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Beyond Visual Realism : *Epistemic Authenticity and Multisensory Mediation in Virtual Field Trips for Life and Earth Sciences*

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Abstract

Background. Virtual field trips are commonly evaluated through visual fidelity, presence, usability, and learning outcomes, but these criteria do not establish whether a virtual environment preserves the evidentiary conditions of scientific inquiry.

Methods. A structured integrative conceptual synthesis was conducted across 31 foundational and contemporary sources spanning virtual fieldwork, authentic and immersive learning, scientific observation, professional vision, epistemic action, evidence construction, and multisensory virtual reality. Sources were purposively identified through targeted scholarly searches and citation chaining, then coded comparatively for the scientific objects made available, learner actions supported, sensory channels represented, uncertainty preserved, and links between observation, evidence, and explanation.

Results. The synthesis produced five analytically distinct dimensions of authenticity—visual, sensory, experiential, task, and epistemic—and an epistemic mediation framework tracing how physical environments are transformed through capture, modelling, interface design, learner action, evidence evaluation, and scientific explanation. It also identified seven forms of epistemic distortion, ten design principles, and a preliminary operational framework for evaluating virtual field trips. Smell is analysed as a revealing case showing that sensory cues can be decorative, contextual, or epistemic depending on their role in the task.

Conclusions. Virtual field trips should not be judged by sensory completeness or photorealism alone. Their educational quality depends on whether design choices preserve, disclose, or responsibly reconstruct the observations, uncertainties, epistemic actions, and evidentiary relations needed for disciplinary knowing.

1 Introduction

Field experiences occupy a distinctive place in Life and Earth Sciences education because they situate learners within environments where scientific knowledge must be constructed from spatially distributed, incomplete, and sometimes ambiguous evidence. In geology, students learn to identify contacts, structures, textures, and spatial relations, then coordinate these observations to infer processes and histories that are not directly visible. In ecology and environmental science, learners similarly connect organisms, substrates, microclimates, disturbances, and spatial patterns to develop explanations of living systems. Field learning therefore involves more than exposure to authentic places. It requires disciplined ways of noticing, moving, measuring, comparing, representing, evaluating, and inferring.

Virtual field trips (VFTs) have become increasingly prominent as accessible alternatives or complements to physical fieldwork. They can reduce financial, geographic, physical, safety, and scheduling barriers while enabling repeated visits, remote comparison, and access to fragile or inaccessible sites (Cliffe, 2017; Pugsley et al., 2022; Youlyouz et al., 2026). Photogrammetry, 360-degree imagery, geographic information systems, three-dimensional modelling, desktop environments, and immersive head-mounted

displays now make it possible to represent field sites with considerable visual and spatial detail. Research has consequently examined learner satisfaction, presence, accessibility, engagement, navigation, usability, spatial understanding, and achievement.

Yet a visually convincing representation is not necessarily an educationally faithful one. A high-resolution virtual outcrop may reproduce colour and geometry while omitting tactile texture, hardness, smell, humidity, wind, bodily effort, uncertainty, scale cues, or the freedom to select and use tools. It may also introduce distortions through mesh simplification, texture artefacts, camera placement, lighting, interpolation, and interface design. Guidance can further preselect what learners should notice, replacing inquiry with answer-signalling. The result may appear realistic while changing the conditions under which evidence is generated and interpreted.

This article therefore asks a different question from whether virtual field trips are immersive, enjoyable, or effective: To what extent do they preserve the epistemic conditions of field-based scientific inquiry? The proposed answer is organised around the concept of epistemic authenticity. The aim is not to claim that epistemic action, professional vision, evidence construction, or perception-action coupling are new. Each has an established theoretical basis (Goodwin, 1994; Kirsh & Maglio, 1994; Kastens et al., 2008). The contribution is an integrative framework explaining how immersive design mediates access to scientific evidence and how that mediation should inform the design and evaluation of VFTs.

The framework is particularly relevant to Life and Earth Sciences because field environments are multisensory, spatial, materially constrained, and evidentially open. The question raised by smell makes the problem visible: when a coastal, volcanic, wetland, cave, soil, or ecological site becomes a primarily visual-spatial simulation, what is preserved, what is omitted, and what educational consequences follow? The answer should not be that every sensation must be reproduced. Rather, sensory and interactive fidelity should be judged in relation to the observations and inferences required by the instructional task.

Accordingly, the study addressed three research questions:

RQ1. How do established theories explain the relationship among digital representation, sensory access, epistemic action, evidence construction, and scientific explanation in virtual field learning?

RQ2. Which dimensions are required to evaluate the authenticity of virtual field trips as environments for disciplinary knowledge construction?

RQ3. What design principles, evaluative indicators, and research propositions follow from integrating these theoretical traditions?

2 Methods

2.1 Research design

This study used a structured integrative conceptual synthesis. Integrative synthesis is appropriate when a research problem crosses theoretical traditions and when the objective is to develop a coherent explanatory framework rather than estimate an intervention effect. The design was theory-building: established constructs were compared, their explanatory boundaries were identified, and their relationships were reorganised around the design problem of what virtual environments make available for scientific knowing. The study was not registered as a systematic review and does not claim exhaustive coverage of every publication in the relevant fields.

