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Embodied Metaphor and Spatial Poetics in Serious Games: A Practice-Based Study on Reconstructing Science Communication Narratives

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***Abstract*—Science-communication games often inherit an *edutainment* split: scientific content is delivered through text, quizzes, or symbolic panels, while play remains an only loosely related wrapper. This paper asks how serious games might instead construct scientific understanding as an embodied and spatial narrative experience. To explore this possibility, we designed AFTERMATH: GRAVITY ANOMALY, a 2.5D narrative puzzle prototype that combines two theoretical lenses: Lakoff and Johnson's embodied metaphor and Bachelard's poetics of space. The prototype translates gravity-related concepts into manipulable local fields, composes the level as a layered industrial ruin, and embeds science communication in diegetic research archives rather than external lesson screens. We contribute (i) a design framework that links scientific concepts to sensorimotor image schemas and spatial-poetic worldbuilding, (ii) a practice-based account of how this framework is instantiated in a playable prototype, and (iii) a mixed-methods evaluation protocol for future empirical validation. Rather than claiming completed learning effects, the paper positions the prototype as a research-through-design probe: a concrete artifact for examining how embodied mechanics and expressive space can expand the narrative repertoire of science communication in serious games.**

***Index Terms*—Serious Games, Embodied Metaphor, Spatial Poetics, Science Communication, Mechanics-as-Metaphor, Game Design, Practice-Based Research**

I. INTRODUCTION

A. Motivation and Background

Serious games—digital play artifacts whose primary purpose extends beyond entertainment to education, persuasion, or scientific outreach—have become an important site for science communication [1], [2]. Compared with text, lecture, or video, games can make a scientific relation operational: a player does not only read that a force changes a trajectory, but acts within a system where force, trajectory, resistance, and failure become repeatedly negotiable. This capacity makes games especially relevant to scientific domains whose concepts are difficult to visualize or narrate through linear media alone.

The evidence base, however, is more nuanced than the general optimism around game-based learning sometimes suggests. Meta-analytic work reports positive cognitive and motivational effects for serious games, while also showing that outcomes depend strongly on integration, instructional support, duration, and context [3]. The U.S. National Research Council similarly frames games and simulations as promising but still under-specified tools for science learning, calling for stronger links between design, theory, and assessment [4]. The key question is therefore not whether games can communicate science, but how their mechanics, spaces, and narrative systems should be designed so that play becomes a meaningful mode of scientific sense-making.

In many educational games, that link remains weak. A familiar *edutainment* pattern places scientific content in textbook panels, pop-up explanations, or quizzes, while the core interaction is a conventional mini-game only loosely attached to the topic. The player learns from one layer and plays in another. This split is not merely a production shortcut; it is a design problem, because it prevents the procedural and spatial affordances of games from participating in the act of explanation.

This disjunction is sometimes called the *chocolate-covered broccoli* problem: the game mechanics are supposed to make educational content palatable, but the two remain compositionally separate. Habgood et al.'s work on endogenous fantasy and intrinsic integration shows why this matters: learning is stronger when content is internal to the activity structure rather than extrinsically bolted on [5], [6]. Our framework can be read as a theoretical deepening of this empirical finding: intrinsic integration is not just a production tactic but

a consequence of taking embodied cognition seriously.

We argue that the split between lesson and play is also a theoretical limitation. It treats scientific knowledge as primarily propositional and disembodied, even when the target concepts are built on experiences of force, balance, path, containment, and scale. If conceptual understanding is partly grounded in bodily and spatial experience, then games should not merely decorate science with interactivity. They should create playable situations in which scientific relations can be felt, tested, and narratively situated.

B. The Proposed Approach

This paper explores that possibility through the design of a serious game that combines *embodied metaphor* and *spatial poetics*. Lakoff and Johnson's theory of embodied metaphor [7] suggests that abstract concepts are structured through sensorimotor image schemas rooted in bodily experience. Bachelard's poetics of space [8] treats architectural and inhabited spaces as affectively charged sites of memory, reverie, and meaning rather than neutral containers. We bring these lenses into game design by asking two practical questions: which scientific relations can become mechanics that players enact, and what kind of world can make those relations emotionally and narratively legible?

