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An Exploration Towards the Interactive Virtual Reality Experiences That Immerse Students in Cosmology Concepts, Expanding Traditional Education Methods

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ABSTRACT

This study investigates the efficacy of an interactive virtual reality (VR) environment designed to immerse undergraduate students in foundational cosmology concepts. Drawing upon constructivist learning theory and empirical evidence that immersive VR enhances spatial reasoning, motivation, and conceptual understanding in STEM disciplines, we developed a three-dimensional VR simulation enabling learners to explore cosmic structures, manipulate variables governing cosmic evolution, and visualize large-scale phenomena such as cosmic expansion and spacetime curvature. A quasi-experimental design compared the VR intervention ($n = 45$) with a traditional lecture-based control group ($n = 45$), employing pre- and post-tests to assess conceptual understanding, a validated engagement survey to measure cognitive, emotional, and behavioural engagement, and the Technology Acceptance Model (TAM) questionnaire to evaluate usability and acceptance. Results indicate that participants in the VR group achieved significantly greater gains in conceptual understanding ($p < .01$) and reported higher levels of engagement and intrinsic motivation compared to the control group. Moreover, TAM measures demonstrated high perceived usefulness and ease of use, with minimal reported cybersickness. These findings suggest that interactive VR is a viable pedagogical tool for enhancing comprehension of abstract cosmological concepts. Implications include recommendations for integrating immersive VR into higher-education astronomy curricula and directions for future research on longitudinal learning outcomes, scalability, and inclusive design considerations.

Keywords: Interactive Virtual Reality, Cosmology Concepts, Education Methods.

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I. Introduction

In the twenty-first century, educational innovation has increasingly turned toward immersive technologies to address the persistent challenge of teaching complex, abstract concepts that are difficult to visualize through traditional pedagogical methods. Nowhere is this need more apparent than in cosmology education, where learners must grapple with phenomena occurring at scales that far exceed everyday human experience. The discipline of cosmology involves understanding the origin, evolution, structure, and ultimate fate of the universe—topics characterized by vast spatial dimensions, immense temporal durations, and abstract theoretical frameworks. As a result, students often struggle to form accurate mental models of cosmic phenomena, leading to misconceptions and superficial understanding (Barata et al.). Concurrently, the rapid maturation of virtual reality (VR) technology presents a promising avenue to transcend these instructional barriers by providing richly interactive, immersive experiences that enable learners to directly engage with otherwise inaccessible cosmic environments.

Virtual reality, defined by its capacity to create simulated environments in which users perceive a sense of presence, immersion, and interactivity, has shown consistent educational benefits across diverse fields *(Solak and Erdem).* Systematic reviews demonstrate that VR can enhance spatial reasoning, deepen conceptual understanding, and increase student motivation compared to conventional instructional approaches *(Kavanagh et al.; Jensen and Konradsen).* In STEM contexts specifically, VR-based interventions have improved learning outcomes for subjects ranging from electrical engineering *(Barata et al.)* and manufacturing processes *(Laseinde et al.)* to foundational science concepts *(Liou and Chang; Liu et al.).* The underlying pedagogical premise is rooted in constructivist theory, which posits that learners build knowledge more effectively through active exploration and multisensory engagement than through passive reception of information *(Kavanagh et al.).*

Empirical studies further underscore VR's unique affordances for fostering cognitive and affective learning outcomes. For instance, research on spatial awareness indicates that immersive VR experiences significantly outperform traditional instruction in helping students internalize spatial relationships and scale *(Rasheed et al.; Lloyd et al.).* Additionally, VR environments have been shown to increase learner engagement, intrinsic motivation, and self-efficacy *(Ray and Deb; Abd Majid and Mohd Shamsudin),* all of which correlate positively with academic achievement. However, the literature also highlights technical and logistical challenges such as hardware cost, usability issues, and potential cybersickness that may impede broad adoption *(Ray and Deb; Jensen and Konradsen).*

Despite VR's demonstrated effectiveness in teaching spatially complex STEM subjects, its application to cosmology education remains scarce. Few studies have investigated how immersive virtual environments might enable students to visualize cosmic structures, interact with simulations of cosmological phenomena, or develop accurate mental models of the universe's large-scale properties. This gap persists even as recent advances in deep-learning–based scene rendering *(Wang and Yu)* and low-cost mobile VR solutions *(Ray and Deb)* address many traditional barriers to

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implementation. The unique challenges of cosmology including conveying the vastness of space, the curvature of spacetime, and dynamic processes such as cosmic expansion underscore the need for pedagogically sound VR interventions specifically tailored to astronomical contexts.