2.2 Source identification and search logic

The analytic corpus was developed between June and July 2026 through targeted searches of scholarly search engines, ERIC records, publisher databases, and backward citation chaining from foundational papers and recent reviews. Search combinations included “virtual field trip” OR “virtual outcrop” with “learning,” “authenticity,” “observation,” “evidence,” or “inquiry”; “epistemic action” with “science education” or “geology”; “professional vision” OR “disciplinary noticing”; “scientific observation”; and “olfactory,” “haptic,” or “multisensory” with “virtual reality” and “learning.” Citation chaining was used to recover foundational theoretical work that predates current database terminology.

2.3 Eligibility and analytic corpus

Sources were eligible when they contributed directly to at least one of six analytic domains: (a) virtual field-trip design or evaluation, (b) authentic or immersive learning, (c) scientific observation and disciplinary noticing, (d) epistemic action and perception–action coupling, (e) evidence construction and epistemic cognition, or (f) multisensory and olfactory virtual reality. Peer-reviewed journal articles, scholarly books, and foundational book chapters were included. Purely technical VR studies without an educational, perceptual, or epistemic contribution were excluded, as were papers that used “authenticity” only to describe visual realism. The final analytic corpus comprised 31 sources listed in the reference section.

Analytic domain	Illustrative search concepts	Role in synthesis
Virtual fieldwork	virtual field trip; virtual outcrop; immersive fieldwork	Representation, access, navigation, and field-task design
Authentic and immersive learning	authentic learning; presence; CAMIL; task authenticity	Distinguishing realism, experience, task, and learning mechanisms
Scientific observation	scientific observation; professional vision; disciplinary noticing	Explaining how features become consciously and disciplinarily observable
Epistemic action and evidence	epistemic action; evidence construction; epistemic cognition	Linking movement, investigation, data, evidence, and explanation
Multisensory VR	olfactory VR; haptic learning; multisensory attention	Identifying sensory preservation, omission, and substitution

2.4 Concept extraction and comparative coding

Each source was read for five questions: What aspect of authenticity or learning does it explain? What scientific information is assumed to be available to the learner? Which learner actions or sensory channels are treated as consequential? How are observations transformed into evidence or explanation? Which design assumptions remain implicit? Concepts were entered into a comparative matrix and coded under representation, sensory access, learner agency, disciplinary observation, epistemic action, uncertainty, evidence evaluation, and explanatory use. Overlapping concepts were retained under their original theoretical names rather than relabelled as novel mechanisms.

2.5 Framework construction

Framework construction proceeded through constant comparison. First, constructs that were frequently conflated—such as visual realism, presence, task authenticity, and evidentiary adequacy—were separated. Second, causal and mediating relations were traced from the physical field site through digital capture and design to learner observation and inference. Third, recurrent failure modes were grouped as epistemic distortions. Fourth, design principles and research propositions were derived only when supported by more than one theoretical domain or when a domain-specific finding exposed a clear consequence for immersive field learning.

2.6 Rigour and boundary conditions

Three safeguards were used to reduce conceptual overclaiming. The analysis actively searched for existing constructs equivalent to the initially proposed idea of instructional relevance appraisal; this led to rejection of that construct as insufficiently distinct from goal-focused attention, epistemic cognition, and professional vision. Foundational concepts were attributed to their established traditions rather than presented as new. Finally, novelty was located at the level of integration: how designed virtual representations mediate sensory and epistemic access to scientific environments. Because the synthesis was conducted by one author and was purposive rather than exhaustive, its framework should be treated as a testable theoretical product rather than a definitive taxonomy.

3 Results

3.1 Why visual realism is insufficient

Visual realism is valuable. Accurate geometry, texture, scale, colour, and spatial relations can support recognition, orientation, observation, and comparison. In virtual outcrop work, photorealistic models may allow learners to inspect structures from viewpoints that are inaccessible in the physical field and to revisit the same site repeatedly (Pugsley et al., 2022). Nevertheless, the educational significance of visual fidelity depends on what is represented and what the learner is expected to do with it.

Three problems limit visual realism as a primary criterion. First, realism is selective. Cameras and scanners capture some properties while excluding others. Second, realism is constructed. Models

contain decisions about resolution, colour correction, lighting, scale, occlusion, navigation, and interaction. Third, realism is interpreted. Novices and experts may look at similar locations but extract different observations because disciplinary knowledge shapes perception and inference (Goodwin, 1994; Barth-Cohen & Braden, 2022).

A virtual environment can consequently possess high visual authenticity but low epistemic authenticity. A model may look like a real outcrop while making diagnostic contacts too blurry to inspect, preventing measurement, removing uncertainty, or displaying labels that directly identify the interpretation. Conversely, a less photorealistic simulation may preserve stronger inquiry opportunities if it enables measurement, multiple viewpoints, comparison, annotation, hypothesis testing, and revision.