C. Overview of Contributions and Practice

AFTERMATH: GRAVITY ANOMALY is our practice-based response to these questions. It is a 2.5D narrative puzzle prototype set in the wreckage of a collapsed civilization whose gravitational field has been destabilized by industrial-scale energy extraction. The player manipulates local gravity to traverse ruins, solve spatial problems, and reconstruct a scientific account of the catastrophe through diegetic research archives. We do not present the prototype as a finished educational product or as evidence of measured learning gains. Instead, we present it as a research-through-design artifact for investigating how science communication can become embodied, spatial, and narrative at the same time.

The contributions of this paper are fourfold:

- We formulate a design problem in serious-game science communication: the persistent separation of scientific exposition from playable action.
- We articulate a framework that maps scientific concepts to embodied image schemas and spatial-poetic worldbuilding strategies (Section II).
- We document AFTERMATH: GRAVITY ANOMALY as a practice-based instantiation of the framework, including its gravitational-anomaly mechanic, layered ruin environment, and diegetic research interface (Section III).
- We specify a mixed-methods protocol through which the framework can be empirically tested in future work, including an A/B control condition, validated engagement scales, learning measures, telemetry, and interviews (Section IV).

Section V discusses theoretical and practical implications and outlines strategic future work, and Section VI concludes.

II. THEORETICAL FOUNDATIONS

A. Embodied Metaphor and Kinesthetic Cognition

Lakoff and Johnson's *Metaphors We Live By* [7] and subsequent work on embodied cognition [9], [10] argue that abstract reasoning is shaped by recurring structures of bodily experience. Image schemas such as CONTAINER, PATH, BALANCE, FORCE, and VERTICALITY are not scientific concepts by themselves, but they provide experiential scaffolds through which more formal concepts can become intelligible. For science communication, this matters because many difficult concepts are already taught through embodied language: fields *pull*, systems *fall* out of equilibrium, bodies *resist* acceleration, and trajectories *curve*.

The program has substantial empirical backing across cognitive science. Behavioral experiments demonstrate that bodily postures influence abstract judgments—tilting one's body alters numerical estimation [11], simulated weight changes the perceived importance of decisions [12]. Neuroimaging shows that processing action verbs activates the motor cortex regions associated with the action's effector [13]. Together, this evidence converges on the view that "higher" cognition is densely interlaced with sensorimotor processing, not implemented atop it as an autonomous symbolic layer. For game design, the practical takeaway is straightforward: if we want the player to think a thought, we should give the player's body something to do that rehearses the schema that thought requires.

Digital play offers an unusually direct channel for activating image schemas. When a player tilts an avatar, the BALANCE schema becomes operational; when an avatar falls, VERTICALITY and FORCE become matters of timing, anticipation, and recovery; when the camera inverts, the player must reorganize spatial expectation. Kirsh and Maglio's work on epistemic action in Tetris [14] provides a useful precedent: players act on a system not only to change the world state, but also to simplify perception and thought. In our context, gravity manipulation is designed to let players think with the system: to treat field direction, fall trajectory, and spatial orientation as playable hypotheses. We call this design principle *mechanics-as-metaphor*: a scientific relation is translated into a recurring player action that activates an appropriate image schema, while text, diagrams, and archives support rather than replace that action.

This principle differs from a narrow simulation-first approach. Numerical fidelity can be valuable, but a physically accurate system does not automatically become a communicative one. For this project, the design question is not how to reproduce gravitational physics exhaustively, but how to construct interactions through which non-specialist players can encounter gravity as orientation, instability, path curvature, and scale. The aim is not to replace formal explanation; it is to create an embodied pre-understanding that makes later explanation more meaningful.

B. Spatial Poetics and Expressive Ruins

Bachelard's *The Poetics of Space* [8] reframes inhabited space as a phenomenological correlate of reverie, memory, and

existential mood, rather than a neutral Cartesian container. The cellar, the attic, and the nest are not merely geometric volumes; they are charged with affective valence. We extend Bachelard's intuition to the level design of serious games: a game scene is not just a stage on which mechanics unfold but a poetic instrument that can pre-tune the player's affective response to the science being communicated.

