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From Virtual Presence to Physical Competence: Consequence-Preserving Transfer in K-12 Spatial STEM

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Critical integrative analysis and prospective research protocol

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Abstract

Spatial computing can make science vivid without establishing that learning remains useful outside a simulation. This critical integrative analysis develops consequence-preserving transfer as a testable extension of Freedom Cheteni's proposed Movement Thinking framework. The contribution combines a consequence map, an evidence-linked revision record, and an explicit transfer contract. It distinguishes meaningful control over scientific consequences from display immersion, motor activity, and reported presence. A prospective classroom-cluster randomised trial would compare a structured prediction-action-revision sequence with an equally resourced active curriculum, offering accessible immersive and non-headset routes in both arms. The primary estimand is the intention-to-treat effect on independently scored, delayed physical transfer among baseline-enrolled eligible participants. The protocol specifies allocation, outcome validation, power simulation, clustering, missingness, participant protections, and falsification criteria. No primary data or efficacy results are reported. The resulting research agenda treats accessibility, evidential limits, and the capacity to act competently after a device is removed as central conditions of educational value.

Keywords: Movement Thinking, Designership, spatial STEM, extended reality, transfer of learning, accessible design, cluster randomised trial, K-12

1. The educational claim begins outside the headset

A student who completes a virtual laboratory has demonstrated competence in that environment. Whether the student can reason, act safely, and revise a design in a physical laboratory remains a separate question. That distinction matters for K-12 systems investing in spatial computing. Attractive environments, confident learners, and polished demonstrations can be educationally valuable, but none establishes transfer. A signature Designership research programme should therefore begin with a demanding criterion: students must use what they learned when the display, objects, interaction controls, and social situation change.

This article develops consequence-preserving transfer as a proposed extension of Freedom Cheteni’s Movement Thinking framework. The contribution is an inspectable design logic: preserve the consequential relationship between a learner’s decision, an observable outcome, and a justified revision while allowing the interface and physical demands to vary. An experiment follows from that logic. The relevant intervention is not simply access to a headset; it is a curriculum that requires prediction, action, comparison, explanation, and subsequent application to unfamiliar physical materials.

The argument concerns secondary STEM education, particularly introductory engineering and mechanics. It does not claim that existing VR School practice has already produced the effects proposed here. No participants were recruited, primary outcomes collected, or trial results estimated for this article. The manuscript combines a critical integrative analysis with a prospective research protocol. Its value lies in specifying claims that could fail, documenting how they would be evaluated, and making an accessible alternative part of the intervention rather than an exception to it.

2. Evidence selection and limits of this analysis

The analysis uses a deliberately bounded set of foundational empirical studies, a theory of immersive learning, a transfer taxonomy, and authoritative accessibility and research-governance documents. Searches conducted on 16 October 2026 used combinations of immersive virtual reality, embodied learning, physical transfer, science learning, high school, mixed reality, accessibility, and cluster randomised trial. Publisher pages and author-institution repositories were preferred; DOI metadata were checked against Crossref. The selection was purposive and question-led. It was not an exhaustive database search, screened systematic review, quantitative synthesis, or estimate of average XR effectiveness.

Sources were selected to test a tension rather than accumulate endorsements: action can contribute to learning, while immersion can add demands without improving knowledge. The analysis distinguishes college physics, whole-body mixed reality, and high-school virtual science studies rather than treating their populations and technologies as interchangeable. Published experimental effects support the

plausibility of mechanisms within their original settings. They do not validate Cheteni's framework, determine a school district's expected benefit, or supply a transferable effect size for the proposed trial.

3. What embodiment supports-and what it leaves unproven

Kontra, Lyons, Fischer, and Beilock investigated physical experience in science learning through laboratory experiments and a college physics field experiment. Their work supports taking action-relevant experience seriously when teaching a physical concept; it does not establish that any movement, headset, or immersive scene improves K-12 learning. A student can move vigorously while attending to the wrong relationship. The instructional question is whether action makes a consequential scientific distinction available for inspection. [R1]

Lindgren, Tscholl, Wang, and Johnson examined embodied interaction within a mixed-reality simulation. Their study provides a closer precedent for designing movement around a scientific relation rather than adding movement as decoration. Johnson-Glenberg's educational design account similarly makes gesture and manipulation central considerations. These contributions motivate a design commitment, not a universal prescription: the permitted action should correspond to the concept the learner needs to understand. [R2, R3]

Consider balancing an unfamiliar beam. Rotating a virtual model with a controller is an interface action. Predicting how moving a load changes balance, observing an unexpected result, and revising the prediction is epistemic work. A seated learner using a switch or keyboard may undertake that same epistemic work. Consequently, this article locates the proposed mechanism in accessible control over meaningful consequences, not in a required body movement. Physical realism is useful only where it preserves information needed for the target task.

