A Virtual Reality Framework for Teaching Artwork Forgery Detection

Alessio Ferrato[1,*], Carla Limongelli[1], Giuseppe Sansonetti[1] and Giuliana Calcani[2]

[1]*Department of Engineering, Roma Tre University, Rome, Italy*
[2]*Department of Humanities, Roma Tre University, Rome, Italy*

Abstract

Art forgery is a pervasive and costly phenomenon that undermines the integrity of the global art market, with financial losses estimated in the billions of euros annually. Detecting forgeries requires a sophisticated investigative process that extends far beyond surface observation. Yet, hands-on experience remains confined to specialized conservation laboratories, making forgery literacy virtually inaccessible to students, enthusiasts, and even many heritage professionals. In this paper, we present the rationale behind an interactive Virtual Reality laboratory designed to teach forgery detection by letting users apply simulated versions of real conservation instruments and practices to digitized artworks. Grounded in a curated collection of seized forgeries studied at the Laboratorio sul Falso of Roma Tre University the system places users in a virtual lab where forgeries can be picked up, rotated, and examined with virtual tools that mimic commonly used instruments. The system adapts its guidance progressively based on the user's interaction. We describe the framework architecture, the mapping of real forensic techniques to VR interactions, and outline a planned user study to evaluate knowledge acquisition across different user profiles.

Keywords

Artwork, Forgeries, VR, Adaptive Learning

1. Introduction

Art forgery remains a significant problem for cultural heritage preservation. Estimates suggest that a substantial fraction of artworks on the international market may be forged or misattributed [1], and law enforcement operations continue to uncover large-scale forgery networks [2]. Forged objects span paintings, ceramics, coins, and composite works, requiring investigators to draw on visual, material, and chronological analysis techniques that are difficult to acquire outside specialized laboratories.

A structural accessibility problem compounds this challenge. The objects of study, seized forgeries, are subject to strict handling protocols and cannot circulate for educational purposes. The knowledge needed to combat forgery is therefore concentrated among a small number of experts, with limited pathways for training new practitioners. University curricula in art history and conservation science typically address forgery detection only theoretically, through case studies and slide-based lectures, without affording students the opportunity to practice the investigative procedures themselves. Hands-on training is currently confined to specialized Master's programs aimed at professionals, where some practical exposure may be possible but remains limited in scope and accessible only to a small number of practitioners. This disconnect between theoretical knowledge and procedural skill is particularly problematic because forgery detection is fundamentally a hands-on discipline: the ability to recognize diagnostic cues depends on repeated exposure to both authentic and forged objects under controlled analytical conditions.

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*Corresponding author.

alessio.ferrato@uniroma3.it (A. Ferrato); carla.limongelli@uniroma3.it (C. Limongelli); gsansone@dia.uniroma3.it (G. Sansonetti); giuliana.calcani@uniroma3.it (G. Calcani)
0000-0001-5405-3018 (A. Ferrato); 0000-0003-4953-1390 (G. Sansonetti)

[1] https://itsartlaw.org/art-law/when-imitation-is-not-flattery-art-fakes-forgeries-and-the-market-they-fool (last access: May 26, 2026)

[2] https://sothebysinstitute.com/articles/how-to-series-art-forgery (last access: May 26, 2026)

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In this paper, we propose an interactive VR framework that addresses this gap by transposing the investigative workflow of forgery detection into an immersive environment. Like flight simulators allow pilots to develop procedural skills in safe conditions before operating real aircraft [1], the proposed system allows users to examine digitized forgeries with simulated instruments and to receive adaptive guidance that adjusts to their demonstrated level of expertise. The framework draws on a subset of the university collection of seized objects studied in the *Laboratorio sul Falso* of Roma Tre University [2]. A central design goal is the adaptive guidance system, which observes user behavior in real time and dynamically adjusts the level of instructional scaffolding. This allows the same environment to serve users ranging from curious non-specialists to conservation trainees without requiring manual configuration or separate training modules.

The remainder of the paper is organized as follows. Section 2 reviews related work. Section 3 presents the framework architecture. Section 4 describes the adaptive guidance system in detail. Section 5 discusses limitations, and Section 6 outlines the planned evaluation.

2. Related Work

Our work draws on three research areas: diagnostic techniques for forgery detection, virtual laboratories for education, and adaptive systems for cultural heritage.