The trope of the *ruin* is especially powerful in this regard [15]. Ruins are material residues of a collapse; they confront the visitor with the simultaneous presence of order (the bones of the structure) and entropy (the slow violence of decay). Simmel observed that a ruin is most affecting precisely when the vestiges of human intention are still visible—when the arch still reads as an arch, even as vegetation erupts from its keystone. In the context of a science-communication game about cosmological catastrophe, expressive ruins offer a spatial language for entropy, deep time, and the existential weight of irreversible change—registers that are difficult to convey through text or equations alone.

We also draw on Yi-Fu Tuan's concept of *topophilia* [16]: the affective bond between person and place. A sterile test-chamber level design cannot evoke topophilia; a ruined industrial cathedral can. By composing the scene as a layered ruin rather than as a clean abstract test chamber, the designer can let the space itself participate in the act of explanation. The ruin does not merely *illustrate* the physics of collapse; it *feels* like collapse, and that feeling is an additional layer of knowledge—one that textbooks cannot provide.

C. Reconstructing Science Communication Narratives

Game studies offers complementary resources for this move. Procedural rhetoric [17] frames rule systems as argumentative structures; Sicart's account of mechanics clarifies how player actions are organized by game states and affordances [18]; Jenkins's environmental storytelling situates narrative in the architecture of game space [19]; and reflective game design shows how games can pose questions rather than deliver closed answers [20]. Together, these strands suggest that a science-communication game need not choose between concept, action, and story. Its rules can model relations, its spaces can stage interpretation, and its narrative fragments can turn play into inquiry.

Within this milieu, our framework contributes a specific synthesis: embodied-metaphor mechanics, drawn from cognitive linguistics, combined with spatial-poetic level design, drawn from phenomenology, oriented toward science communication rather than entertainment alone. The framework has three steps. First, identify the scientific relation to be communicated. Second, map that relation to image schemas and recurring player actions. Third, compose a spatial and narrative context that makes the consequences of those actions meaningful. The remainder of the paper documents how this framework shaped AFTERMATH: GRAVITY ANOMALY and how it could be evaluated.

It is worth situating this synthesis relative to two influential but distinct positions. Salen and Zimmerman's *rules of play* [21] treats game design as the production of meaningful play through formal systems; our framework agrees but emphasizes that meaning can be deliberately shaped through image-schematic correspondence. Juul's *half-real* framework [22] emphasizes that games are simultaneously real rules and fictional worlds; we extend this by arguing that the fictional world's spatial and material qualities should be designed to carry cognitive content, not merely to provide a diegetic wrapper for the rules. The difference is between a game world that *decorates* the mechanics and one that *thinks* with them.

III. GAME DESIGN AND PROTOTYPE ARCHITECTURE

The framework described above is instantiated in AFTERMATH: GRAVITY ANOMALY, a 2.5D narrative puzzle prototype. The design goal is exploratory: to test whether science communication can be organized around embodied action and spatial interpretation rather than around detached explanatory panels. This section details three prototype systems: the gravitational-anomaly mechanic, the layered expressive-ruin scene model, and the diegetic research archive.

A. Mechanics as Metaphor: The Gravitational Anomaly System

The game's core mechanic operationalizes gravity as a local, manipulable relation rather than as a fixed downward constant. In ordinary traversal, the player's avatar walks, jumps, and interacts with physics objects using platformer conventions. When the player activates the *Gravity Anomaly* mode, a selected point within range becomes a temporary local field source, pulling nearby objects and the avatar toward it. The mechanic therefore turns direction, magnitude, and locality into decisions the player must make under spatial pressure.

The design intention is not to simulate general relativity with numerical precision. Rather, the goal is to communicate qualitative relations that are central to public understanding of gravity: that "down" is not an absolute direction, that trajectories depend on fields, and that local interventions can produce global instability. These relations are made available as repeated acts of aiming, falling, correcting, and reorienting.

Concretely, each activation of the anomaly mechanism affords the player three degrees of freedom:

- **Gravity strength:** Continuous slider from zero-g to $2g$, with corresponding effects on jump height, fall time, and mass-dependent acceleration.
- **Gravity direction:** Fully reconfigurable from $0°$ to $360°$ relative to the current gravity vector, enabling wall-walking, ceiling-walking, and spherical gravity wells.
- **Radius of influence:** Bounded zone within which the override applies, creating sharply delineated anomalies that the player must navigate carefully.

