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Managing Innovation in Geoheritage Education: A VR Case Study of Shek O, Hong Kong

Boris L. F. Pun[1,*], **Anthony Y. H. Fung**[2,*], **Jeremy Ko**[3,*,**], **Chun Kai Leung**[4,5,6], **Chung Shing Chan**[7]

[1]Hong Kong Institute of Asia-Pacific Studies, The Chinese University of Hong Kong, Hong Kong
[2]School of Journalism and Communication, The Chinese University of Hong Kong, Hong Kong
[3]Department of Humanities, Social and Political Sciences, ETH Zurich, Switzerland
[4]Global Society and Sustainability Lab, Faculty of Social Sciences, The University of Hong Kong, Hong Kong
[5]Fairbank Center for Chinese Studies, Faculty of Arts and Sciences, Harvard University, Cambridge, MA, USA
[6]Hong Kong Institute of Humanities and Social Sciences, The University of Hong Kong, Hong Kong
[7]Department of Geography and Resource Management, The Chinese University of Hong Kong, Hong Kong

ABSTRACT

This article examines the use of virtual reality (VR) in geoheritage education through the lens of innovation management, focusing on Shek O, a historic fishing village in southeastern Hong Kong with rich geological and cultural heritage. By comparing two groups of primary school students—one using VR alone and another through a blended learning model combining VR with an on-site field trip—the study investigates their impacts on knowledge acquisition, emotional engagement, and conservation attitudes. Findings reveal that while VR enhances accessibility and introduces learners to Shek O's heritage, combining VR with physical experiences significantly deepens understanding, emotional connections, and commitment to preservation. Drawing on human geography, sociology, and anthropology, the study highlights how blending digital and place-based learning fosters transformative educational outcomes. VR emerges as a scalable tool for expanding access to heritage education, but its limitations in replicating multisensory and social dynamics underscore the value of hybrid approaches. Blended learning models integrating VR and physical experiences are recommended to optimize inclusivity, learning outcomes, and conservation values. These findings provide insights for educators, policymakers, and heritage managers seeking to leverage emerging innovative technologies for sustainable and innovative cultural education strategies.

Keywords: *Geoheritage education, Virtual reality (VR), Cultural heritage management, Blended learning, Cultural preservation, Place-based learning, Innovation management*

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*Co-First Authors.
**Correspondence to: Jeremy Ko, Department of Humanities, Social and Political Sciences, ETH Zurich, Switzerland.
E-mail: jereko@ethz.ch

1. INTRODUCTION

Geoheritage education is not only a pedagogical endeavor; it is also an innovation management challenge for custodians of fragile landscapes. In the context of sustainable transition and the digital era, heritage organizations must deliver high-quality, place-based learning while managing visitor flows, conserving sensitive sites, and widening equitable access. This requires rethinking service design, resource allocation, and technology adoption in ways that align educational goals with site-level management and governance. In practice, geoheritage education intersects with educational management and innovation strategy by shaping responsible visitation, standardizing pre-visit preparation at scale, and informing operational decisions on carrying capacity, safety, and conservation (Dowling & Newsome, 2018). As geographers and sociologists remind us, geoheritage is not only about physical landforms but also about place-making—how people construct meanings, identities, and attachments in relation to landscapes (Cresswell, 2004; Massey, 1994; Tuan, 1977). Education that links geological processes to lived histories fosters stewardship and compliance, but doing so equitably and sustainably demands new delivery models (Zafeiropoulos & Drinia, 2024).

Field trips remain the gold standard for cultivating embodied, place-based knowledge—supporting contextual understanding, sensory immersion, and social interaction rituals that anchor norms and collective meaning-making (Goffman, 1959; Ingold, 2000; Lo, Wünsche, Manfredini, & Hooper, 2025; Merleau-Ponty, 1962; Spicer & Stratford, 2001). Yet the logistical and equity constraints of in-situ learning—costs, distance, weather, safety, and the need to protect culturally sensitive sites—create a persistent capacity-management problem (Smith & McNeal, 2024). From an innovation perspective, this is a classic case for complementary assets and blended delivery: rather than replacing fieldwork, digital tools can be sequenced to prime, standardize, and extend learning while reducing strain on sites (Geels, 2002; Teece, 1986).

Against this backdrop, virtual reality (VR) functions as a service and process innovation in geoheritage education. Properly designed, VR can democratize access by offering scalable, standardized pre-visit preparation independent of geography or budget; it can shape demand and norms by communicating rules, safety, and conservation messages before limited on-site access; and it can scaffold learning by aligning mental models and expectations in advance (Lo et al., 2025; Makransky & Lilleholt, 2018; McKercher & Du Cros, 2014; Nikolaou, Schwabe, & Boomgaarden, 2022). VR's affordances—immersion, presence, narrative integration, and interaction—enable thick description of place and culture, including intangible heritage, while providing resilience during disruptions (Garcia, Nadelson, & Yeh, 2023; Geertz, 1973; Law, Yee, Ng, & Fong, 2023). At the same time, VR cannot fully substitute for the tactile, social, and serendipitous dimensions of fieldwork that deepen sense of place and stewardship (Lave & Wenger, 1991; Leininger Frézal & Sprenger, 2022; Urry, 2007). The management question, then, is not whether to digitize, but how to orchestrate complementarities—what sequence, scale, and governance model unlock the most educational and conservation value.

We approach VR as part of an innovation portfolio for heritage managers: a modular, scalable layer that complements quota-managed field visits. This portfolio lens emphasizes adoption costs, complementary capabilities (teacher training, content updates, device logistics), partnerships (schools, NGOs, EdTech), data governance, and metrics for public value (learning outcomes, behavioral intent, safety compliance) (Chesbrough, 2003). It also foregrounds equity and risk: VR can reduce cost barriers and standardize pre-visit orientation, but it raises questions around the digital divide, content authenticity, and potential crowding-out of field experiences if misapplied. Effective implementation thus hinges on sequencing (VR-first), change management (teacher facilitation), and continuous improvement based on feedback loops.