The scientific detection of forgeries relies on combining complementary analytical methods. Portable digital microscopes such as the Dino-Lite series enable conservators to inspect surface features including craquelure morphology, brushstroke layering, tool marks on ceramics, and casting seams on coins. Raman spectroscopy provides molecular identification of pigments and binders without requiring physical sampling, enabling the detection of anachronistic materials (e.g., synthetic pigments in a work purportedly from the Renaissance). Radiocarbon (^{14}C) dating offers absolute chronological constraints on organic materials such as canvas, wood, and ivory [3]. Kunz and Ottaviano [4] demonstrated the pedagogical value of Raman-based forgery detection in a physical laboratory setting, where students applied problem-based learning to authenticate paintings. Single techniques are often insufficient in isolation. Each method has known blind spots, and robust authentication requires triangulating evidence across visual, molecular, and chronological analyses. Recent work has shown that deep learning can complement physical diagnostics: Boccuzzo et al. [5] trained neural networks to identify the hand of the forger Wolfgang Beltracchi from brushstroke-level image patches, achieving high accuracy even when many forgeries remain unidentified. While such computational approaches are promising, they analyze surface features from digital images and cannot replace the material-level investigation (e.g., pigment chemistry, radiocarbon dating) that our system aims to teach.

Virtual Reality Laboratories (VRLs) have demonstrated effectiveness for procedural training in scientific disciplines [6]. Studies on VR-based laboratory training report increased learner confidence and procedural retention, with particular benefits for novice users who lack prior hands-on experience [6]. Immersive VR and AR heritage experiences have been proposed for virtual museum tours and archaeological site reconstruction [7]. Rodriguez-Garcia et al. [8] conducted a PRISMA-based systematic review of 94 studies on virtual 3D reconstructions of cultural heritage in immersive VR, finding that applications for education favor highly interactive experiences with six degrees of freedom, yet noting that the vast majority of existing systems focus on site reconstruction and guided tours rather than procedural skill training. Similarly, Caponi et al. [9] recently developed a Unity-based VR experience for learning about the Roman theatre of Palmyra, incorporating semantic enrichment and guided thematic paths; while pedagogically grounded, it exemplifies the content-consumption paradigm (i.e., exploring a reconstructed site) rather than the active forensic investigation our framework targets. To our knowledge, no VR laboratory has been designed specifically for cultural heritage forensics or forgery detection training. The present work extends this line by combining immersive forensic simulation with real-time adaptive scaffolding designed for skill acquisition rather than content consumption.

Zahabi and Abdul Razak [10] provided one of the first comprehensive frameworks for adaptive VR-based training, identifying three fundamental components: performance measures, adaptive logic, and adaptive variables. The authors state that effective systems should incorporate real-time behavioral and physiological data to tailor the training experience. Their review found that most existing adaptive VR systems were feasibility studies, and called for further empirical validation of adaptive mechanisms in domain-specific contexts. The adaptive guidance we propose (Section 4) adopts a similar three-component structure but replaces generic performance metrics with domain-specific forensic workflow coverage, diagnostic reasoning quality, and expertise trajectory.

3. Framework Architecture

The framework comprises three main components: a digitized object archive, the VR laboratory environment with simulated instruments, and an adaptive guidance system (described in Section 4).

3.1. Digitized Object Archive

The system is grounded in a collection of seized objects held at an interdisciplinary *Laboratorio sul Falso* [2]. The collection is heterogeneous, encompassing forged paintings attributed to modern and contemporary masters, ceramics and pottery imitating ancient production, counterfeit coins replicating Roman and Greek numismatic types, and composite objects known as pastiches. Objects have been studied with both humanistic methods (e.g., stylistic analysis, provenance research) and scientific diagnostics (i.e., Raman spectroscopy, digital microscopy), providing the ground-truth metadata that the VR system uses to generate diagnostic overlays and assessment feedback.

3.2. VR Laboratory and Instruments

The user enters a virtual conservation laboratory and can pick objects placed in the lab through natural hand gestures. The laboratory provides several workstations: an easel and a desk for positioning paintings, a turntable for rotating three-dimensional objects and inspecting them from all angles. The user has full control over object placement and analysis, mimicking what really happens in the lab. For example, paintings can be flipped to inspect the verso, an action central to real-world authentication but impossible in typical museum settings.