4. Presence is a process variable, not the learning verdict

Makransky, Terkildsen, and Mayer compared head-mounted and desktop science simulations with university students. Greater reported presence accompanied poorer learning in that experiment. The result is not a verdict against all immersive learning; it is a direct counterexample to treating presence as sufficient evidence of educational value. A district can produce an impressive experience while making the central explanatory work harder. [R4]

More directly relevant to secondary schooling, Makransky, Andreasen, Baceviciute, and Mayer studied high-school students using immersive science simulations or video. Immersion did not by itself provide the reported learning advantage, while post-lesson enactment benefited procedural knowledge and transfer in the immersive condition. This finding motivates testing what learners do around the simulation, including reconstruction and explanation, rather than evaluating a headset as an isolated

treatment. It does not establish the effectiveness of the beam-and-balance curriculum proposed below. [R5]

The Cognitive Affective Model of Immersive Learning provides a framework for separating technological features, presence and agency, cognitive and affective processes, and different learning outcomes. This manuscript adopts that separation while narrowing its causal claim to a particular instructional sequence and physical transfer task. Enjoyment and presence will be measured as secondary process variables. They will never substitute for competent performance, justify excluding uncomfortable learners, or determine the decision to scale. [R6]

5. Consequence-preserving transfer as a Movement Thinking proposition

Movement Thinking is used here as Cheteni's proposed orientation toward visible questions, bounded authority, preserved revision, and accountability for consequences. Consequence-preserving transfer makes that orientation experimentally specific. It predicts that learners will transfer more successfully when they repeatedly commit to a prediction, control a relevant variable, inspect the outcome, explain a discrepancy, and test a revision across representations. Each link is necessary for the instructional claim; a simulation that supplies the explanation before a student makes a prediction is a different intervention.

The proposed contribution has three components. First, a consequence map states which physical relationships a representation preserves and which it omits. Second, a revision record connects the learner's initial prediction, observed outcome, and changed explanation. Third, a transfer contract defines the unfamiliar task on which learning must remain useful. Together these components make the lesson's inferential promise visible. The map concerns model fidelity, the record concerns reasoning over time, and the contract concerns the boundary of generalisation.

For a balance task, the consequence map would preserve load magnitude, distance from the pivot, and direction of rotation while explicitly omitting material deformation and friction unless they are taught. The revision record would capture a prediction before simulation feedback and a reason after it. The transfer contract would require balancing a differently configured physical apparatus and diagnosing a misleading visual arrangement. This specification prevents a strong score on an identical virtual puzzle from being presented as broad engineering competence.

Barnett and Ceci's transfer taxonomy helps identify why changing environments is not a single distance. Content, context, timing, function, and modality can vary together. The proposed curriculum therefore changes representation while controlling the scientific relationship, then evaluates limited transfer across changed materials and conditions. It does not claim far transfer to general intelligence, employability,

creativity, or all future STEM learning. Such outcomes would require their own operational definitions and studies. [R7]

6. Accessibility is part of the treatment definition

The W3C XR Accessibility User Requirements identifies needs spanning navigation, interaction, presentation, and other aspects of immersive environments. It is a Working Group Note, not a certification that a particular lesson is accessible. Its relevance here is architectural: alternative inputs and outputs must be planned before recruitment and built into the curriculum specification. Compliance claims would require evaluation of the actual product and learners' experiences. [R8]

Every lesson would support seated participation, adjustable reach and movement amplitude, remappable inputs, captions, text equivalents, and a stable non-headset route with the same decision sequence. Instructions would avoid colour-only distinctions and timed controller movements as prerequisites for demonstrating understanding. Learners could request breaks or change routes without needing to disclose a diagnostic label to classmates. User testing would include students with relevant sensory, mobility, communication, and attentional access needs, compensated through an approved process.