Situated within this blended paradigm, we examine VR-enhanced geoheritage education in Shek O, a historic fishing village in southeastern Hong Kong. Shek O is a hybrid landscape where geology interlaces with cultural practices—temple rituals, festivals, and fishing livelihoods—shaping local identity and memory (Agriculture, Fisheries and Conservation Department, 2024). This makes it an ideal "living lab" to test instructional pathways against three objectives that double as management KPIs: (1) cognitive understanding of cultural and geological features; (2) affective engagement and sense of place; and (3) stewardship-oriented attitudes aligned with responsible visitation and site-level management (Smith, 2006).

Using a mixed-methods design with two cohorts of Hong Kong primary students, we compare a VR-only pathway to a VR-first blended sequence followed by an on-site field trip. Results show a clear pattern: VR alone is an effective, equitable baseline—building foundational knowledge, orienting learners to key features, and sparking interest. When a field trip follows VR, outcomes strengthen and become more consistent: concepts are consolidated through multisensory, situated encounters; affective attachment deepens via embodied and social interaction; and stewardship norms and readiness for responsible behavior are reinforced. From the innovation management perspective, the VR-first sequence acts as a scalable pre-visit "platform" that standardizes preparation and norm-setting, while quota- and safety-managed site visits serve as a high-impact, scarce complement that consolidates learning and pro-conservation orientations (Avcu & Yaman, 2025; Leininger Frézal & Sprenger, 2022). This orchestrated bundle enhances educational value while relieving operational pressure—an innovation strategy with implications for adoption, scaling, and governance across heritage contexts.

The remainder of the article proceeds as follows. Section 2 synthesizes literature on field-based learning, VR, and blended models, linking them to principles of innovation management and service design in heritage settings. Section 3 details the mixed-methods design, VR platform, and data collection and analysis. Section 4 presents comparative results for VR-only and VR-first blended models. Section 5 discusses implications for policy, educational practice, and site-level innovation governance; notes limitations; and outlines directions for scaling and future research.

2. LITERATURE REVIEW

Geoheritage education fosters awareness, understanding, and conservation of geosites—notable geological features such as landforms, fossils, and rock formations—and cultural landscapes shaped by human interaction with the environment (Zafeiropoulos & Drinia, 2024). Beyond pedagogy, it raises practical questions about how to design, scale, and govern learning services that widen access while protecting fragile assets. Geoheritage sites are not merely physical spaces but places imbued with cultural meaning, history, and identity (Massey, 1994; Tuan, 1977). Conceived as "cultural texts" (Cosgrove & Daniels, 1989), these landscapes support experiential learning that connects theory and practice while requiring delivery models that balance educational value, carrying capacity, and stakeholder legitimacy. In this sense, geoheritage education sits at the intersection of place-based learning and service design—drawing on complementary components, staged delivery, and continuous improvement to align learning with site-level management objectives and broader system transitions (Geels, 2002; Teece, 1986).

2.1. The role of field trips in place-based learning

Traditionally, field trips have been essential in geoheritage education, promoting place-based learning (Gruenewald, 2003). Field trips facilitate embodied knowledge (Ingold, 2000), allowing learners to engage directly with landscapes through tactile, sensory, and emotional experiences. This type of learning fosters what geographers refer to as sense of place—the emotional bonds and meanings people attribute to specific locations (Cresswell, 2004; Relph, 1976). Anthropologists similarly emphasize that sensory engagement with a place enables the development of situated knowledge (Haraway, 1988), which is grounded in personal and collective experience. From a management perspective, these embodied and social encounters are precursors to stewardship and on-site rule compliance, linking pedagogy to practical conservation outcomes and, by extension, to measurable site-level benefits.

Field trips also promote social learning through group interactions and collective experiences (Lave & Wenger, 1991). Sociologist Erving Goffman (1959) highlights the importance of interaction rituals—the shared, often spontaneous exchanges that occur during group activities. These interactions help build a communal understanding of heritage, fostering a collective sense of responsibility and stewardship. Additionally, direct encounters with heritage sites encourage affective engagement (Davidson & Milligan, 2004), where emotional connections drive a deeper commitment to conservation and cultural preservation (Ho, 2024). Translating these benefits into policy and operations requires attention to capacity limits, safety protocols, staffing and facilitation, and community legitimacy—elements that determine how scarce field access is scheduled, delivered, and evaluated.

However, field-based learning faces significant challenges. Logistical constraints such as financial costs, time limitations, and accessibility issues can exclude many learners, particularly those from marginalized backgrounds (Bourdieu, 1986; Smith & McNeal, 2024). Certain sites, such as sacred or environmentally sensitive locations, may not be suitable for mass visitation, raising ethical considerations about preservation and respect for local communities (Dabamona & Cater, 2019). These constraints foreground a design problem for public-facing programs: how to scale high-quality, in-situ learning while protecting fragile assets and ensuring fair allocation of scarce access, including quotas, small-group formats, and careful sequencing with preparatory activities.

2.2. Virtual reality: Enhancing accessibility and engagement

In response to these challenges, VR offers a complementary channel for geoheritage education. VR enables learners to explore virtual representations of place (Soja, 1996) through immersive simulations that approximate physical environments. This technology allows for mediated experiences that, while not fully substituting for physical engagement, provide rich sensory and cognitive stimulation. VR platforms incorporate 360-degree imagery, spatial audio, and interactive elements, facilitating multimodal learning (Jewitt, 2008). Beyond pedagogy, VR can standardize pre-visit orientation (rules, protocols, safety), shape demand ahead of limited field slots, and reach schools unable to travel—advancing equity and reducing travel-related externalities in line with sustainable transition goals.

VR can provide thick descriptions of heritage sites (Geertz, 1973), embedding detailed narratives and cultural contexts into digital experiences. These narratives often include oral histories and community stories, which foster empathy and a deeper understanding of place-based heritage (Richards, 2018). VR's ability to simulate cultural narratives aligns with the sociological concept of symbolic interactionism (Blumer, 1969), where meanings are constructed through interactions with symbols and representations. When co-created with local custodians, such narratives can enhance legitimacy and acceptance of conservation norms.