These parameters are intentionally legible rather than exhaustive. They make the field's magnitude, orientation, and reach visible as design variables. Every puzzle decision is therefore also a conceptual rehearsal: increasing strength changes tempo and risk; rotating direction unsettles the assumption of a privileged "down"; expanding radius dramatizes

the difference between local control and systemic consequence. The interface functions less as a didactic diagram than as an instrument for testing how gravitational relations feel in action.

Crucially, the mechanic is not treated as a puzzle gimmick added to a separate science lesson. It is the primary communicative medium. When the avatar is pulled along an unusual trajectory, the player rehearses source–path–goal and force schemas before encountering archival explanation. The effect is reinforced by camera motion, screen distortion, lighting shifts, and color grading around extreme gravity events, so that the body of the player, the body of the avatar, and the visual field are all implicated in the same relation.

We can trace the embodied-metaphor correspondence more precisely. The SOURCE–PATH–GOAL schema structures our everyday understanding of motion: a moving entity starts somewhere, traverses a path, and arrives at a destination. In classical physics, a trajectory is a source–path–goal under a constant downward force. In general relativity, the trajectory is still a source–path–goal, but the path is curved by the geometry of spacetime itself. The anomaly mechanic lets the player *reconfigure the geometry of the path* by reorienting the gravity vector: the source–path–goal schema fires, but the path is now non-Euclidean, and the player's body must adapt. This is the kinesthetic experience of what a textbook calls "geodesic motion in a curved metric." The player does not need the formalism to understand the concept; the body has already understood it.

Similarly, the EQUILIBRIUM schema—the felt sense of balance versus imbalance—is activated when the avatar stands on a surface whose effective orientation is about to change. In a uniform platformer world, equilibrium is stable and predictable. In the anomaly system, the equilibrium point shifts as the field is redirected, requiring continuous correction. The mechanic externalizes a basic scientific intuition: stability is not a default state but an achieved relation among forces, surfaces, and motion.

Figure 1 shows the current visual form of this mechanic in the prototype. Rather than presenting gravity as a detached diagram, the scene places the luminous anomaly object inside the same ruined play space that the player must traverse. The white orbiting slabs, drifting architectural fragments, and unstable horizon make the field readable as both a navigational device and a sign of world-scale collapse.

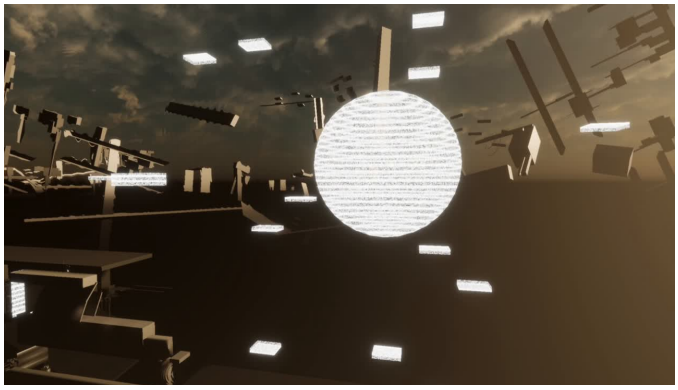

Fig. 1: Prototype view of the gravitational-anomaly space. The bright local field object, orbiting slabs, and suspended ruin fragments translate gravity from a formula into a manipulable spatial condition.

B. Spatial Poetics: Layered Ruin as Science-Communication Space

The game's visual aesthetic and level architecture are composed as a three-layer scene model, each layer corresponding to a different temporal and affective register of the world's collapse. Together they materialize Bachelard's intuition that a space is not a monolith but a nest of concentric phenomenological zones, each charged with its own reverie [8].

- **Foreground: Clean puzzle volumes.** The platformer geometry that the player directly interacts with consists of sharp-edged, untextured cubic volumes. These blocks are the playground of the anomaly mechanic: they float, fall, shift orientation, and assemble into puzzles. Their geometric clarity establishes the player's spatial agency; they are the zone of *control*.
- **Midground: Industrial ruins.** Surrounding and behind the puzzle volumes lies a decaying industrial landscape: bent girders, cracked concrete, abandoned machinery, and rusted pipes. This layer is the zone of *entropy*. The ruins are never directly navigable, but their presence frames the puzzle as a salvage operation taking place inside a dead civilization.
- **Background: Chaotically floating debris.** Far in the distance, large, irregularly shaped fragments of architecture and rock drift aimlessly, rotating slowly against the sky. This layer is the zone of *the sublime*. It signifies the scale of the catastrophe—the planet itself is breaking apart, and the orderly puzzle volumes are a fragile remnant of coherence floating on the surface of a cosmic chaos.

