Paradigm Academic Press
Research and Advances in Education
ISSN 2788-7057
NOV. 2025 VOL.4, NO.9

The Enriched Twin: An Updated Ethical-Pedagogical Framework for K-12 Digital Heritage Education in the Agentic AI Era

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doi:10.63593/RAE.2788-7057.2025.11.003

Abstract

The rapid evolution of agentic artificial intelligence (Agentic AI) and digital twin technologies has profoundly transformed cultural heritage preservation and education. These tools enable immersive, interactive reconstructions of historical sites and artifacts, fostering deeper engagement with the past. However, they also pose significant risks, including the amplification of biases, perpetuation of colonial narratives, and erosion of community data sovereignty if applied without critical oversight. This updated framework revisits the 'Enriched Twin' project-based learning (PBL) program within a STEAM (Science, Technology, Engineering, Arts, and Mathematics) context, incorporating advancements in Agentic AI from 2024–2025. It interweaves three core conceptual threads: (1) the progression from static digital twins to semantically enriched, Agentic AI-augmented knowledge ecosystems; (2) a critical hermeneutics of AI, scrutinizing Agentic AI's dual capacity as an analytical instrument and a propagator of cognitive biases; and (3) decolonizing methodologies that prioritize community data sovereignty and ethical co-creation. Practical modules encompass drone-based data capture and Agentic AI-assisted 3D modeling, culminating in collaborative development of 'enriched' digital twins for local heritage sites. This model cultivates technical proficiency alongside digital literacy, critical judgment, and ethical responsibility, aligning with UNESCO's 2021 Recommendation on the Ethics of Artificial Intelligence and recent Agentic AI guidelines for education (UNESCO, 2025a). By embedding these principles, the framework extends beyond technical instruction to promote holistic development, preparing K-12 students as responsible digital stewards. Future research trajectories include cognitive-affective evaluations, design-based iterations, and action research on community partnerships to validate and refine this approach for broader applicability in digital humanities education.

Keywords: agentic AI, digital twin, cultural heritage, K-12 education, curriculum design, digital humanities, decolonizing methodology, project-based learning, STEAM, AI ethics

1. Introduction

The integration of agentic AI (Agentic AI) and digital twin technologies into cultural heritage education represents a paradigm shift, offering transformative opportunities for K-12 learners. Students can now digitally reconstruct ancient ruins, simulate environmental impacts on artifacts, and generate interactive narratives that bring history to life. For instance, Agentic AI tools allow for real-time analysis of vast cultural datasets, enabling personalized learning experiences (UNESCO, 2025b). However, this technological frontier is fraught with ethical challenges. Data sources often stem from colonial archives, and Agentic AI algorithms, trained on biased corpora, can perpetuate societal prejudices, presenting a 'technologized version of a single, dominant story' (Noble, 2018; Manalikul, 2023).

Recent developments underscore these concerns. UNESCO's 2025 expert report on AI and culture emphasizes the need for 'cultural-AI literacy' that balances technical skills with critical thinking (UNESCO, 2025b). Similarly, studies on Agentic AI in heritage preservation demonstrate enhanced interactivity but warn of cultural

misrepresentation risks (npj Heritage Science, 2025). The emergence of agentic AI—autonomous systems that plan, act, and learn independently—further complicates this landscape. Agentic AI extends traditional AI by enabling proactive interventions, such as real-time bias detection in heritage narratives or adaptive community collaborations, but raises new concerns about accountability and over-automation in educational settings (Jones, 2025; Cunningham-Nelson et al., 2019). In response, this article presents an updated 'Enriched Twin' framework for K-12 education. Rooted in PBL and STEAM, it trains students not only in digital production but also in critical reflection on AI's implications. The paper is structured as follows: a conceptual framework, pedagogical design including skill modules and capstone, ethical integration strategies, and directions for empirical validation.

2. Conceptual Framework

The curriculum is anchored in three interconnected pillars, refreshed with 2025 insights on Agentic AI and decolonization.