Evidence indicates that VR enhances cognitive engagement, knowledge retention, and positive attitudes toward conservation (Avcu & Yaman, 2025; Maqbool et al., 2025). Its immersive nature supports affective geographies by evoking emotional responses that can drive conservation-oriented behavior. At the same time, VR lends itself to programmatic scale and consistency: modular content can be reused across cohorts, marginal delivery costs are low once materials are developed, and pre-visit expectations can be aligned across diverse classrooms. Implementation, however, depends on complementary capabilities such as teacher training, content localization, device logistics, and data governance, and may benefit from partnerships with schools, heritage NGOs, and EdTech providers to ensure reach and quality (Chesbrough, 2003).

2.3. The limitations of virtual environments

Despite its advantages, VR cannot fully replicate the embodied, multisensory experience of physical field trips (Leininger-Frézal & Sprenger, 2022; Merleau-Ponty, 1962). Human geographers argue that tactile engagement with landscapes—feeling the texture of rocks, experiencing the climate, and walking the terrain—plays a crucial role in developing place attachment (Relph, 1976; Tuan, 1977). Anthropologists further highlight the importance of situated practices (Lave & Wenger, 1991), where learning occurs through direct participation in cultural contexts. From a management viewpoint, relying on VR alone risks weaker norm internalization and lower stewardship, particularly when opportunities for social interaction, local voices, and in-situ reflection are limited.

VR also lacks the spontaneous social interactions and peer-to-peer learning that occur during group field trips (Urry, 2007). These social dynamics are critical for constructing shared meanings and reinforcing collective conservation values (Richards, 2018; Smith, 2006). Consequently, VR is best employed as a complementary pedagogy rather than a replacement for physical field experiences (Jimura, 2011; McDaniel, 2025; Spicer & Stratford, 2001). Effective delivery further requires attention to digital inclusion, teacher capacity, and content management (privacy, accessibility, and localization) to ensure equitable, culturally legitimate experiences in public systems. Risk controls—such as co-creation with community stakeholders, accessibility audits, and clear indicators for learning and behavioral intent—help maintain quality and trust at scale.

2.4. Blended learning: Integrating VR and field trips

Blended learning approaches in geoheritage education draw on constructivist theories of learning (Kolb, 1984), which emphasize the iterative cycle of abstract conceptualization and concrete experience. VR serves as a preparatory tool that introduces learners to key concepts, spatial layouts, and cultural narratives before they visit a site (Alazmi & Alemtairy, 2024). This approach enhances cognitive scaffolding (Vygotsky, 1978), where VR provides a conceptual framework that supports deeper engagement during the field trip. Sequencing also enables standardized pre-visit messaging, smoother risk management, and more efficient allocation of limited on-site access.

Post-visit VR sessions can reinforce learning by enabling learners to revisit sites virtually, reflect on their experiences, and explore additional content (Hurrell et al., 2025). This iterative process aligns with anthropological and sociological theories of reflexivity (Bourdieu & Wacquant, 1992), where learners critically examine their experiences and the social contexts that shape them. For field trip management, a blended pipeline supports carrying-capacity policies (small-group quotas, staggered schedules) and monitoring (linking classroom indicators to on-site compliance and incident data). It also clarifies roles and capabilities across the delivery chain: VR modules handle orientation and baseline knowledge at scale; field visits consolidate learning through embodied and social encounters; and post-visit activities sustain motivation and stewardship intentions. Feedback loops across these components enable ongoing refinement of content and logistics (McDaniel, 2025).

2.5. Literature gap and contribution

A detailed comparison with existing literature clarifies where this study advances the field conceptually. Prior research typically treats VR and field trips as substitutes or evaluates them in isolation—VR for engagement, presence, and access; field trips for embodiment, affect, and place-making (Alazmi & Alemtairy, 2024; Kolb, 1984; Leininger-Frézal & Sprenger, 2022; McDaniel, 2025; Yang et al., 2023). This study reframes these modalities as complementary and interdependent: VR provides conceptual scaffolding and context, while in-situ encounters deepen multisensory understanding and meaning-making. This integrative lens moves beyond "virtual versus real" debates by specifying how blended sequencing aligns with experiential learning theory and place-based education, rather than positioning VR as a wholesale replacement for fieldwork (Ho, 2024; Spicer & Stratford, 2001; Vygotsky, 1978).

Mechanistically, earlier work highlights engagement, presence, and affect but less often explains how digital and physical experiences co-produce learning (Avcu & Yaman, 2025; Tussyadiah, Wang, Jung, & tom Dieck, 2018; Webster, 2016). This study contributes a process-based account linking three pathways: cognitive scaffolding (pre-visit mental models), social learning (interaction rituals and peer negotiation of meaning), and sense of place (symbolic and embodied attachments), connecting these to stewardship-oriented orientations. This connects sociocultural and geographical theory—situated learning, interaction rituals, and symbolic interactionism—to practical heritage education, articulating why and how blended designs cultivate durable knowledge and pro-conservation orientations (Geertz, 1973; Goffman, 1959; Lave & Wenger, 1991; McDaniel, 2025; Relph, 1976). It also relates these pathways to program delivery choices—sequencing, facilitation, and capacity allocation—that determine consistency and reach.

Methodologically, many VR studies rely on single-group or non-comparative designs or emphasize usability over educational constructs (Lin, Li, Yao; Özgen, Afacan, & Sürer, 2021). This study contributes a cohort-comparative, mixed-methods design that operationalizes cognitive, affective, and stewardship-related constructs and triangulates standardized instruments with thematic analysis. Community co-creation further grounds the VR content in culturally legitimate narratives, addressing critiques of techno-centric implementations and enhancing authenticity in heritage contexts (Braun & Clarke, 2006; Yang et al., 2023). The approach also foregrounds practical considerations—teacher training, device management, and content updates—so that findings map onto real-world delivery constraints in schools and heritage sites.