The three layers are further unified by a consistent high-contrast black-and-white lighting scheme, punctuated by a warm golden sunset that spills from the horizon. The light is not merely decorative: it reinforces the mood of an ending world, a last sunset before the final blackout.

To understand the affective logic of the three-layer model, it helps to consider it as a phenomenological gradient. The foreground is the zone of *agency*: here the player can act, plan, and solve. The midground is the zone of *loss*: it was once a zone of agency (people worked in those factories, lived in those apartments) but that agency has been withdrawn by entropy. The background is the zone of the *sublime*: it exceeds the player's scale of action entirely and evokes the Kantian mathematically sublime—a magnitude that overwhelms the imagination but is nonetheless grasped by reason [23]. The gradient thus enacts a recursive layering of Bachelardian reverie: each zone is a different mode of spatial imagination nested inside the next.

Technically, the parallax separation between the layers is driven by the camera's position and is exaggerated relative

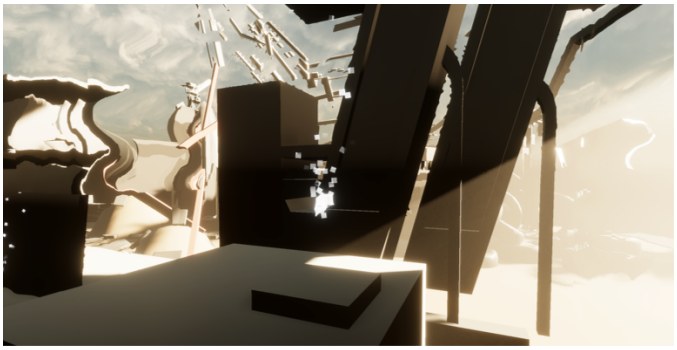

Fig. 2: Layered ruin composition in the playable prototype: clean foreground volumes, dense industrial silhouettes, and distant floating debris are composed as one continuous field of action and reverie.

to realistic depth, creating an uncanny sense that the world is deeper than it should be—as if the space itself has been stretched by the same gravitational anomalies that the player is manipulating. This deliberate spatial distortion subtly destabilizes the player's assumptions, reinforcing the thematic content of the game at a pre-reflective level.

The available scene captures show that the prototype does not separate these registers into a clean explanatory diagram. Instead, the layers are fused in moment-to-moment play: platform edges in the foreground, heavy industrial silhouettes in the middle distance, and broken structures suspended against the sky. Figure 2 presents the most direct full-scene view, while Figure 3 collects several camera angles that reveal how the same spatial grammar persists across traversal.

C. Diegetic Research Archive

Rather than delivering exposition through linear dialogue or cut-scenes, the prototype embeds science communication in a diegetic archive that the player consults during exploration. The interface has two linked functions: it records scientific interpretations of observed phenomena, and it reconstructs the social history of the collapsed civilization.

a) Research Interface: Science as Kinesthetic Archive.: The player can open the Research Interface at any time. It presents scientific concepts as collectible research records combining environmental illustration, short explanatory prose, and anatomical sketches of bodies under force. In the current asset set, an eclipse record is paired with an image of a lone observer standing in a fractured landscape and a hand-drawn figure bent under pressure. The scientific claim is therefore staged as a bodily and spatial event: light, gravity, posture, and landscape are read together rather than separated into textbook notation.

b) Event Interface: Environmental Storytelling.: As the player progresses, they discover data fragments scattered throughout the ruins: corrupted log files, partial communications, and fragmented diary entries. These fragments gradually assemble a narrative about the civilization that once inhabited the planet: its over-exploitation of gravity as an energy source, the warnings ignored, the final attempts to reverse the collapse. The Event Interface organizes these fragments chronologically and thematically, letting the player reconstruct the backstory as they reconstruct the physics.