2.1 The Semantic Digital Twin: From Replica to Agentic AI-Augmented Knowledge Ecosystem

Digital twins in cultural heritage have advanced from static 3D replicas to dynamic ecosystems enriched by IoT sensors and Agentic AI (Bruno et al., 2019; Gavrilov et al., 2021). Recent innovations include AI-powered 'living' digital twins for historical sites, enabling predictive conservation and immersive experiences (Mixflow.AI, 2025). Agentic AI enhances semantic annotations and hypothetical reconstructions, as seen in AI-assisted analysis of ancient manuscripts (Jones, 2020). This evolution enables inquiry-driven learning, shifting from passive viewing to active exploration. Students can query correlations between structural weaknesses and climate data projections, fostering STEAM integration.

2.2 AI-Augmented Hermeneutics: Navigating Cultural Narratives with Agentic AI

Agentic AI's analytical prowess revolutionizes cultural studies, but its biases demand scrutiny (Kaplan & Haenlein, 2019; Noble, 2018). Studies show Agentic AI favoring Western perspectives in heritage contexts (Manalikul, 2023). The framework employs 'critical AI-assisted hermeneutics': students use Agentic AI for initial interpretations, then deconstruct outputs for biases, cross-referencing with community sources. This aligns with initiatives on AI literacy in museums (Sineglossa, 2025). Extending this to agentic AI, which operates autonomously to achieve objectives with minimal supervision (Jones, 2025), introduces proactive hermeneutics. Agentic systems can independently monitor digital twin interactions for emerging biases, suggest alternative narratives, or facilitate real-time community feedback loops, enhancing critical engagement while requiring safeguards against unintended autonomy in educational tools (Cunningham-Nelson et al., 2019; Xie et al., 2024).

2.3 Decolonizing the Digital Archive: Ethical Imperatives and Sovereignty

Digitizing heritage risks replicating colonial power dynamics (Christen, 2012). Recent scholarship advocates Indigenous Data Sovereignty (First Nations Information Governance Centre, 2014; Tiribelli & Mhlambi, 2023). A 2025 study uses NLP to expose biases in colonial records (Cambridge University Press, 2025). The framework mandates community co-creation, data sovereignty agreements, and platforms like Mukurtu CMS (Christen, 2015). By interrogating representation at every stage, it disrupts biased AI-training loops (Das & Lally, 2021; Lally, 2022). Agentic AI can support decolonization by autonomously curating diverse sources and flagging colonial legacies, but must be programmed with ethical overrides to ensure community control (Walsh et al., 2023).

2.4 Weaving Ethics into the Workflow: Challenges and Mitigation Strategies

Ethical risks include cultural misrepresentation, algorithmic bias, and privacy breaches. Mitigation incorporates Traditional Knowledge Labels and Principles of Seville (Bentkowska-Kafel, 2015). Algorithmic bias is addressed through bias statements on Agentic AI outputs (ResearchGate, 2025). Privacy in drone operations follows FAA guidelines and consent protocols (Finn & Wright, 2016). These strategies embed ethics into workflows, fostering internalized awareness among students. For agentic AI, additional mitigations include transparent audit trails and 'human-in-the-loop' requirements to prevent autonomous decisions from overriding ethical considerations (Xie et al., 2024).

3. Proposed Curriculum: The Enriched Twin Framework

A PBL-STEAM structure centers on creating enriched digital twins (Larmer et al., 2021; Liao, 2016).

3.1 Module 1: The Drone as an Ethical Data-Gathering Tool

Students master drone piloting for photogrammetry and LiDAR, drawing from established curricula. Ethical training covers privacy and surveillance, operationalizing AI's 'Perception' idea (AI for K-12 Working Group, 2021). Assessments require community consent plans.

3.2 Module 2: Agentic AI-Augmented 3D Modeling for Reconstruction and Narrative

Using tools like MeshLab, students process data into models, then augment with Agentic AI for annotations and bias analysis (Cignoni et al., 2008). This transforms models into multi-layered narratives, addressing societal impacts. Incorporating agentic AI, students deploy simple agents to autonomously scan models for bias indicators or generate adaptive annotations based on user interactions, promoting deeper critical analysis (Cunningham-Nelson et al., 2019).

3.3 Capstone Integration and Assessment

Teams collaborate with communities to build enriched twins, activating all Five Big Ideas in AI (AI for K-12 Working Group, 2021). Agentic AI can facilitate this by coordinating data flows and suggesting ethical adjustments in real-time. Public presentations justify technical, interpretive, and ethical choices, ensuring accountability.