The distinction parallels the broader authentic-learning literature, which has long argued that authenticity is not reducible to surface resemblance. Authentic learning environments are characterised by complex tasks, multiple perspectives, sustained inquiry, collaboration, reflection, and integration of assessment rather than by realism alone (Herrington & Oliver, 2000). For virtual fieldwork, however, task authenticity must be extended to the representational and sensory conditions under which scientific evidence becomes available.

A further difficulty is that realistic materials do not have uniform effects. Reviews of authentic learning report generally promising cognitive and motivational outcomes, but they also show that realistic materials and resemblance to real-life settings can support motivation without necessarily improving conceptual learning. The educational effect depends on how materials, tasks, assessment, inquiry, and collaboration are combined, and on whether learners themselves perceive the experience as authentic. Consequently, photorealism should be treated as one design resource rather than as evidence that authentic learning has been achieved.

Virtual field experience research illustrates this problem clearly. Dolphin et al. (2019) found that virtual experiences can respond to logistical and enrolment pressures, yet they also raise pedagogical questions concerning how students develop descriptive and explanatory models. Digital access does not automatically reproduce the observational work of field geology. A learner may navigate a representation successfully while failing to identify, document, or interpret the relationships needed for geological explanation.

3.2 Five dimensions of authenticity

These dimensions interact but should not be treated as interchangeable. Sensory additions may increase presence without improving scientific reasoning. Guidance may improve immediate performance while reducing the need to notice and justify. An impossible aerial viewpoint may reduce physical authenticity but increase access to a spatial relation that supports conceptual understanding. Epistemic authenticity is therefore not equivalent to maximal fidelity; it concerns whether design decisions preserve or responsibly transform the knowledge-generating structure of the task.

Dimension	Primary object of fidelity	Central educational risk
Visual	Appearance and spatial form	Photorealism masks missing or distorted evidence
Sensory	Task-relevant perceptual cues	More stimulation is mistaken for better learning
Experiential	Coherent presence and agency	Presence is treated as a proxy for inquiry
Task	Activities and problems	Procedures resemble science but lack evidentiary purpose
Epistemic	Observation, evidence, uncertainty, and inference	The environment predetermines what can be known

3.3 Epistemic mediation in immersive scientific environments

Epistemic mediation refers to the ways in which representational fidelity, sensory selection, interaction affordances, spatial organisation, guidance mechanisms, and computational constraints shape what learners can observe, act upon, treat as evidence, and infer.

A virtual field trip is not a transparent window onto a physical site. Between the phenomenon and the learner lie multiple transformations: site selection, camera placement, image capture, model reconstruction, cleaning, simplification, texturing, platform conversion, navigation design, interface tools, annotations, assessment prompts, and hardware constraints. Each stage can preserve, transform, exaggerate, or eliminate information.

The framework proposed here represents this process as a mediated chain: physical phenomenon or field site; digital capture and modelling; designed immersive environment; available sensory cues and affordances; learner epistemic actions; observation and data construction; disciplinary evidence evaluation; scientific explanation; and recursive revision of search and interpretation.

This chain is recursive rather than linear. A learner's provisional explanation affects where they move and what they inspect. New observations may change what is considered relevant, trigger return to an earlier location, or motivate a different measurement. Epistemic action research already shows that actions can be undertaken to simplify cognition or reveal information (Kirsh & Maglio, 1994). In geoscience education, learners may rotate models, align representations, juxtapose alternatives, or reorganise notes to support reasoning (Kastens et al., 2008). The distinctive role of VR lies in designing the environment through which such actions become possible, constrained, logged, scaffolded, or distorted.

Professional vision adds a disciplinary and social dimension. Scientists learn culturally organised ways of coding, highlighting, representing, and interpreting phenomena (Goodwin, 1994). A novice may perceive a coloured line; a geologist may interpret a stratigraphic contact, fault, unconformity, or

weathering artefact. A virtual field trip therefore does not simply present features. It participates in the development of what can be seen as a disciplinary object and what can count as evidence.

Observation itself must therefore be treated as an intellectually organised scientific method rather than as passive sensory reception. Kraus (2024) characterises scientific observation through dimensions such as conscious rather than unconscious perception, active rather than passive attention, repeated rather than singular inspection, and unavoidable theoretical or perceptual bias. These dimensions are directly relevant to virtual field design. A system that only permits a single fixed view, removes opportunities for repeated inspection, or directs attention without making the basis of selection visible may preserve visual content while weakening the method of observation.

Research in geology likewise shows that scientific observation involves both noticing features and interpreting them through disciplinary expectations. Remmen and Frøyland (2020) found that students' rock classification depended on whether they noticed situation-relevant features, connected them to prior experience, and interpreted them within geological processes. This suggests that VFT evaluation should examine the quality of observations learners produce—not only gaze locations, navigation success, or time on task.

Figure 1 provides a visual summary of the proposed framework, showing how virtual field trips mediate the relationship between physical field environments, digital representation, learner actions, evidence construction, and scientific explanation.

3.4 Multisensory epistemic resources

Physical field environments are multisensory. Vision is often dominant in educational design, but sound, smell, temperature, humidity, wind, touch, material resistance, vibration, bodily effort, and proprioception can contribute to recognition, orientation, attention, hypothesis generation, and interpretation. A typical VFT preserves only a selective subset of these resources.