The narrative arc is deliberately non-linear. Fragments are encountered in roughly the order in which the player explores the world, not in the order in which the events they describe occurred. The temporal puzzle of reassembly mirrors the spatial puzzle of navigation: the player must hold partial knowledge in mind, revise it as new fragments arrive, and tolerate uncertainty until a coherent picture emerges. This structure draws on the established design vocabulary of the "walking simulator" genre [24], but it goes further by interleaving the narrative recovery with the physics-puzzle progression, so that the science the player is doing and the story the player is reading converge on the same conceptual climax.

The archive deliberately avoids making formal equations the first point of contact. The goal is not to replace physics instruction but to create an experiential entry point that can make later formalization more approachable. Figure 4 shows the in-game research panel, and Figure 5 shows the broader graphic system used to produce archival records and science-communication inserts.

The archive design rests on an important theoretical commitment: scientific knowledge and narrative meaning are not two separate streams that must be merged after the fact, but two aspects of the same experiential event. When the player falls toward a gravity well and later discovers a record describing the civilization's attempts to harness that same gravity, the kinesthetic and diegetic dimensions reinforce each other. This alignment is the operational core of the framework: embodied metaphor and spatial poetics are not applied in sequence but woven together in play.

From a practical standpoint, the archive also addresses a common usability problem in educational games: the "reading problem," where players skip text-heavy panels because they interrupt the flow of play [25]. By splitting exposition into visual-kinesthetic records and optional narrative fragments, the prototype reduces the likelihood that the player must stop moving in order to receive information. The archive is available during natural pauses in puzzle progression, while the environment and mechanics continue to carry part of the explanation during active traversal.

IV. Evaluation Framework and Experimental Design

Because the central claim of this paper is a design hypothesis rather than a completed empirical result, it must be made testable. This section specifies a mixed-methods evaluation framework—designed but not yet executed—for assessing whether embodied metaphor and spatial poetics improve the science-communication experience relative to a functionally matched control.

A. Proposed Mixed-Methods Methodology

We adopt a convergent parallel mixed-methods design [26]: a quantitative arm estimates effects on aesthetic, narrative,

Fig. 3: Scene montage showing the prototype's recurring spatial vocabulary: backlit ruins, unstable verticals, suspended fragments, and warm horizon light. These images ground the paper's spatial-poetic claims in the actual visual materials rather than in an abstract layer diagram.

Fig. 4: Research Interface screenshot. The tabbed shell embeds a science record inside the play world, combining environmental illustration, concise explanation, and a bodily sketch that frames physics as posture and motion.

and learning dimensions, while a qualitative arm examines how players describe the relationship between mechanics, space, and scientific meaning. The two arms are conducted on the same participant cohort and integrated at the analysis stage. Before recruitment, the protocol will be externally preregistered with fixed hypotheses, exclusion criteria, analysis scripts, and condition descriptions.

B. User Study Configuration

The planned user study follows a between-subjects A/B design with $n \approx 60$ participants recruited from undergraduate science, design, and communication programs. Participants complete a pre-screening questionnaire on baseline physics familiarity, prior game experience, and visual/vestibular sensitivity, then are randomly assigned to one of two conditions using blocked randomization:

- **Treatment (Embodied-Spatial Build).** The full AFTERMATH: GRAVITY ANOMALY prototype, including the gravitational-anomaly mechanic, layered expressive-ruin scene, kinesthetic research archive, and fragment-driven environmental story.
- **Control (Functional Build).** A matched build that preserves puzzle layout, interaction timing, and gravity-manipulation

Fig. 5: Science-communication graphic system for the prototype. The material sheet shows how archival cards, explanatory illustrations, and restrained typography are designed as diegetic research fragments rather than external lesson slides.

affordances, but replaces the research archive with conventional text-and-equation panels and simplifies the background into a static non-narrative environment.

Each session lasts approximately 50 minutes: 10 minutes of onboarding and consent, 30 minutes of guided play through three matched puzzle clusters, and 10 minutes of post-play questionnaires and interview. All sessions are screen-recorded with consent. Gameplay telemetry records anomaly activations, puzzle solution times, falls and restarts, interface dwell time, archive-open frequency, and optional-object inspection.

C. Measurement Metrics

We pre-specify three quantitative scales and one qualitative protocol.