Practically, while prior work notes VR's accessibility and inclusivity benefits, it seldom links pedagogy to site-level cultural heritage management (Hurrell et al., 2025; Nikolaou et al., 2022). This study proposes an operating model: VR for standardized, equitable pre-visit preparation and norm-setting at scale, followed by small, quota-managed field visits for consolidation. This aligns instructional design with carrying capacity, equity, and sustainable transition goals and offers a replicable pathway for urban, culturally sensitive contexts—complementing a literature base that has often centered on Western geoscience settings and tertiary learners (Gielstra et al., 2024; McKercher & Du Cros, 2014). The model depends on complementary capabilities and partnerships across schools, community custodians, and technology providers, with clear indicators for learning, motivation, and readiness for responsible behavior to guide iterative improvement.

Situated in Shek O, a historic fishing village in southeastern Hong Kong, this study provides a contextual testbed for these contributions. Shek O's hybrid landscape combines significant geological features with a rich cultural heritage shaped by centuries of maritime traditions (Agriculture, Fisheries and Conservation Department, 2024). The community's engagement with heritage preservation reflects broader themes in community-based conservation (Smith, 2006) and participatory geography (Kindon et al., 2007). In an urbanized setting with high demand and sensitive features, Shek O exemplifies common management challenges, including ensuring equitable access, managing capacity limits, and delivering culturally appropriate conservation messaging.

By investigating the role of VR in this context, the study explores how digital technologies can enhance place-based learning, deepen cultural appreciation, and support sustainable conservation practices. This case not only advances the field of digital heritage education but also provides valuable insights for educators, policymakers, and heritage managers. It interprets learning outcomes as proxies for cultural heritage management objectives—such as readiness to follow site rules, strengthened place attachment as a foundation for stewardship, and increased motivation that can be directed through quota-managed, small-group access. By doing so, it shows how educational innovation can be linked to conservation governance and day-to-day operations in the digital era (Dowling & Newsome, 2018; Smith & McNeal, 2024).

3. METHODOLOGY

This study employs a mixed-methods comparative research design to evaluate the educational efficacy of VR in geoheritage learning, using Shek O as a focal case. The approach integrates insights from human geography, sociology, and anthropology to capture the multidimensional aspects of place-making, community engagement, and social learning dynamics. Shek O, with its rich geological diversity and layered cultural narratives, serves as a compelling case study for exploring how VR and field trips can complement each other to enhance geoheritage education. The design also generates decision-relevant evidence for program delivery—sequencing, partnership roles, and resource allocation—under conditions of limited site capacity and high demand.

3.1. Study design and participant selection

The research compares two cohorts: an experimental group exposed to a blended learning approach involving both VR and a physical site visit, and a control group exposed to VR alone. This design addresses a gap in the literature where VR's potential is often assessed in isolation, overlooking its possible synergy with embodied, place-based experiences. The comparison highlights how VR can function as scalable pre-visit orientation, while blended delivery can consolidate stewardship-oriented attitudes without relying solely on high-impact, in-situ exposure. It also mirrors real-world delivery choices: a standardized VR-first layer that can be deployed broadly and a quota-managed in-person component reserved for smaller groups.

Participants were selected from two primary schools in Hong Kong to ensure demographic comparability. The experimental group consisted of 50 students, who first engaged with VR content in the classroom before visiting Shek O. The control group, comprising 114 students, participated in a weekend VR-only event without the subsequent field trip. By selecting participants from similar socioeconomic backgrounds, the study minimizes potential confounding variables and addresses concerns related to educational equity. Interpreted for policy and management, this comparability supports fair access and consistent delivery across school contexts. The approach ensures that findings reflect the impact of the learning modalities rather than differences in prior exposure or background knowledge, thereby informing scalable operating choices in school-based programs. Parental consent and school approval procedures were completed, and all data were anonymized to meet standard ethical and data governance requirements for research with minors.

3.2. VR platform and technological considerations

The VR platform was designed to provide an immersive simulation of Shek O's geological and cultural landscapes. It incorporated 360-degree panoramic imagery, spatial audio, and interactive elements that highlighted the village's coastal geology, cultural landmarks like the Tin Hau Temple, and traditional stilt houses. The content was co-developed with local community organizations, such as the Shek O Heritage Society, to ensure authenticity and cultural relevance. This collaborative process reflects anthropological principles of community-driven conservation, where local knowledge and narratives are integral to heritage education, and, from a management standpoint, strengthens legitimacy, local buy-in, and the durability of conservation messages.

The VR experience featured oral histories and cultural symbols to offer a rich, context-driven understanding of Shek O's heritage. This approach aligns with the anthropological concept of thick description, as described by Geertz (1973), where detailed cultural narratives foster deeper empathy and engagement. Due to pandemic-related restrictions, students accessed the VR content using Oculus Quest headsets or flat-screen monitors with console joysticks. Although this setup limited the level of embodied immersion, it preserved core functionalities and ensured accessibility. Practical considerations included device logistics (charging, sanitation, and rotation schedules), staff facilitation, and offline content availability to mitigate bandwidth constraints in schools. These operational details inform deployment at scale in public systems—clarifying resourcing needs, training requirements for teachers and facilitators, content update cycles, accessibility features (subtitles, voiceover, and motion sensitivity settings), and data-protection practices (local storage, consent, and minimal analytics collection).

3.3. Data collection instruments

The study employed both quantitative and qualitative methods to capture the multifaceted impact of VR and field-based learning. A structured survey was administered post-intervention to measure knowledge enrichment, attitudinal shifts, and platform usability. The survey included Likert-scale items designed to assess students' understanding of Shek O's geological and cultural features, their attitudes toward heritage conservation, and their experiences using the VR platform. This approach aligns with constructivist theories of learning, which emphasize the importance of contextual and experiential knowledge construction. Interpreted as program indicators, these same measures signal readiness for responsible engagement on-site, receptivity to conservation norms, and satisfaction with the preparatory experience—outcomes that can guide resource allocation, staff training, and content refinement.

