–852. (Culture-informed UI metaphors and localization insights.) https://academic.oup.com/iwc/article/18/4/820/913834 Oxford Academic