Aesthetic Flow is measured with an adapted Flow Short Scale [27] comprising 10 items on a 7-point Likert scale, capturing absorption, control, and intrinsic enjoyment. **Narrative Presence** is measured with the Narrative Engagement scale [28], capturing narrative understanding, attentional focus, emotional engagement, and narrative presence. **Perceived Learning** is measured with a custom 8-item instrument assessing self-reported conceptual gain on four target relations: field direction, local influence, trajectory curvature, and stability. These self-reports are benchmarked against a 12-item objective knowledge quiz administered before and after play.

Table I summarizes the metric battery and the design hypothesis it tests against each construct.

The qualitative arm consists of a 10-minute semi-structured interview administered immediately after the post-test quiz, with prompts targeting (i) memorable moments and their somatic correlates ("where did you feel something in your body?"), (ii) the perceived relationship between mechanics and meaning, and (iii) any reflective or existential responses to the ruined-world setting. Interview transcripts will be analyzed using thematic coding [29] with two independent coders and a third-party adjudicator for inter-rater reliability.

TABLE I: Evaluation Metric Battery and Design Hypotheses

Construct	Instrument	Hypothesis
Aesthetic Flow	Flow Short Scale	Treatment > Control (spatial poetics boosts absorption)
Narrative Presence	Narrative Engagement Scale	Treatment > Control (dual interface deepens engagement)
Perceived Learning	Custom 8-item + 12-item quiz	Treatment > Control (embodied metaphor improves conceptual transfer)
Qualitative themes	Semi-structured interview	Treatment elicits somatic and existential vocabulary; control does not

We also pre-specify the analytic strategy to forestall fishing for significance. The primary hypothesis is that the treatment condition will outperform the control condition on a composite engagement-and-learning index. We will test condition effects with regression models that include baseline physics familiarity and prior game experience as covariates, reporting effect sizes and confidence intervals rather than relying only on p-values. Secondary analyses examine whether Aesthetic Flow and Narrative Presence mediate the relationship between condition and post-test learning. The objective knowledge quiz

provides a complementary, design-blind learning measure that anchors the self-report data.

A pilot of $n = 10$ will precede the full study to refine questionnaire wording, calibrate puzzle difficulty across conditions, and validate gameplay telemetry. Pilot data will not be included in the main analysis. We commit to reporting both positive and null results, with the pre-registered protocol serving as a public stake against publication bias. Because the present asset set documents the prototype and its science-communication interface rather than the future laboratory procedure, this section keeps the evaluation design in textual and tabular form instead of introducing a speculative process diagram.

V. Discussion and Future Work

A. Theoretical and Practical Implications

The framework proposed in this paper sits at the intersection of game studies, embodied cognition, and spatial phenomenology. Its theoretical contribution lies in operationalizing two traditions that are often invoked rhetorically in design discourse—embodied metaphor and poetics of space—as design commitments that can be implemented in a game engine and evaluated with players. *Embodied metaphor* becomes a heuristic for choosing and shaping mechanics: a scientific relation is a candidate for playable translation when it can be associated with force, balance, path, containment, orientation, or other sensorimotor schemas. *Spatial poetics* becomes a heuristic for composing worlds: the scene is treated as a phenomenological instrument whose affective register should resonate with the science being communicated.

Practically, the framework offers serious-game developers a way to address the split identified at the outset: scientific exposition on one side, engaging but unrelated play on the other. Aftermath: Gravity Anomaly shows one possible alternative. Its gravity mechanic, ruin environment, and research archive all point toward the same conceptual field, so that scientific content is not only displayed but distributed across action, space, and narrative artifact. This does not guarantee learning, but it produces a design object whose claims can be inspected, compared, and tested.

The broader implication concerns audience positioning. Conventional science communication often casts the public as recipients of simplified expert knowledge. A game built around embodied metaphor begins from a different premise: players already possess bodily and spatial resources that can support initial contact with difficult concepts. The design task is to organize those resources into meaningful encounters without pretending that intuition is equivalent to formal scientific competence.

A further implication concerns the politics of attention. In an era of fragmented attention and algorithmic content streams, conventional science communication often competes by becoming shorter, louder, and more spectacular. The framework we propose moves in a different direction: it asks for sustained embodied engagement and uses that duration to build conceptual and affective context. This is not a strategy for maximizing reach; it is a strategy for deepening the value of the reach one has. We believe there is room, in the contemporary attention economy, for both modes of communication: spectacle for first contact, and embodied play for sustained understanding.