Equivalent intellectual demand does not imply identical sensory experience. The study would audit whether each route exposes the learner to the same scientific relations and permits equally informative predictions and revisions. An independent accessibility review would identify unresolved barriers before trial commencement. Participation in research would never require a student to abandon an existing accommodation. Where access changes the scoring procedure, the change would be documented and assessed for construct equivalence rather than hidden inside an adjustment variable.

7. Prospective study: question, population, and allocation

The primary question is whether a consequence-preserving instructional sequence improves delayed physical transfer relative to an equally resourced simulation curriculum without the structured prediction-and-revision sequence. The proposed study is a parallel, two-arm, classroom-cluster randomised trial in grades 8-10. Both arms receive the same scientific content, total instructional time, teacher contact, equipment access, orientation, and physical assessment. The contrast concerns instructional organisation, not entitlement to resources.

Participating schools would be recruited across differing resource settings before teachers learn allocation. Eligible students would be enrolled in participating STEM classes and able to undertake the scientific decisions through at least one accessible route. Device discomfort or disability would not be an automatic exclusion. Clinical or equipment-specific safety concerns would be managed through a reviewed individual

access plan and a non-headset route. Research consent would be obtained separately from ordinary curriculum access. The final population definition and exclusion rules would be registered before assignment.

An independent statistician would generate allocation after class rosters, baseline measures, and teacher commitments are fixed. Classrooms would be randomised within schools and grade bands, balancing teacher blocks where feasible. If teachers teach both arms, scripted materials and observation would monitor cross-arm contamination; if spillover cannot be limited, schools rather than classes would become clusters, requiring a revised power plan before recruitment. Allocation would remain concealed from recruiters until baseline enrolment closes. Students and teachers cannot be blinded to the sequence; physical-task assessors and primary analysts would be masked to coded assignment.

The study would follow an adapted cluster-trial reporting plan: identify recruitment relative to allocation, explain cluster and student eligibility, describe the randomisation unit, report attrition at both levels, and account for clustering in analysis. These requirements draw on the CONSORT extension for cluster trials; the educational protocol would also identify departures arising from school scheduling and consent. No registration number, ethics approval, participating district, or committed recruitment site is claimed here. [R9]

8. Intervention specification and active comparator

The intervention would comprise four curriculum sessions over two weeks, followed by an immediate assessment and a delayed assessment four weeks after the final lesson. These are proposed design choices, not completed procedures. Sessions would begin with accessible orientation common to both arms. Learners would investigate balance and moments through parameter-controlled simulations and an identical allocation of hands-on materials. The intervention arm would record predictions before changing parameters, receive outcome feedback, explain discrepancies, and test one documented revision.

The active comparator would receive the same demonstrations, examples, simulation capabilities, hands-on time, and teacher explanations. Its practice sequence would use conventional worked examples and answer checks without the required prediction-outcome-revision record. It would include an equal-duration note activity so that writing time is not the principal contrast. The study would therefore estimate the added effect of the structured sequence over a credible alternative. It would not estimate an unqualified VR-versus-no-VR effect, nor isolate every component of Movement Thinking.

Both arms would offer a choice between compatible immersive and non-headset routes under the same accessibility policy. Route choice, switching, and exposure would be documented before and during lessons. Because route is not randomised,

differences between route users would be descriptive and potentially confounded. A later factorial trial could isolate immersion, but the present study prioritises the effect of an inclusive instructional policy. Teachers would use common stopping and support rules, and receive preparation in delivering both arms without enthusiasm or feedback asymmetries.

Fidelity would be assessed using a prespecified sample of lesson observations and de-identified work records. Observers would score whether the required decision preceded feedback, whether a consequence was visible, and whether an explanation supported revision. They would also document hints, departures from scripts, technical failures, and extra instruction. Fidelity would inform interpretation and future implementation; excluding low-fidelity classrooms from the primary estimate would undermine the policy question the trial is designed to answer.

9. Hypotheses, estimand, and outcomes

H1 predicts a positive average effect of assignment to the consequence-preserving sequence on delayed physical transfer. H2 predicts that the sequence improves explanation-supported revision rather than merely increasing the number of edits. H3 predicts that any primary benefit remains interpretable alongside access and tolerability: an advantage accompanied by systematic loss of participation or increased harm in an access-needs group cannot support an unrestricted adoption claim. H2 is secondary; H3 is a decision constraint assessed with uncertainty, not a promise that a small trial can prove subgroup equivalence.