The absence of a sensory channel is not automatically an educational defect. The relevant question is whether the omitted information contributes to the intended disciplinary task. Rock hardness may be central to mineral identification but peripheral to a task focused on regional fold geometry. Wind direction may matter in an ecological or pollution investigation but not in a stratigraphic correlation exercise. Sensory fidelity should therefore be task-sensitive.

This principle can be called task-sensitive sensory preservation: the deliberate preservation, representation, substitution, or explicit disclosure of sensory information according to its contribution to the intended observations and inferences. When a sensory cue cannot be reproduced, the designer may provide a measurement, a short field note, a spatialised sound, an annotated uncertainty, or a prompt encouraging the learner to recognise the limitation.

Task-sensitive sensory preservation also includes haptic information. Touch can provide information about texture, resistance, shape, mass distribution, and material properties that is difficult to infer visually. Novak (2021) found that haptic exploration of authentic objects influenced learning experience and memory, while also cautioning that touch requires cognitive resources and does not produce a universal benefit. For virtual field trips, the implication is not that every object requires force feedback, but that designers should identify whether tactile or material properties carry disciplinary information and decide whether to reproduce, substitute, measure, describe, or explicitly mark their absence.

The same reasoning applies to sound, wind, and temperature. Spatialised sound may reveal water flow, animal activity, machinery, erosion, or human disturbance; wind may support interpretation of exposure and environmental transport; and thermal differences may matter in ecological or microclimatic investigations. These modalities should be included because of their functional relation to the scientific problem, not simply because they increase immersion.

3.4.1 Smell as a revealing case

Olfactory virtual reality research has largely examined presence, affect, realism, attention, memory, and user experience. Congruent scents can increase presence in some environments, although effects depend on whether participants perceive and correctly identify the stimulus (Munyan et al., 2016; Persky & Dolwick, 2020). More importantly for the present framework, olfactory cues can function as information rather than decoration. Alkasasbeh and Ghinea (2020) found that synchronised olfactory media could improve learning performance in an e-learning task, while Andonova et al. (2023) reported that multisensory VR and smell conditions influenced recall and creativity. These findings do not establish a general olfactory advantage, but they demonstrate that scent can participate in instructional communication.

Smell can also redirect spatial attention. Dozio et al. (2021) showed that olfactory and auditory stimulation altered visuospatial search in VR, supporting the idea that scent can orient users toward locations or objects. For a scientific VFT, this possibility is double-edged. A task-relevant odour might guide learners toward a source that should be investigated, but an inaccurately positioned, overly intense, or semantically misleading scent could create false evidentiary salience. Olfactory design therefore requires spatial, temporal, semantic, and epistemic congruence.

Technical limitations further complicate olfactory authenticity. Odours do not start and stop with the precision of visual or auditory cues; they disperse, linger, mix, and lead to sensory adaptation. Individual thresholds, associations, cultural interpretations, and health sensitivities also vary. A scientifically responsible system should document the scent composition, delivery location, timing, intensity, ventilation or clearing procedure, and the intended evidentiary function. Where accurate reproduction is impossible, a qualitative field note or instrument reading may be more epistemically honest than a generic fragrance.

For Life and Earth Sciences, smell should not be treated only as atmosphere. Sulfurous odours, hydrocarbons, stagnant water, decomposing organic matter, wet soil, marine aerosols, smoke, vegetation, and microbial activity can function as environmental cues. Smell alone rarely constitutes sufficient evidence, but it can initiate attention, raise a hypothesis, orient search, or motivate measurement.

Three functions should be distinguished. Decorative scent creates atmosphere. Contextual scent supports recognition, memory, or sense of place. Epistemic scent contributes to observation, hypothesis generation, source localisation, evidence collection, or interpretation. A coastal scent added merely to make a VFT feel realistic may enhance sensory authenticity. The same scent becomes epistemically meaningful only when it is linked to a scientific question and can be investigated in relation to other evidence.

Thus, the aim is not to reproduce every smell. In many geological tasks, olfaction will be unnecessary. In others, especially environmental, ecological, soil, water-quality, volcanic, or pollution contexts, omitting smell may remove a potentially productive cue. The design decision should be justified by the epistemic demands of the task rather than by the assumption that more sensory stimulation is always better.

3.5 Epistemic actions and immersive affordances

Movement and interaction are not inherently educational. Teleporting, clicking, rotating, collecting, or opening menus may be interface operations with little connection to scientific reasoning. An action becomes epistemic when it changes access to information, reduces uncertainty, enables comparison, tests an interpretation, externalises a relationship, or supports evidence construction.

In a virtual geological field trip, epistemic actions may include approaching a surface to inspect texture; changing viewpoint to distinguish a real structure from a perspective effect; moving laterally to test continuity; measuring orientation or thickness; comparing distant outcrops; annotating and photographing observations; aligning maps with visible structures; revisiting a feature after generating a new hypothesis; and recording contradictory evidence.