In addition to the survey, qualitative data were gathered through open-ended responses, group interviews, and field observations. Open-ended survey questions allowed students to express their perceptions, reflections, and emotional connections to Shek O. Group interviews with selected students, teachers, and community members provided deeper insights into themes such as cultural identity, place attachment, and social learning dynamics. These interviews were informed by anthropological and sociological frameworks, emphasizing how cultural narratives and social interactions shape learning experiences. Field observations documented students' spontaneous interactions and learning behaviors during the site visit. These observations captured the peer-to-peer exchanges and collective meaning-making that occurred in real-time, reflecting the sociological concept of interaction rituals. Together, these data collection methods provided a comprehensive understanding of how VR and field trips influenced students' cognitive and affective engagement, while offering practical insights for delivery—such as the value of teacher facilitation, the pacing of VR modules, and the adequacy of pre-visit messaging for safety and etiquette.

3.4. Data analysis procedures

The analysis combined quantitative and qualitative techniques to provide a nuanced interpretation of the data. Quantitative survey responses were analyzed using descriptive statistics, including means and standard deviations, to summarize the overall trends. To identify significant differences between the VR-only and blended cohorts, unpaired two-sample t-tests were conducted. Where relevant, effect sizes were calculated to assess the magnitude of observed differences. This statistical approach is well-suited for detecting differences in learning outcomes—such as knowledge retention, place-based interest, and stewardship-oriented attitudes—between the two groups. These differences also help infer the potential of VR and blended models to standardize conservation messaging and strengthen pro-conservation orientations at scale, informing decisions about sequencing, class-time allocation, and the size and frequency of field visits.

Qualitative data from open-ended responses, interviews, and observations were analyzed using thematic analysis. Key themes related to sense of place, cultural identity, and social interactions were identified and interpreted through human geography, sociology, and anthropology frameworks. For example, students' descriptions of their emotional connections to Shek O were analyzed in the context of place attachment and embodied learning, while their group interactions during the field trip were examined through the lens of social learning theories. Coding combined deductive categories (knowledge, affect, stewardship intent, and social interaction) with inductive theme development to capture emergent patterns. These qualitative interpretations provide context for how digital and embodied components operate together in a delivery sequence aligned with cultural heritage objectives, highlighting mechanisms—such as pre-visit mental model alignment and on-site interaction rituals—that can be supported through teacher training, community facilitation, and iterative content updates.

3.5. Validity and reliability considerations

To ensure the validity and reliability of the study, several measures were implemented. Triangulation of data sources—surveys, interviews, and observations—helped cross-verify findings and enhance the robustness of the results. Pilot testing the survey with a small subset of students ensured that the instrument was clear and comprehensible. Efforts were made to maintain equivalence between the two school cohorts in terms of demographic profiles and baseline knowledge to minimize potential biases. For the qualitative strand, a codebook was developed and iteratively refined; double coding of a subset of transcripts and discussion of discrepancies supported consistency in interpretation. The study prioritized respectful engagement with community partners, ensuring that local narratives and cultural values were represented accurately and sensitively in the VR content. Data handling followed child safeguarding and privacy standards, including anonymization, secure storage, and minimal collection of personally identifiable information.

From the lens of program delivery and responsible technology use, these procedures strengthen the credibility and policy relevance of the evidence for site-level management and equitable implementation. They also clarify what it would take to scale: facilitation guidelines for teachers, device management protocols, accessibility checklists, content governance processes (review cycles, cultural approvals), and outcome indicators that can be integrated into routine monitoring. Together, these elements support the broader goal of culturally informed, inclusive heritage education that can be delivered consistently across diverse classrooms while protecting sensitive places.

4. RESULTS

This section expands the comparative analysis between the VR-only (control) and VR-plus-field trip (experimental) cohorts, incorporating data from Table 1 and Table 2 to illustrate how each modality influenced knowledge enrichment, attitudinal shifts, and platform usability. The findings are interpreted through perspectives on place-making, social interaction, and embodied learning, drawing on human geography, sociology, and anthropology to provide a more nuanced understanding of the results.

4.1. Descriptive statistics

Survey responses demonstrated generally favorable perceptions of the VR activity (Table 1). The eight items assessing participants' views on learning about Shek O's local culture, geography, and conservation significance produced mean scores ranging from 3.82 (Item 2) to 4.04 (Item 1), with standard deviations mostly near 1.0. These values suggest that students

Table 1. Descriptive statistics.

Item No.	Question Items	Mean Score	Standard Deviation
1	This VR activity has allowed me to learn more about the local culture in Shek O.	4.04	0.90
2	This VR activity has helped me become more familiar with the geographical aspects of Shek O.	3.82	1.06
3	This VR activity helps me become more interested in learning about Shek O.	3.95	1.05
4	This VR activity has increased my interest in visiting Shek O to experience the local attractions firsthand.	3.83	1.13
5	This VR activity can help document the culture of Shek O.	4.01	1.02
6	This VR activity can help document photographs and artifacts related to the culture of Shek O.	3.99	0.97
7	This VR activity can showcase the culture of Shek O to the public or be used for publication purposes.	3.92	1.03
8	This VR activity makes me want to learn more about the local culture of Shek O in my spare time.	3.88	1.15

Note: Scores range from 1 (lowest level of agreement with the statement) to 5 (highest level of agreement with the statement).

found the VR platform both engaging and informative. Item 1, which focused on whether the VR activity had enhanced understanding of Shek O's local culture, showed a mean of 4.04 (SD = 0.90), indicating that most participants considered VR effective in introducing cultural insights. Item 2, which assessed students' familiarity with Shek O's geographical features, yielded a mean of 3.82 (SD = 1.06), revealing somewhat lower—but still positive—perceptions of VR's impact on spatial understanding (Makransky & Lilleholt, 2018; Yang et al., 2023). Item 3 (mean = 3.95, SD = 1.05) and Item 4 (mean = 3.83, SD = 1.13) indicated that VR stimulated interest in learning about Shek O and motivated students to visit in person.