The primary estimand is the student-average intention-to-treat effect of assignment among consenting, baseline-enrolled eligible students in the recruited clusters. It compares two instructional policies with their common access options. The primary endpoint is the total score on an independently administered physical transfer assessment four weeks after instruction. The scoring blueprint would be frozen before allocation: prediction under an unfamiliar load configuration, justified selection of a corrective action, diagnosis of a misleading configuration, and explanation of evidence supporting revision. Curriculum developers would not score their own students’ primary tasks.

Rubric dimensions would separate scientific correctness, evidential justification, and safe procedure. Task variants would alter materials and surface features while preserving the targeted scientific relationships. Expert review and a separate pilot would examine content coverage, reading burden, accessibility, and scoring reliability; pilot participants would not enter the confirmatory trial. Two masked assessors would independently score a prespecified subset, reconcile training disagreements before final scoring, and report agreement with uncertainty. The total score and weighting would not be redesigned after inspecting treatment differences.

Secondary outcomes would include immediate transfer, concept knowledge, revision quality, completion, adverse symptoms, route switching, and teacher workload. Revision quality would require a coded connection between evidence and a changed scientific explanation; edit counts alone would not qualify. Presence and enjoyment would be brief process measures with instrument versions and permissions established before use. Public artifacts would contain neither identifiable student videos nor eye, face, voice, or fine-grained movement traces. No biometric measure is necessary to test the principal educational claim.

10. Analysis, power, and missing observations

The primary analysis would estimate assignment effects using a model that includes the registered baseline task score and randomisation blocks and accounts for students clustered within classrooms. Where school-level randomisation is required, the model and uncertainty calculation would follow that level instead. The protocol would specify whether inference uses a multilevel model or cluster-robust estimation with an appropriate small-sample correction, chosen before outcomes are revealed. An allocation-consistent randomisation analysis would provide a sensitivity check where the number and arrangement of clusters permit it. Analysis will target equal weight for each baseline-enrolled eligible student, using prespecified individual weights, cluster-size handling, and marginal standardisation. Sensitivity analyses will assess informative cluster size rather than assume that a generic multilevel-model coefficient automatically equals the student-average effect.

Power would be determined through simulation after a separate feasibility study supplies plausible task-score variability, intraclass correlations, cluster sizes, baseline-outcome association, and attrition. Educators and assessment specialists would define the smallest educationally worthwhile improvement in advance, using its implications for competent physical performance and instructional cost. Simulations would vary uncertain design parameters and report the number of clusters required across credible scenarios. The paper supplies no fabricated sample size or power percentage. If recruitment cannot support the registered precision target, the project would remain a feasibility study and its claims would be narrowed.

The primary outcome, contrast, covariates, scoring decisions, and analysis code would be registered before assignment. H1 would constitute the sole primary confirmatory test. Secondary estimates would carry confidence intervals and an explicitly declared multiplicity policy; exploratory subgroup analyses would be labelled accordingly. Mediation through revision quality would remain exploratory because the mediator is not randomised and post-treatment confounding may remain. A model that fits a plausible pathway is insufficient evidence that the sequence operates through that pathway.

Missingness would be tabulated by assignment, cluster, access route, reason, and assessment point. Absence, withdrawal, discomfort, equipment failure, and inability to schedule a physical task would remain distinguishable. The primary missing-data approach would be specified using the feasibility study and might use multilevel multiple imputation under a stated missing-at-random assumption. Complete-case estimates and prespecified departures from that assumption would be sensitivity analyses. Discomfort-related noncompletion would also be reported as an implementation outcome, not imputed away as if it were educationally irrelevant.

The registered estimand would not condition on lesson completion, use of a headset, or later consent to publicity. Per-protocol comparisons and route-specific summaries would be secondary descriptions with their selection limitations stated. A school leaving the study would count as cluster attrition even if replacement recruitment is possible; a new school would not silently replace it in the original randomisation. All deviations, scoring changes, and analytic revisions would have a dated amendment trail.