Affordances should therefore be evaluated by their disciplinary function. A measurement tool is not valuable merely because it is interactive; it is valuable when measurement is necessary for reasoning. An aerial view may be epistemically useful if it reveals landscape-scale relations, but it should be identified as a representational transformation unavailable in ordinary field experience. A highlight or label may scaffold novices, but excessive cueing can suppress professional vision by making the relevant evidence visually obvious.

The key design question is not how many interactions are available, but whether the environment supports a productive perception-action-evidence loop.

This distinction suggests a functional taxonomy of interaction. Navigational actions change location or viewpoint; observational actions improve perceptual access; measurement actions transform phenomena into quantified data; representational actions externalise observations through photographs, sketches, maps, or annotations; comparative actions place evidence in relation; and inferential actions connect observations to claims or models. The same interface gesture can serve different functions depending on the task, so interaction counts alone are an inadequate indicator of epistemic engagement.

Designers should also preserve the possibility of revising an interpretation. In field inquiry, an observation often acquires meaning only after another location has been inspected. VFTs should therefore support revisitation, persistent records, comparison across scale and location, and access to contradictory observations. Without these functions, exploration may remain episodic rather than developing into cumulative evidence construction.

3.6 Epistemic distortion

Immersive design can support inquiry, but it can also alter the validity of learners' observations and inferences. Epistemic distortion occurs when representational or interaction choices mislead, conceal, overdetermine, or decontextualise the evidence available to the learner.

Not all transformations are undesirable. Educational design frequently makes the invisible visible, compresses time, changes scale, or provides perspectives unavailable in the field. The requirement is transparency and epistemic justification: designers should specify what was transformed, why it was transformed, and how the transformation affects observation and inference.

Epistemic distortion should be evaluated at three levels. At the source level, capture may fail to preserve a feature. At the interface level, navigation, rendering, labels, or tools may change its visibility and apparent importance. At the interpretive level, learners may be unaware that a feature is reconstructed, simplified, or absent and may draw conclusions with unwarranted confidence. Documentation should therefore distinguish verified site information, reconstructed content, pedagogical enhancement, and known uncertainty.

A useful design response is representational provenance: a transparent account of where each important observation originates and how it has been transformed. Provenance may include capture date, spatial resolution, measurement accuracy, model gaps, colour processing, reconstructed surfaces, inaccessible areas, and expert validation. Such information need not overwhelm learners, but it should be available to instructors, researchers, and advanced users and should inform the limits of permissible inference.

3.7 Design principles for epistemically authentic virtual field trips

Preserve diagnostic features: Prioritise the spatial, material, biological, and relational features required for the intended reasoning rather than merely the most visually attractive elements.

Design backward from epistemic tasks: Begin with the observations, measurements, comparisons, uncertainties, and inferences learners should perform, then determine the necessary representation and tools.

Support genuine epistemic action: Enable movement, viewpoint change, measurement, comparison, annotation, documentation, revisitation, and hypothesis testing when these actions serve disciplinary goals.

Use task-sensitive sensory preservation: Reproduce, substitute, describe, or disclose sensory information according to its evidentiary value.

Preserve productive uncertainty: Avoid preselecting all relevant evidence or eliminating ambiguity that learners should learn to manage.

Separate scaffolding from answer-signalling: Provide graduated, optional, and fading support rather than permanently highlighting the correct interpretation.

Disclose representational transformations: Identify missing data, modelling artefacts, impossible viewpoints, altered scale, and reconstructed features.

Validate epistemically, not only technically: Ask disciplinary experts to evaluate whether the environment preserves evidence, relationships, and inquiry practices, not only whether it looks accurate.

Compare virtual and physical affordances explicitly: Treat differences from fieldwork as design variables rather than hidden deficits.

Log evidence-oriented behaviour: Use gaze, movement, measurements, annotations, and revisitations to study reasoning, while avoiding the assumption that behavioural traces alone reveal understanding.

3.8 Research propositions

P1. Visual realism and epistemic authenticity are related but empirically distinct properties of a virtual field trip.

P2. The educational value of multisensory reproduction depends on the evidentiary demands of the task rather than on sensory richness alone.

P3. Immersive actions contribute to scientific learning when they change access to evidence, support comparison, reduce uncertainty, or enable hypothesis testing.

P4. Guidance can improve immediate performance while reducing epistemic authenticity if it preselects evidence or eliminates productive uncertainty.

P5. Representational omissions and modelling artefacts can affect not only presence and usability but also the validity of scientific inferences.

P6. Novices and experts may display similar gaze locations while differing in the observations and evidentiary interpretations constructed from those locations.

P7. Explicit disclosure of representational limitations will support more calibrated scientific reasoning than unqualified photorealism.

P8. Virtual field trips designed around epistemic authenticity will produce stronger evidence-selection and explanation outcomes than visually matched environments designed primarily around presence.

P9. Task-relevant sensory substitution may be educationally equivalent or superior to literal sensory replication when the substitution preserves evidentiary function.

P10. Hybrid field designs will be strongest when virtual and physical experiences are coordinated according to complementary epistemic affordances rather than treated as interchangeable formats.