B. Limitations and Strategic Future Work

This paper is a practice-based study; its empirical claims are therefore deliberately limited. The most important limitation is that the user study designed in Section IV has not yet been executed. The current evidence consists of the prototype, its design rationale, and a specified evaluation plan, not measured learning outcomes or player-experience data. Until the A/B study is completed, claims about cognitive efficacy remain hypotheses rather than findings.

The second limitation is scope. The prototype focuses on gravity-related science communication and uses a ruin-based aesthetic vocabulary. Other scientific domains may require different mechanics and different spatial registers. The third limitation is accessibility: gravity inversion, camera distortion, and high-contrast visual effects may challenge players with vestibular sensitivity or low vision, and this must be addressed before public deployment.

The primary future-work commitment is therefore to run the empirical study and report both positive and null results. Beyond this immediate commitment, three additional directions are worth pursuing.

a) Multimodal physiological measurement.: We plan to augment the questionnaire-based protocol with eye-tracking and galvanic skin response (GSR) data, capturing real-time attention and arousal in response to specific design events—for example, the moment a player first triggers a large-scale gravitational anomaly, or the moment the camera reveals the background drift layer for the first time. Such data will let us anchor self-report measures in physiologically observable correlates of aesthetic flow and narrative presence.

b) Expansion to other scientific domains.: The mechanics-as-metaphor heuristic generalizes well beyond astrophysics. A future game on thermodynamics could use heat diffusion as both mechanic and metaphor; one on evolution could let players manipulate selection pressures as a level-design tool. We are interested in cataloging a wider library of *schema-mechanic-science* triples that can serve as off-the-shelf design recipes for serious-game studios.

c) Cross-cultural adaptation.: The Continental theories invoked here—particularly Bachelard's poetics of space—carry culturally specific connotations of ruin, reverie, and existential mood. A meaningful future direction is to investigate whether the framework transfers across cultural contexts, or whether the affective registers must be re-tuned for audiences with different spatial-poetic vocabularies.

Together, these directions outline a multi-year research agenda whose first milestone is the empirical validation of the framework through the study designed in this paper.

d) Open authoring tools.: A final, more ambitious direction is to abstract the framework into an authoring tool that other designers can use to build embodied science games. Such

a tool would expose image schemas as mechanic prompts, spatial-poetic archetypes as environment prompts, and an evaluation harness connected to the measures described in Section IV. The goal is not to standardize design but to lower the barrier between theory and practice for science museums, university outreach programs, and independent studios. Whether such a tool can support design without flattening the theoretical richness of the framework remains an open research question.

VI. Conclusion

This paper has presented a practice-based exploration of science-communication narrative in serious games. Grounded in embodied metaphor and spatial poetics, it proposed a framework for translating scientific relations into player actions, spatial atmospheres, and diegetic research artifacts. The framework was instantiated in Aftermath: Gravity Anomaly, a 2.5D narrative puzzle prototype whose gravitational-anomaly mechanic, layered expressive-ruin scene model, and research archive collectively materialize the design commitments.

The central claim is not that the prototype has already proven learning effects. Rather, the prototype makes a design proposition concrete: digital interactive media need not function only as delivery mechanisms for simplified scientific facts. They can stage scientific relations as sequences of embodied and spatial events, then use narrative artifacts to invite reflection on what those events mean. In Aftermath: Gravity Anomaly, gravity is not only described; it is aimed, misjudged, corrected, archived, and situated inside a ruined world.

The intended result is not a substitute for formal physics education, but a prologue to it. A player should not be expected to leave the game with mastery of formal equations. The stronger and more realistic ambition is that play can create memorable intuitions about orientation, field influence, trajectory, and instability, giving later explanation something experiential to attach to. In an era where science communication is often dominated by short-form spectacle and abstract visualization, this framework offers another route: communication that moves through action and space as well as through representation.

Methodologically, the paper argues for a middle path between design reflection and empirical evaluation. The prototype gives the theory material form; the proposed study gives the material form a route toward falsification. The next step is to run the experiment and determine whether the embodied and spatial intuitions designed here measurably affect engagement, narrative presence, and conceptual understanding.

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