Items 5, 6, and 7, which collectively probed whether VR could serve as a tool for documenting and showcasing Shek O's culture, recorded mean scores above 3.90, suggesting that participants believed in VR's potential to support cultural and heritage documentation. Item 8 (mean = 3.88, SD = 1.15) underscored a strong inclination among students to learn more about Shek O on their own time. These initial statistics align with existing research on the utility of VR in promoting baseline knowledge and interest in geographical and cultural content (Leininger-Frézal & Sprenger, 2022). From a management perspective, this positive baseline supports the use of VR as a standardized, low-cost pre-visit orientation that can be deployed equitably across schools to prepare learners for responsible, capacity-managed access.

4.2. Comparative analysis: VR-Only vs. VR-Plus-Field Trip

Table 2 offers a more detailed look at how the two cohorts differed in their evaluations of the same eight survey items. The experimental group consistently recorded higher mean scores across all items, with every difference reaching statistical significance ($p < 0.001$). For Item 1, the control group averaged 3.85 (SD = 0.97), whereas the experimental group reached 4.48 (SD = 0.50), reflecting a stronger perception of cultural learning when VR was followed by an in-person trip to Shek O. For Item 2, which addressed students' familiarity with Shek O's geographical aspects, the control cohort obtained a mean score of 3.68 (SD = 1.15), while the experimental group recorded 4.14 (SD = 0.73). These gains corroborate constructivist theories that knowledge acquisition is enhanced when abstract digital content is complemented by direct sensory engagement

Table 2. Descriptive statistics between the experimental and control groups.

Item No.	Group	Mean Score	Standard Deviation	*t*-test (*p*-value)
1	Control	3.85	0.97	−4.89 (0.0000)
	Experimental	4.48	0.50	
2	Control	3.68	1.15	−4.47 (0.0000)
	Experimental	4.14	0.73	
3	Control	3.75	1.12	−6.14 (0.0000)
	Experimental	4.42	0.67	
4	Control	3.52	1.18	−7.66 (0.0000)
	Experimental	4.54	0.54	
5	Control	3.79	1.05	−5.73 (0.0000)
	Experimental	4.50	0.76	
6	Control	3.79	1.03	−6.49 (0.0000)
	Experimental	4.46	0.61	
7	Control	3.68	1.08	−5.72 (0.0000)
	Experimental	4.46	0.65	
8	Control	3.60	1.22	−5.56 (0.0000)
	Experimental	4.54	0.58	

Note: Scores range from 1 (lowest level of agreement with the statement) to 5 (highest level of agreement with the statement). All *t*-tests indicate statistically significant differences ($p < 0.001$) between the control and experimental groups.

with real-world environments (Kolb, 1984; Vygotsky, 1978). They also align with the concept of place-making in human geography, wherein site-based encounters cement a deeper sense of meaning (Cresswell, 2004). From a cultural heritage management lens, these differences indicate that a VR-first, blended model may strengthen stewardship-relevant attitudes while allowing managers to maintain small, quota-limited, low-impact field access.

The results for Items 3 and 4, centered on interest and inclination toward visiting Shek O, showed that control group means hovered around 3.52 to 3.75, while the experimental group exceeded 4.40. These figures confirm that physically experiencing Shek O exerts a stronger influence on students' affective attachment, echoing studies on how embodied interactions heighten conservation-minded attitudes (Ho, 2024; Relph, 1976). Higher scores in the experimental cohort for Items 5, 6, and 7 also suggest that students who made an on-site visit believed more strongly in VR's role as a culturally authentic platform, likely because their personal experiences validated and enriched what they had seen in the virtual environment (Ingold, 2000; Lo et al., 2025). Item 8 showed a particularly pronounced gap (control mean of 3.60 vs. experimental mean of 4.54), indicating that physical field trips inspired greater independent interest in Shek O's heritage. The *t*-tests (all *p*-values = 0.0000) reinforce the statistical robustness of these differences. For policy and management, this pattern supports a two-stage operating model: VR to standardize pre-visit norms at scale, followed by focused, small-group field visits that consolidate pro-conservation attitudes without escalating site pressure.

4.3. Qualitative insights: Embodied and social learning dynamics

Qualitative feedback offered insights into how these quantitative patterns emerged. Students in the blended cohort often mentioned that VR provided an introduction to Shek O's features but that the physical visit rendered the experience "more real," especially when they touched the rocks, heard the sounds of the coast, and observed the temple's architecture firsthand

(Tuan, 1977). This response fits the anthropological perspective that embodied, situated knowledge shapes deeper connections to place (Ingold, 2000). It also resonates with the sociological emphasis on social interactions as a catalyst for learning (Goffman, 1959), as field observations revealed students discussing the VR content in real time and pointing out discrepancies or novelties when compared to the actual setting. Such peer-to-peer exchanges align with situated learning theories, which posit that collective meaning-making is integral to knowledge internalization (Lave & Wenger, 1991). From a cultural heritage management standpoint, these social processes help embed conservation norms and peer reinforcement, which are valuable for on-site behavior and adaptive implementation.

Students in the experimental group also demonstrated more pronounced attitudinal shifts regarding conservation and heritage protection. Comments such as "It's different when you see the temple in person; you realize why it needs protection" suggest that the cumulative effect of VR-based awareness and on-site sensory immersion strengthened empathetic responses (Smith, 2006). The desire to safeguard Shek O's cultural and ecological features reflects the anthropological notion that personal encounters intensify moral and affective commitments to heritage sites (Richards, 2018). As such, these qualitative shifts point to higher expected compliance and stewardship during managed visits.

4.4. Usability and technological limitations

Although participants rated the VR platform favorably, several expressed that their experience could have been more immersive. Flat-screen displays and console joysticks were used by most students due to health measures restricting the use of headset-based VR, which may have limited the sense of presence that more advanced setups typically provide (Leininger-Frézal & Sprenger, 2022; Yang et al., 2023). The slight differences in mean usability scores between the two cohorts (4.1 for VR-only vs. 4.2 for the blended group) may reflect how the onsite experience positively influenced perceptions of VR's authenticity, even though the actual interface was the same in both cases. For innovation management, these technological enhancements, including motion tracking and haptic feedback, may address these limitations and bring virtual environments closer to the direct, multisensory experiences that occur during field trips. As such, these observations inform practical choices about procurement, device sharing, and training required for scalable, equitable deployment in public systems.