11. Minors, research governance, and participant protection

Before recruitment, the responsible institution would obtain an appropriate independent ethics determination and resolve jurisdictional requirements, data agreements, device age restrictions, and school permissions. In settings governed by the United States HHS research regulations, Subpart D provides additional protections for children, including applicable requirements for parental permission and child assent. Whether a particular school study is exempt, minimal risk, or subject to other requirements is an institutional determination; this manuscript does not confer an exemption or approval. [R10]

Students would receive age-appropriate explanations and a practical way to decline or stop research participation without academic penalty. A conventional or accessible lesson route would remain available. A student’s refusal would override a wish to obtain a visually impressive demonstration. Staff would check comfort, provide immediate stopping options, maintain a safe physical area, and record adverse experiences using a prespecified escalation plan. The trial would not expose students to hazardous loads, high voltage, or unsupervised workshop machinery.

Identities and research data would be separated under role-based access, with a documented retention schedule and secure deletion process. Public release would prioritise task specifications, code, aggregate findings, and synthetic demonstration records. A de-identification review would precede any release of student-level data, especially where small schools, rare accommodations, or distinctive projects make reidentification plausible. Commercial platforms would not receive student research

records for model training. Photography, public authorship, and public agent demonstrations would require separate, genuinely optional permissions.

12. Decision rules and practical implementation

A district should adopt an evidential decision ladder. First establish feasibility, accessible participation, and reliable scoring. Next test the registered primary outcome with sufficient precision. Only then examine cost and staffing alongside educational benefit. A positive immediate test with no delayed transfer would support a short-term learning claim, not durable competence. A null result with a wide interval would support further uncertainty, not proof of no effect. A sufficiently precise interval excluding the prespecified worthwhile improvement would argue against scaling the present design.

Three findings would directly challenge the proposed framework. More vivid engagement without better delayed physical performance would reject the intervention’s principal educational claim. More revisions without better evidence-based explanations would challenge the revision mechanism. A benefit confined to students already comfortable with the device, accompanied by avoidable participation barriers, would challenge its inclusive policy value. Negative or mixed findings should trigger a revised curriculum or narrower use case rather than a change of outcome after the fact.

Implementation records would include staff preparation, lesson time, equipment maintenance, route support, technical interruptions, and opportunity cost. These quantities would be reported per participating class and student, with amortisation assumptions made explicit rather than hidden in a cost-per-headset figure. Schools would retain a usable lesson if a vendor changes terms or a device fails. Designership infrastructure should preserve the consequence map, versioned lesson, scoring rubric, and amendment history so that another teacher can inspect what actually produced a reported effect.

13. Boundaries, contribution, and research transparency

This protocol tests a specific instructional sequence within a limited scientific domain. It cannot establish that Movement Thinking is a general theory of cognition, that XR reorganises children’s brains, or that digital campuses replace the social functions of schools. Teacher expectations, contamination, variable access routes, imperfect masking, and selective school participation remain important threats. The inclusive policy estimand improves practical relevance while deliberately leaving the independent effect of immersion unresolved. Replication would need new tasks, sites, age groups, and accessibility conditions.

The contribution is a shift in what a school asks technology to prove. A successful environment would make consequential scientific relationships available to diverse

learners, preserve the reasoning behind revision, and support competent action after the environment is removed. Such evidence could justify a place for XR in a coherent STEM curriculum. Its absence would be equally informative. Designership becomes a research programme when attractive experiences are accompanied by credible tests of their limits.

Author and assistance disclosure: Dr. Freedom Cheteni is the intended human author and originator of the Movement Thinking orientation used in this manuscript. AI assistance supported literature discovery, synthesis, protocol drafting, and editorial development; the human author remains responsible for approving the claims, verifying the manuscript, and addressing corrections. No AI system is an author or human peer reviewer. Independent human peer review and ethics approval are not claimed. No trial data, funding award, external institutional affiliation, or registered DOI has been created by this article.

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Source and authorship notes

The seed attachment supplied themes and proposed studies, not a verified bibliography, completed data, or evidence of independent human peer review.

The manuscript is an original argument and prospective design; cited papers remain attributed to their original authors and venues and are not republished here.

Literature discovery and metadata verification conducted 2026-10-16. Eight DOI references verified against Crossref plus publisher/author-institution sources; two official governance/accessibility documents verified directly.

The author-approved Movement Thinking orientation is a proposed framework. This manuscript does not claim it has already been experimentally validated.

No primary dataset has been analysed; no quantitative effect size, achieved power, participant sample, ethics approval, DOI registration, or completed human peer review is claimed.

The proposed trial is not prospectively registered yet. Registration and independent ethics determination must precede recruitment.