We plan to provide three simulated diagnostic instruments. When the instrument's active area contacts the object, the system renders the corresponding diagnostic view:

- **Dino-Lite digital microscope**: renders a magnified view of surface micro-features such as craquelure patterns, brushstroke layering, tool marks on ceramics, casting seams on coins, and surface discontinuities at join points on composite objects. The user can toggle between white-light and UV illumination modes, as on the real device.
- **Raman spectrometer**: displays the Raman spectrum for a targeted region, with key peaks annotated. The system flags anachronistic materials when detected (e.g., a modern binder in a supposedly period-consistent paint layer). Comparing spectra from different regions of the same object can reveal compositional discontinuities that indicate restoration, overpainting, or fabrication.
- **Radiocarbon sampling tool**: the user selects a location on the object to simulate extracting a micro-sample for ^{14}C dating. The system returns a simulated date with confidence interval. Critically, the result depends on *where* the sample is taken, which directly teaches users about the limitations of this technique.

All diagnostic data rendered by the instruments will be derived from real analyses of the physical objects in the collection, ensuring scientific fidelity rather than procedurally generated approximations.

A key pedagogical rationale for exposing users to multiple instruments is that no single technique reliably detects all forgery strategies. This is well illustrated by *pastiches*, composite objects in which a genuine antique fragment (e.g., a Roman marble base or an ancient ceramic body) is embellished with modern additions (e.g., a sculpted head or decorative handles) to create a seemingly complete and more valuable work. The joins are concealed through careful surface treatment designed to simulate uniform aging. Pastiches specifically exploit the constraints of radiocarbon dating. Because samples must be extracted from inconspicuous locations to minimize visible damage, the sampling point often falls on a genuinely old component, returning an authentic date that effectively validates the forgery. The modern additions, which may constitute the art-historically significant portions of the work, go untested. The deception can be identified only by triangulating evidence across methods.

4. Adaptive Guidance System

The adaptive guidance system is the mechanism through which the framework accommodates users of different expertise levels without requiring manual configuration or separate training tracks. It operates through three interconnected components: interaction monitoring, user modeling, and scaffolding delivery. This design aligns with the adaptive training framework proposed by Zahabi and Abdul Razak [10], who identified performance measures, adaptive logic, and adaptive variables as the core components of effective adaptive VR systems.

4.1. Interaction Monitoring and User Model

The system continuously logs user behavior during each examination session, tracking the actions the user performs, the position within the lab, and the object the user observes. Recorded events include: which instruments are applied, in what order and for how long; which regions of the object surface receive instrument contact; temporal patterns such as dwell time per region and overall pacing; whether the user inspected the verso of a painting or the base of a three-dimensional object; and which steps were omitted entirely. Omissions are diagnostically informative: a user who never inspects the verso, or who applies radiocarbon dating without first checking for surface discontinuities on a pastiche, is missing critical steps in the forensic workflow.

These traces feed a user model that maintains three running estimates. *Procedural coverage* tracks how many steps of the standard forensic workflow have been completed for each object. A complete examination of a painting, for instance, involves frontal inspection under normal and UV light, microscopic examination of craquelure and signature regions, Raman analysis of pigments, and verso inspection. *Diagnostic reasoning* assesses whether instrument usage reflects purposeful, hypothesis-driven investigation (e.g., applying Raman spectroscopy to a region flagged as anomalous under UV, or examining join lines on a pastiche after rotating the object) or undirected exploration characterized by random tool application with short dwell times. An overall *expertise trajectory* is updated after each object examination.

4.2. Scaffolding Modes

Based on the current user model, the system selects from three scaffolding modes:

- **Guided mode**: the system actively structures the examination. After the user selects an object, a suggested examination sequence is presented. If the user neglects a diagnostically important region, the system highlights it with a subtle visual cue. After each instrument application, an explanatory panel describes what was observed and its diagnostic significance.
- **Prompted mode**: direct instructions are replaced by questions that encourage hypothesis formation before the system provides confirmation or correction. For example, after a Raman measurement the system might ask: “How does this spectrum compare to the adjacent region?” When a user has not yet inspected a painting’s verso, it might prompt: “Is there information on the back of this canvas that could inform your assessment?” This mode is designed to develop independent analytical reasoning while still providing structure.