4 Discussion

The proposed framework complements rather than replaces established theories of multimedia and immersive learning. The Cognitive Affective Model of Immersive Learning explains how technological features can influence presence, agency, embodiment, motivation, cognitive load, and learning (Makransky & Petersen, 2021). These mechanisms are important for understanding the learner experience, but they do not by themselves determine whether the environment preserves the disciplinary evidence and investigative practices required by a scientific task. Epistemic authenticity adds an evaluative layer focused on the relationship between representation, action, evidence, and inference.

Similarly, the Cognitive Theory of Multimedia Learning explains how learners select, organise, and integrate verbal and pictorial information (Mayer, 2021). In virtual field environments, however, the learner is not always selecting from a fixed sequence of prestructured instructional elements. Information may become available only after movement, viewpoint change, measurement, comparison, or interaction. Epistemic mediation therefore extends attention from the design of presented content to the design of conditions under which potentially relevant evidence can be discovered.

Authentic-learning frameworks emphasise complex tasks, multiple perspectives, collaboration, reflection, articulation, and integrated assessment (Herrington & Oliver, 2000). Epistemic authenticity

builds on this tradition by asking whether a virtual environment preserves the evidentiary structure of disciplinary practice. A task can resemble professional activity while still providing over-simplified evidence, eliminating uncertainty, or restricting the actions through which knowledge would normally be produced.

Professional vision and epistemic action clarify why this distinction matters. Disciplinary expertise shapes what is noticed, categorised, represented, and treated as evidence (Goodwin, 1994), while epistemic actions reorganise or reveal information in ways that support reasoning (Kirsh & Maglio, 1994; Kastens et al., 2008). In immersive science learning, the interface mediates both processes. It influences which features are visible, which actions are possible, which representations can be constructed, and which comparisons can be made.

The framework therefore positions epistemic authenticity as a bridge across four levels: technological design, learner experience, disciplinary practice, and knowledge construction. Its contribution lies in examining their alignment. A technically advanced and highly immersive environment can remain epistemically weak when its affordances do not support the observations and reasoning required by the learning objective.

4.1 Epistemic authenticity as alignment

Epistemic authenticity can be conceptualised as alignment among four components: the intended scientific problem, the evidence available in the environment, the epistemic actions afforded to the learner, and the explanation or decision the learner is expected to construct. Misalignment occurs when the task requires evidence that is absent, when tools reveal conclusions without investigation, when available details are unrelated to the intended reasoning, or when assessment measures recall rather than evidence-based interpretation.

Alignment can fail in several ways. A scientifically important feature may be visible but impossible to measure; a tool may be available but irrelevant to the stated problem; a task may demand inference from evidence that the model cannot preserve; or an assessment may reward correct terminology without requiring justification. These mismatches explain why a technically impressive VFT can still produce shallow learning. Alignment analysis makes such failures inspectable before learner testing.

The learner's developing competence must also be considered. Experts can use sparse cues because they possess professional vision, whereas novices may require scaffolds that reveal how observations are generated and compared. Epistemic authenticity is therefore compatible with guidance, provided that guidance supports the practice and can be faded rather than permanently replacing it.

This alignment perspective avoids equating authenticity with difficulty or unrestricted realism. Educational scaffolds can increase epistemic authenticity when they help learners engage in disciplinary reasoning without supplying the final interpretation. Examples include optional measurement tools,

prompts to compare competing observations, uncertainty indicators, field notebooks, and progressive hints that direct a process rather than identify an answer.

4.2 Operationalising epistemic authenticity

For empirical use, epistemic authenticity can be examined through five domains: representational adequacy, sensory and contextual adequacy, epistemic affordances, uncertainty and learner agency, and evidence-to-explanation alignment. Each domain can be evaluated through expert review, task analysis, learner behaviour, and the quality of resulting scientific products.

Representational adequacy concerns whether diagnostic features and spatial relations are preserved at a usable resolution. Sensory-contextual adequacy examines whether task-relevant nonvisual information is reproduced, substituted, or disclosed. Epistemic affordances concern whether learners can inspect, measure, compare, document, and revisit. Uncertainty integrity concerns whether ambiguity, error, missing information, and alternative interpretations remain visible. Practice-explanation alignment concerns whether the actions and evidence available are sufficient to justify the expected scientific claims.

Operationalisation should use multiple sources of evidence. Expert review can assess representational validity; task analysis can identify required observations and actions; learner traces can document search and investigation; student products can reveal evidence selection and justification; and interviews or stimulated recall can clarify how learners interpreted their actions. No single score should replace this profile, because a serious weakness in one domain may invalidate conclusions despite strengths elsewhere.

Domain	Example indicators	Possible evidence
Representational adequacy	Diagnostic features visible; scale and geometry validated	Expert audit; model-to-site comparison
Sensory-contextual adequacy	Relevant cues preserved or transparently substituted	Field log; sensory inventory; learner report
Epistemic affordances	Inspect, measure, compare, annotate, revisit	Task walkthrough; interaction logs
Uncertainty integrity	Gaps, error, ambiguity, and alternatives remain accessible	Provenance record; explanation analysis
Practice-explanation alignment	Available evidence can justify expected claims	Task analysis; student evidence maps

A future validation instrument could combine these domains into an expert-review rubric and a learner-performance protocol. The purpose would not be to calculate a single universal authenticity score, but to make design trade-offs explicit and to identify where a virtual environment supports or constrains disciplinary inquiry.