4.5. Integrative interpretation

The combined evidence from Tables 1 and 2 underscores that VR is a powerful introduction to geoheritage sites but achieves its maximum educational value when paired with physical field trips. The interplay between digital and tangible exposure aligns with constructivist theories that emphasize the fusion of abstract and concrete experiences in knowledge construction (Kolb, 1984; Vygotsky, 1978). Students in the blended cohort not only acquired higher levels of factual knowledge but also showed stronger affective commitments to heritage preservation, validating the importance of place-making and embodied engagement (Cresswell, 2004; Lo et al., 2025; Merleau-Ponty, 1962). The social learning dimension further emerged through classroom and on-site discussions that deepened collective understanding (Lave & Wenger, 1991). In sum, VR can successfully prepare learners with foundational insights into Shek O, but it is the subsequent physical exploration that solidifies emotional bonds, fosters empathy, and stimulates conservation-oriented attitudes. These results point to a pragmatic, two-stage management model—VR for standardized, equitable pre-visit preparation and small-group field visits for norm consolidation—that can help managers balance access, site protection, and sustainable transition objectives without altering educational quality.

5. DISCUSSION AND CONCLUSION

5.1. Discussion

Integrating VR with traditional field trips creates a robust learning environment that strengthens cognitive understanding, deepens affective connection, and supports stewardship more reliably than VR alone. In cultural heritage management and digital innovation terms, sequencing standardized, scalable pre-visit preparation (via VR) with capacity-managed, in situ experiences aligns instruction with site-level goals by balancing access, authenticity, and impact. This approach mitigates logistical barriers—cost, time, and distance—while preserving the immersive qualities of learning on-site and reinforcing authenticity, place-making, and interactive social dynamics that underpin responsible visitation and compliance with conservation norms (McKercher & Du Cros, 2014; Zafeiropoulos & Drinia, 2024). It also clarifies roles within a delivery pipeline: VR modules handle norm-setting and baseline knowledge at scale; field visits deliver scarce, high-impact encounters; and facilitation by teachers and local custodians ties both layers to community legitimacy and safety practices. Crucially, feedback loops from field observations to VR content updates and teacher guidelines allow continuous quality improvement without adding pressure to sensitive sites.

Cognitively, the dual emphasis on conceptual understanding and tangible experience proved effective. VR provided a shared initial framework—cognitive scaffolding and thick description—of Shek O's geological and cultural features, presenting the site as a cultural text and spatial narrative that learners could later recognize on the ground (Cosgrove & Daniels, 1989; Geertz, 1973; Magalhães, Melo, Fernando Coelho, & Bessa, 2024). Upon arrival, students engaged the material realities of Shek O through their senses, anchoring abstract information in tactile and sensory encounters consistent with embodied and situated knowledge. The interplay between digital introductions and real-world observations appears to reinforce retention and interpretation, with the blended group showing clearer recognition of features and concepts than the VR-only group. For program design, this implies that pre-visit modules should include salient spatial cues, vocabulary, and task prompts that map directly to on-site signage, wayfinding, and guide scripts—reducing cognitive load and improving the efficiency of on-site facilitation.

Affectively, virtual exposure supplied context and narrative, but direct contact with rocks, the temple, and the coastal setting generated layered emotional connections that VR could not fully replicate. These embodied encounters are closely tied to sense of place and affective geographies, helping to embed memories and emotions that translate into care for Shek O's cultural and geological heritage (Magalhães et al., 2024; McDaniel, 2025; Relph, 1976). The blended pathway thus more strongly activated responsibility and conservation-oriented attitudes than VR alone, suggesting that emotional resonance depends on being in place even when initial interest is sparked digitally. In practical terms, designing field itineraries to include moments of reflection, ritualized pauses, and community storytelling can amplify these affective anchors, while VR's role is to prime expectations and introduce the cultural lexicon that makes those moments legible and meaningful.

Collective learning was also more pronounced in the blended environment. In situ, students exchanged immediate reactions, posed real-time questions, and co-interpreted natural and cultural elements—interaction rituals that build communal meaning and reinforce bonds (Goffman, 1959). These co-present dynamics align with situated learning and communities of practice, where knowledge is negotiated socially and stabilized through shared experience (Lave & Wenger, 1991; McDaniel, 2025). The VR-only group, lacking these spontaneous exchanges, had fewer opportunities for collaborative meaning-making. Structuring small-group tasks, peer explanation, and shared observation checklists during field visits can maximize these dynamics and translate them into measurable readiness for responsible conduct. Moreover, aligning teacher facilitation and local guide narratives with the pre-visit VR storyline creates consistency across touchpoints and supports on-site compliance.

Together, these patterns reveal a clear division of labor: VR serves as an equitable foundation for conceptual orientation, standardized rule-setting, and expanding access, while field trips reinforce learning through hands-on experiences, social interactions, and emotional connections. This sequencing aligns with management goals by addressing carrying-capacity constraints, enhancing cultural legitimacy when co-created with local custodians, and providing a scalable solution for urban, culturally sensitive contexts where high-quality learning and conservation outcomes are equally important. Operational details—device pools shared across schools, teacher professional development, content governance with community review, and monitoring dashboards linking classroom indicators to on-site behavior—turn this design into a repeatable operating model.

5.2. Conclusion

The integration of VR and on-site field trips emerges as a powerful catalyst for meaningful and enduring geoheritage education. The dual-mode approach introduces learners to geological and cultural dimensions through virtual means, then deepens their understanding and emotional investment through embodied, place-based encounters (Magalhães et al., 2024). This synergy amplifies the importance of engaging both the symbolic and material characteristics of place, in line with established perspectives in human geography and anthropology that emphasize multisensory involvement in shaping learning and conservation values.