4. Future Research and Implications

The 'Enriched Twin' framework, as proposed in this article, is not intended as a finished product but rather as a dynamic, evolving model that invites rigorous empirical investigation and iterative refinement. Its implementation in real K-12 classrooms offers fertile ground for multiple lines of scholarly inquiry that can contribute meaningfully to the intersecting fields of educational technology, digital humanities, curriculum studies, and AI ethics. Three complementary yet distinct research trajectories are proposed below, each designed to generate robust, transferable knowledge about the pedagogical efficacy, ethical implications, and community impact of integrating agentic AI and digital twins into heritage education.

4.1 Trajectory A: Cognitive-Affective Exploration of Student Learning Outcomes

The first line of inquiry adopts a mixed-methods, quasi-experimental design to systematically evaluate the holistic impact of the Enriched Twin curriculum on students' cognitive, affective, and ethical development. A treatment group participating in the full curriculum would be compared with a matched control group receiving conventional digital heritage or technology education. Key research questions include:

- To what extent does participation in the Enriched Twin program enhance students' technical proficiency in drone-based data capture, 3D modeling, and agentic AI application?
- How does the curriculum influence students' critical awareness of cultural diversity, historical power imbalances, and the epistemic biases embedded in AI systems?
- In what ways does engagement with community co-creation and decolonizing methodologies foster empathy, ethical reasoning, and a sense of responsibility toward cultural heritage stewardship?

Quantitative instruments would include pre- and post-intervention assessments of technical skills, validated scales measuring cultural competence and AI literacy, and attitudinal surveys on ethical responsibility. Qualitative data would be collected through analysis of student artifacts, semi-structured focus group interviews, and classroom observations. Longitudinal follow-up studies could track whether these learning outcomes persist over time or transfer to other academic and civic contexts.

4.2 Trajectory B: Design-Based Research for Iterative Framework Validation and Refinement

The second trajectory employs Design-Based Research (DBR) methodology (Cobb et al., 2003) to collaboratively develop, implement, test, and refine the Enriched Twin framework in authentic educational contexts. Working closely with practicing teachers, school administrators, and community partners, researchers would conduct multiple iterative cycles of design-enactment-analysis-refinement. Core research questions include:

- What are the essential design principles, instructional scaffolds, and facilitation strategies that enable successful implementation of the Enriched Twin curriculum across diverse school settings?
- How do variations in teacher expertise, student age/grade level, and community partner characteristics influence the feasibility, fidelity, and outcomes of the curriculum?
- What adaptations are required to make the framework scalable and sustainable within existing school infrastructures, budgets, and scheduling constraints?

Each iteration would produce refined curriculum materials, professional development resources, and implementation guidelines grounded in both critical theory and classroom practice.

4.3 Trajectory C: Participatory Action Research on Community-School Co-Creation Dynamics

The third trajectory focuses on the socio-cultural and relational dimensions of the curriculum through a Participatory Action Research (PAR) approach. Researchers would embed themselves within selected school-community partnerships to document, analyze, and co-interpret the processes and outcomes of collaborative digital twin creation. Central questions include:

- What tensions, power dynamics, and negotiation processes emerge when K-12 students, teachers, and heritage community members co-construct enriched digital twins?

Data collection would involve ethnographic observation, in-depth interviews, co-created reflective artifacts, and analysis of data sovereignty agreements and Traditional Knowledge Labels. The resulting thick descriptions and critical case studies would serve as powerful exemplars for ethical community-school collaboration in the digital humanities. An additional extension could explore the integration of agentic AI in these partnerships, examining how autonomous agents facilitate or complicate decolonizing processes (Jones, 2025).

Collectively, these three research trajectories would generate a robust, multi-layered evidence base that not only validates the Enriched Twin framework but also contributes foundational knowledge to broader debates about responsible AI integration in education, decolonizing digital practices, and the role of schools in cultural heritage stewardship.

5. Conclusion

The 'Enriched Twin' framework represents a deliberate shift away from technology-centric digital heritage education toward a critically conscious, humanistic, and ethically grounded model. By centering agentic AI-augmented digital twins within a project-based STEAM curriculum and embedding critical AI hermeneutics and decolonizing methodologies throughout, this approach empowers K-12 students to become more than skilled technicians. It cultivates them as responsible digital stewards capable of interrogating biases, practicing data sovereignty, and co-creating culturally respectful representations of heritage. In an era of widespread agentic AI adoption, this framework offers a pathway to transform digital education into a site of social justice and cultural empowerment.

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