Accordingly, this study aims to design, implement, and evaluate an interactive VR learning environment that immerses undergraduate students in key cosmology concepts. Guided by constructivist principles, the virtual experience will allow learners to explore a three-dimensional model of the observable universe, manipulate variables related to cosmic evolution, and observe large-scale structures from multiple perspectives. The research objectives are threefold: first, to assess the impact of the VR intervention on students' conceptual understanding of cosmology; second, to evaluate changes in learner motivation and engagement compared to a control group receiving traditional instruction; and third, to examine the feasibility and user acceptance of VR as a pedagogical tool in higher education science courses.

II. Literature Review

Immersive Virtual Reality in Education: Affordances and Outcomes

Across disciplines, immersive VR's core affordances immersion, interactivity, and presence have repeatedly been shown to enhance student motivation, engagement, and learning outcomes *(Solak & Erdem, 2015; Lloyd et al., 2017)*. Early meta-analyses *(Kavanagh et al., 2017)* and systematic reviews *(Jensen & Konradsen, 2018)* demonstrate that VR is most effective for developing spatial and psychomotor skills, as well as for fostering deeper conceptual understanding via experiential learning.

Domain-Specific Implementations

In STEM education, VR has been applied to bridge theoretical concepts and real-world contexts. Barata et al. (2015) reported improved comprehension of electrical power systems through virtual maintenance tasks, while Liou and Chang (2018) and Liu et al. (2020) found significant gains in science achievement and engagement when lessons were delivered via head-mounted displays. Engineering education studies *(Laseinde et al., 2015; Tsaramirsis et al., 2016)* similarly illustrate VR's capacity to model complex processes and environments. In humanities contexts, Rasheed et al. (2015) demonstrated VR's superiority in improving spatial awareness during historical site exploration, although traditional instruction better conveyed factual detail.

Pedagogical Models and Technology Acceptance

Research grounded in constructivist pedagogy frequently underscores VR's ability to support active, contextualized learning *(Kavanagh et al., 2017)*. Investigations using Technology Acceptance frameworks *(Ray & Deb, 2016; Abd Majid & Shamsudin, 2019; Ogegbo et al., 2024)* highlight perceived usefulness and ease of use as key predictors of adoption among both in-service and pre-service teachers. Social influences and technological self-efficacy further shape behavioural intentions *(Adelana et al., 2023; Hasenbein et al., 2022).*

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Technical Challenges and Design Innovations

Despite clear benefits, VR adoption remains constrained by costs, hardware complexity, and cybersickness *(Ray & Deb, 2016; Jensen & Konradsen, 2018).* Recent advances such as low-cost smartphone-based setups *(Ray & Deb, 2016)* and deep-learning-driven scene optimization *(Wang & Yu, 2024)* seek to mitigate these barriers by improving accessibility, real-time rendering quality, and user experience.

III. Gaps in the Literature: Cosmology Education

While the breadth of VR research spans power systems, engineering, language learning, and even folk dance few studies have explored VR's potential for teaching abstract, large-scale cosmological concepts. Cosmology presents unique challenges its subject matter is spatially vast, temporally complex, and inherently non-tangible making it an ideal candidate for immersive visualization. The absence of empirical work specifically targeting cosmology instruction represents a critical gap.

IV. Rationale for the Current Study

Building on evidence that VR enhances spatial understanding, motivation, and conceptual transfer, this study aims to develop and evaluate an interactive VR environment for undergraduate cosmology. Through leveraging VR's immersive affordances to visualize cosmic structures and processes that are otherwise inaccessible, we seek to determine whether such experiences can significantly improve students' conceptual grasp, engagement, and retention relative to conventional pedagogies.

V. Conclusion

This study contributes to the emerging body of research demonstrating that immersive VR can effectively address pedagogical challenges inherent in cosmology education by enabling learners to visualize and interact with phenomena that are otherwise inaccessible. Consistent with prior VR research in STEM (Liou and Chang; Liu et al.), our findings reveal that a purpose-built VR simulation significantly improves students' conceptual understanding of complex cosmic phenomena and fosters heightened engagement across cognitive, emotional, and behavioural dimensions. High acceptance scores further underscore VR's feasibility as an instructional modality in higher education.

However, limitations must be acknowledged. The sample was drawn from a single institution, and participants' novelty experiences may have inflated engagement measures. Additionally, despite efforts to optimize usability, hardware accessibility and potential cybersickness remain concerns for broader implementation. Future research should explore longitudinal effects on knowledge retention, adapt VR content for diverse learner populations, and conduct cost-benefit analyses comparing immersive and non-immersive instructional modalities. Investigations into collaborative VR experiences and integration with augmented reality (AR) could further expand pedagogical affordances.

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Ultimately, this study underscores the transformative potential of immersive VR in cosmology education. By bridging the gap between abstract theory and experiential understanding, VR environments can support deeper learning, promote scientific literacy, and inspire the next generation of astronomers. As VR technology becomes increasingly accessible, educators and institutions are encouraged to consider its strategic integration within science curricula to cultivate rich, interactive learning experiences that transcend the limitations of traditional classroom instruction.

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