4.3 Theoretical contribution and interpretation

The concept of epistemic authenticity shifts evaluation from resemblance to knowledge-making. Presence, realism, and engagement remain important, but they cannot determine whether learners encounter the evidentiary structure of a discipline. A virtual field trip may be compelling while educationally superficial, or visually simplified while epistemically productive.

The framework also avoids a false choice between replication and simulation. Exact replication is neither possible nor always desirable. Physical fieldwork itself is selective: weather, access, safety, time, instructor guidance, and available tools shape what learners can observe. VR adds another designed layer of mediation. Its value lies partly in enabling repetition, comparison, impossible viewpoints, temporal manipulation, and adaptive support. These affordances become educational strengths when their epistemic effects are explicit and aligned with disciplinary goals.

Smell illustrates the broader principle. The absence of olfaction does not make every VFT inauthentic. Nor does adding scent automatically make it educationally authentic. What matters is the function of the cue in the inquiry. This distinction can prevent multisensory design from becoming technological embellishment and instead connect it to observation, evidence, and explanation.

The framework is integrative rather than foundational. Goal-directed attention, epistemic action, professional vision, authentic learning, and evidence construction are established. The proposed contribution is to connect these traditions to the designed representational layer of immersive science environments. Future empirical research must determine whether epistemic authenticity can be operationalised reliably and whether it predicts learning outcomes beyond presence, usability, and visual fidelity.

The framework also clarifies why learner experience and epistemic quality may diverge. A sensory-rich environment can feel convincing while directing attention toward features with little disciplinary value. Conversely, an interface that openly displays missing data or requires laborious comparison may feel less seamless while supporting more calibrated scientific judgement. Future evaluations should therefore report presence and usability alongside, rather than in place of, observational and evidentiary outcomes.

A second implication concerns equivalence between physical and virtual fieldwork. The goal should not be to demonstrate that the two formats are identical. Each offers different epistemic affordances: physical fieldwork provides material resistance, uncontrolled complexity, bodily scale, and direct environmental variability; VFTs provide repetition, accessibility, controlled comparison, data overlays, alternative perspectives, and detailed behavioural logging. Strong designs may use these differences complementarily, assigning each format the tasks it can support most honestly.

5 Implications and research agenda

Empirical work should move beyond asking whether VFTs improve satisfaction or test performance and examine the quality of observation, evidence, and explanation. One approach is to compare photorealistic and epistemically functional versions of the same environment while holding content and task constant. Another is to compare highly labelled and inquiry-oriented designs to examine whether guidance changes what learners notice and how they justify interpretations.

Physical-virtual comparisons should analyse the evidence learners collect, the routes they take, the measurements they perform, the uncertainties they recognise, and the explanations they construct. Eye tracking, head movement, navigation logs, annotations, and think-aloud protocols can provide complementary traces, but these measures should be interpreted together with disciplinary products. Gaze identifies where attention was directed; it does not by itself establish what was observed or understood.

Multisensory studies should manipulate cues according to task relevance. A scent, sound, or haptic cue can be congruent yet educationally irrelevant. Research should therefore compare decorative, contextual, and epistemic sensory conditions, and test whether cues improve hypothesis generation, source localisation, evidence selection, retention, or transfer.

Development studies should document the complete representational chain from field capture to learner interface. This includes model resolution, missing surfaces, colour calibration, scale validation, texture quality, navigation constraints, available tools, annotations, and known artefacts. Such documentation would allow researchers to relate design decisions to epistemic outcomes.

Finally, the framework should be tested beyond geoscience. In ecology, virtual environments can mediate access to organism-environment relationships, seasonal changes, and spatial distributions. In biology, they can support observation of morphology, habitats, and processes across scales. In environmental science, they can combine visual, auditory, chemical, and spatial data. Across these domains, epistemic authenticity offers a common language for examining whether a virtual environment preserves the conditions for disciplinary knowing.

6 Limitations

This study has four limitations. First, the synthesis was purposive and integrative rather than systematic; the 31-source corpus was selected for conceptual relevance and cannot support bibliometric claims about the prevalence of particular ideas. Second, coding and framework construction were conducted by one author, so future work should test conceptual clarity and domain coverage through independent expert review or Delphi procedures. Third, the framework is grounded most strongly in geoscience and field-based Life and Earth Sciences; transfer to laboratory, molecular, clinical, or highly abstract domains requires empirical examination. Fourth, epistemic authenticity has not yet been validated as a measurement construct. The proposed domains and indicators should therefore be treated as hypotheses for instrument development, design-based research, and comparative physical–virtual field studies.

The framework also does not assume that physical fieldwork is an unmediated gold standard. Physical experiences are themselves constrained by weather, access, instructor guidance, tools, safety, and learners' prior knowledge. The appropriate comparison is consequently not between a "real" and an "artificial" environment in the abstract, but between the epistemic opportunities, constraints, and distortions produced by each learning arrangement.