For cultural heritage and innovation management, the same sequencing provides a scalable pathway to standardize conservation messages, support equitable access, complement carrying-capacity management, and potentially reduce travel-related externalities during the sustainable transition. Shek O illustrates how digital and physical experiences can be combined to foster a deeper connection between students and the heritage they study, laying the groundwork for informed and responsible attitudes toward preservation. As VR technologies advance, educators and policymakers can design pedagogical frameworks that are inclusive, culturally attuned, and respectful. By nurturing curiosity, empathy, and collective responsibility, these blended approaches can inspire future generations to protect and celebrate the geological and cultural richness that defines their world.

5.3. Policy and educational implications

The findings point to a policy model that integrates VR as a complement—not a substitute—to in-person field experiences from a management perspective. A VR-first, standardized, low-cost pre-visit orientation broadens equitable access, primes learners for responsible visitation, and, when paired with small, quota-managed field trips, consolidates stewardship outcomes without increasing pressure on sensitive sites. This sequencing reflects experiential and constructivist principles in which abstract conceptualization precedes and strengthens concrete experience, improving transfer and retention while preserving the authenticity of being in place (Kolb, 1984; Stoddard, 2025). It also supports carrying-capacity and impact-management objectives in cultural heritage settings (Makransky & Mayer, 2022; McKercher & Du Cros, 2014). Policy guidance should specify student-to-guide ratios, prioritized itineraries, and safety protocols, with VR content aligned to these parameters.

Targeted investments in accessible VR platforms help mitigate logistical barriers—high transportation costs, limited time, and strict access protocols—that disproportionately affect learners from lower-income schools and those far from heritage sites (Bourdieu, 1986; Smith & McNeal, 2024). To maximize cognitive gains, pre-visit modules should provide thick description and salient spatial cues so students arrive with usable mental maps and narrative context, treating the site as a cultural text and spatial narrative (Cosgrove & Daniels, 1989; Geertz, 1973; Soja, 1996). Procurement and implementation plans can prioritize device-sharing pools, classroom-friendly content, motion-sickness mitigations, multilingual options, and offline functionality. This approach can reduce disparities in participation and lower travel-related externalities consistent with sustainable transition objectives.

Cultural authenticity is central to educational legitimacy. Collaboration with local communities—heritage organizations, resident experts, and site managers—grounds digital content in lived experience and accurate narratives, strengthening symbolic meaning-making and acceptance of conservation norms (Blumer, 1969; Richards, 2018). Co-creation and community-led storytelling sustain cultural resonance and foster mutual ownership, aligning with participatory heritage management and enhancing compliance. Governance structures should formalize content review cycles, cultural approvals, and attribution and include safeguards for sensitive knowledge while ensuring that benefits—visibility, educational resources, or micro-grants—flow back to local custodians.

Effective implementation also depends on technical and instructional capacity. Reliable infrastructure (connectivity where needed, user-friendly devices, and robust software support) and teacher preparation enable seamless integration of VR into curricula. Professional development that emphasizes cognitive scaffolding before visits and reflective consolidation afterward strengthens learning, with post-visit VR supporting iterative reflection and narrative extension (Bourdieu & Wacquant, 1992; Hurrell et al., 2025). Multimodal design and classroom communities of practice can help educators blend mediated preparation with interactive, place-based pedagogy and social engagement (Jewitt, 2008; McDaniel, 2025). Clear operating guidelines—covering facilitation, device logistics, accessibility standards, and data protection—support consistent delivery. Monitoring and evaluation should track a small set of indicators across the pipeline: knowledge and affective gains, readiness for responsible visitation, observed on-site compliance, and equity metrics on participation and reach. These indicators can anchor procurement, staff training, and continuous improvement.

In settings where sites require protection from overexposure, a blended pathway—virtual introductions followed by focused, small-scale site visits—guides visitors toward responsible practices while preserving fragile features. Standardized pre-visit conservation messaging supports readiness and compliance on site, linking preparation to pro-conservation attitudes and behaviors associated with affective bonds and sense of place (Ho, 2024; Relph, 1976).

Device sharing and refurbishment, as well as accessible content localization, can extend reach within existing resource constraints. Public–private partnerships can amplify impact by combining platform design, content co-creation, and pedagogical expertise across technology firms, heritage organizations, and schools. Pilot programs seeded by government and industry can scale through open standards and localization. Systematic evaluation should track outcomes across the pipeline: pre/post measures of knowledge and affect, readiness for responsible visitation, on-site compliance data, and equity metrics on access and participation. Anchoring capacity building and resource allocation to these indicators creates a feasible operating model that links educational investments to management goals of readiness, compliance, and equitable access.

5.4. Limitations and future research

Several constraints impact generalizability and depth. Health measures limited the availability of headset-based VR, pushing many students to rely on flat-screen displays and console joysticks. This likely reduced immersion compared with headsets, suggesting the need to examine how interface modalities shape learning and emotional engagement. The focus on primary school students in Hong Kong narrows applicability; future work should explore older cohorts and diverse cultural and geographical contexts. For innovation management stakeholders, subsequent research could incorporate cost-effectiveness, lifecycle, and emissions accounting to assess the efficiency and sustainability of VR-enabled blended models at system scale.

Extending the timeline of inquiry would clarify whether cognitive gains and conservation attitudes endure. Longitudinal designs could test whether affective connections formed during blended experiences translate into sustained behaviors and perspectives. Broader adoption of emerging VR technologies—such as haptics or full-motion tracking—also merits exploration to gauge how enhanced realism influences presence and learning. Comparative studies might evaluate how degrees of VR immersion intersect with pedagogical approaches, identifying optimal design strategies for blended interventions and possible spillovers to household behaviors relevant to conservation norms.

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CONFLICT OF INTEREST STATEMENT

The authors declare that an earlier version of this research, with partial data, was presented as a conference proceeding at the 14th Asian Conference on Cultural Studies (ACCS2024) and is available at https://papers.iafor.org/submission81044. This version of the research article has been extensively built upon, with additional qualitative data analysis and the integration of the perspective of geoheritage education. The authors have also obtained approval from the conference organizing body of ACCS2024 (International Academic Forum) to submit a revised and expanded version of the research, originally published in the ACCS2024 Proceedings, to a different journal. Other than this, the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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