- **Free investigation mode**: no scaffolding is provided during examination. The user conducts a self-directed investigation and, upon completion, submits an assessment: their judgment of the object's authenticity and the evidence supporting their conclusion. The system then provides a detailed comparison between the user's assessment and the ground-truth analysis, highlighting any missed evidence or misinterpreted results.

Mode transitions are given by a threshold-based policy over the expertise trajectory, set conservatively to favor promoting users to less-scaffolded modes rather than holding them in guided mode unnecessarily. The underlying pedagogical assumption is that guided discovery is more effective than passive instruction, and that premature exposure to independence is less harmful than prolonged hand-holding.

5. Limitations

Several limitations of the proposed approach should be acknowledged. The most important is that VR cannot fully reproduce tactile feedback: conservation experts rely on the weight, texture, and flexibility of objects as diagnostic information that current haptic technology does not adequately simulate. However, this limitation could be partially mitigated through emerging haptic solutions. Krumpen et al. [11] showed that combining VR-based object inspection with 3D-printed replicas can convey shape features through direct tangible interaction, while commercial haptic gloves provide vibrotactile and force feedback that may approximate certain surface properties. We plan to evaluate the integration of such devices in future iterations of the framework as a complement to the visual and analytical simulation.

The system simulates a subset of available diagnostic techniques. The selected instruments (i.e., digital microscopy, Raman spectroscopy, and radiocarbon dating) were chosen because they represent complementary analytical approaches (i.e., visual, molecular, chronological) and their outputs translate effectively to visual rendering in VR.

Legal constraints on seized objects limit which items can be digitized and included. Each digitization must be authorized under protocols that prevent misuse of the digital reproductions. Finally, the adaptive guidance system's user model relies on behavioral heuristics rather than validated psychometric instruments; the planned evaluation is designed, in part, to assess whether the inferred expertise levels correspond to actual diagnostic competence. However, we plan to propose such system only during public events and to other labs that study forgeries but have no access to physical objects.

6. Planned Evaluation

Although this paper presents the design, we are currently in the development stage. Our system exploits the Meta Quest and the virtual lab is constructed using Unity. Testing with users is planned by the end of 2026. We are designing a two-phase user study. As a first step, we will compare knowledge acquisition and forgery identification accuracy between participants trained with our VR system and a control group receiving classical slide-based instruction, which represents the dominant current practice in university curricula. This comparison is intended to establish whether VR-based training provides measurable benefits over standard pedagogy. Subsequently, we will evaluate the framework along four further dimensions: (1) *Knowledge acquisition*, measuring improvement in forgery identification across object types; (2) *Interaction analysis*, examining instrument usage patterns, spatial attention distributions, and time-on-task to identify behavioral signatures of different expertise levels; (3) *Scaffolding effectiveness*, comparing learning outcomes between participants who receive adaptive scaffolding and a control group receiving static, non-adaptive guidance at a fixed intermediate level, in order to isolate the contribution of the adaptive mechanism itself; and (4) *Usability*, assessing subjective experience via standardized questionnaires (SUS [12], NASA-TLX [13]) and semi-structured interviews exploring perceived learning, engagement, and suggestions for improvement.

We plan to test this system with novice users with no art background, art history students with theoretical knowledge but limited hands-on experience, and conservation professionals or law enforcement trainees.

7. Conclusion

We have presented a VR framework for teaching artwork forgery detection through simulated forensic examination of digitized objects. The system addresses a concrete accessibility problem: forgery detection skills are difficult to acquire, and the study materials, seized forgeries, cannot circulate freely. By providing complementary diagnostic instruments whose limitations become apparent through use, and an adaptive guidance system that infers user expertise from interaction patterns, the framework creates a reusable training environment suitable for diverse user profiles.

Future work will focus on finishing the implementation of the VR prototype, conducting the planned user study, expanding the digitized collection, investigating haptic feedback integration for surface texture simulation, and exploring collaborative VR sessions where multiple users examine the same object simultaneously and discuss their findings, mimicking the collaborative nature of real conservation work.

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Declaration on Generative AI

During the preparation of this work, the authors used Claude (Anthropic) and Grammarly in order to: Grammar and spelling check, Paraphrase and reword. After using these tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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