7 Conclusion

The educational authenticity of a virtual field trip should not be judged by how completely it reproduces the sensation of being in the field. It should be judged by how faithfully and transparently it preserves, transforms, or reconstructs opportunities for disciplinary observation, epistemic action, evidence construction, uncertainty management, and scientific inference. Virtual environments mediate not only what learners see, but what they are able to sense, investigate, and know. Epistemic authenticity provides a framework for making that mediation visible, designing it responsibly, and evaluating its educational consequences.

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Consent for publication: Not applicable.

Data availability: No empirical dataset was generated. The analytic corpus is fully identified in the reference list, and the conceptual coding categories are described in the Methods section.

Use of generative AI: Generative AI was used for making the figure 1.

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Figures

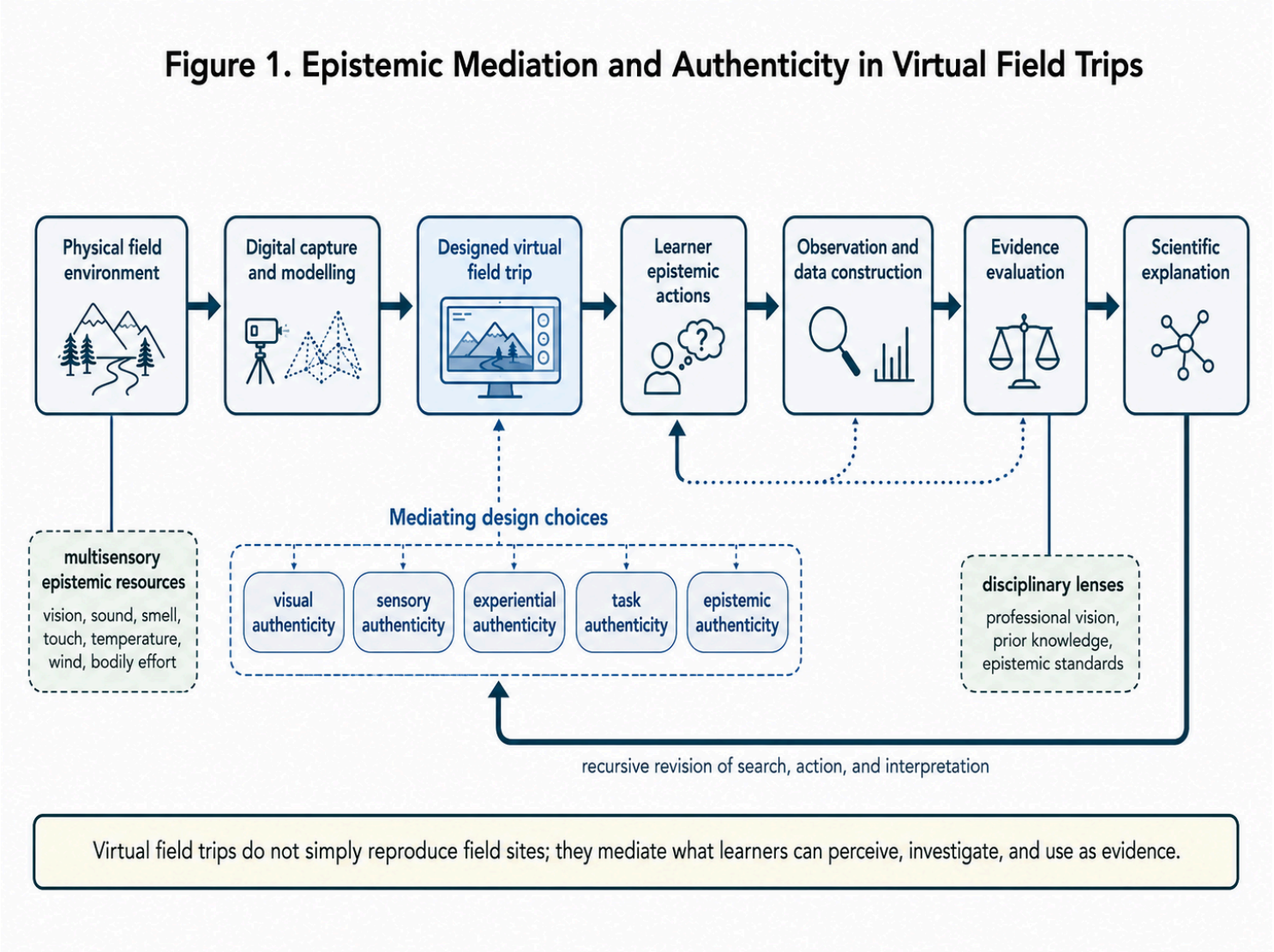


Figure 1

Epistemic mediation and authenticity in virtual field trips. The figure illustrates how multisensory field environments are transformed through digital capture and design choices into virtual learning environments that shape what learners can perceive, investigate, construct as evidence, and explain scientifically. The recursive loop highlights the continual revision of search, action, and interpretation.

Source: Author's conceptual framework.