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Learning Analytics for the Metaverse: A Review of Descriptive Analytics and Visualization Tools for Metaverse-Based Learning Environments

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Abstract: The adoption of metaverse technology in education offers new possibilities for experiential, collaborative, and immersive learning, while simultaneously generating complex, multimodal learner data. Interpreting this dense information, spanning spatial navigation, object manipulation, avatar embodiment, and communication patterns poses a significant challenge for both educators and learners. This review synthesizes 19 peer-reviewed studies identified through systematic database searches and snowballing, focusing on the current state of data visualization and descriptive learning analytics in metaverse-based Learning Environments. The analysis reveals that while platforms like Learningverse and tools such as PLUME enable non-interactive or post-hoc data exploration, there is a lack of real-time, pedagogically integrated visualization systems. Current approaches are largely descriptive, fragmented, and disconnected from immediate instructional support or learner reflection. This review highlights critical research gaps, including the absence of runtime interactive tools, underutilization of immersive analytics, and limited alignment with educational theory. Addressing these gaps is essential to transforming rich multimodal data into actionable insights that can enhance teaching and learning within the metaverse.

Keywords: Metaverse-Based Learning Environments, Immersive Learning Analytics, Data Visualization, Immersive Learning Environments, Multimodal Learning Analytics

1. Introduction

The concept of the metaverse, originating from Neal Stephenson’s 1992 novel Snow Crash, has evolved into a composite of modern technological advancements such as the Internet of Things and blockchain. Although recent interest has shifted toward Artificial Intelligence (AI), researchers continue to view AI as a component of metaverse environments. These immersive, persistent, and social virtual spaces have garnered significant attention in educational contexts for their potential to augment traditional learning. Beyond replicating prior approaches to technology-enhanced learning, metaverse environments introduce new affordances such as increased immersion, embodied interaction through avatars, and simulation of complex or inaccessible scenarios (Singh et al., 2024; Song, Cao, Wu, et al., 2023). This review centers on the study of data visualization methods and descriptive learning analytics (LA) as applied to metaverse-based learning environment (MBLE) settings. These environments produce diverse streams of multimodal data, including gaze, spatial orientation, movement, communication, and object interaction, that can inform embodied and collaborative learning (Song, Cao, Wu, et al., 2023; Cruz-Benito et al., 2014; Donalek et al., 2014; Hentschel et al., 2009; Javerliat et al., 2024; Lampropoulos, 2025; Neto et al., 2015; Qian Ma, n.d.; Salloum et al., 2024; Winer & Geri, 2024; Wong et al., 2024; Yano, 2024). However, the volume and complexity of this data introduces challenges for ethical handling, interpretation, and pedagogical use (Song, Cao, Lei, et al., 2023; Song, Cao, Wu, et al., 2023). Understanding the current tools and limitations of descriptive LA and visualization within these settings is essential for advancing effective and responsible educational practice in the metaverse.

This review addresses three guiding questions:

1. How is the metaverse currently conceptualized and implemented within educational contexts?
2. What pedagogical frameworks guide the design and evaluation of learning experiences in the educational metaverse?
3. What tools and techniques are used for applying learning analytics and data visualization to understand and enhance learning in these environments?

2. Methodology

2.1 Literature Search

The initial search employed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Page et al., 2021). Searches were conducted in Scopus, Web of Science (WoS), and PubMed using combinations of keywords such as “metaverse,” “virtual reality,” “learning analytics,” “data visualization,” “immersive analytics,” and “education.” Boolean operators (AND, OR) were used to refine results, and filters were used to focus on titles, abstracts, and keywords. The initial query yielded 183 records (Scopus = 137, WoS = 37, PubMed = 9).

2.2 Screening and Selection

Duplicate removal and exclusion of records lacking DOIs reduced the set to 147 articles. These were screened by title, abstract, and keyword relevance to eliminate clearly irrelevant entries. Fifty-eight full texts were sought; 26 could not be retrieved. Further 24 articles were excluded based on refined criteria such as lack of focus on education, visualization, or immersive environments. This process resulted in 8 core studies.

Recognizing the potential limitations of low number of articles found through database searches in a rapidly emerging field, a snowballing technique was employed on the initially included 8 studies. This resulted in 11 additional papers, bringing the final set to 19 peer-reviewed publications that explicitly addressed the intersection of metaverse-based learning, LA, and visualization.

2.3 Data Extraction and Thematic Analysis

Key data from each study, such as immersive environment, data types collected, analytics and visualization methods, and reported outcomes, were extracted using a structured template. Thematic synthesis was applied manually to identify common patterns, tool usage, design considerations, and research gaps. No common framework was utilized to code the literature itself, nor was specialized coding tool utilized to classify the articles. The main method of analysis was thematic synthesis, carried out manually through review and comparison of the content from all 19 articles to discern prominent themes, shared issues (e.g., absence of runtime tools), and key research gaps.

3. Results and Discussion

3.1 Metaverse for Teaching-Learning and Analytics

This cluster included works focusing on the application of immersive environments for educational purposes, with a strong emphasis on student learning and instructional design. Studies often utilized the Community of Inquiry (CoI) (Garrison et al., 1999) framework to evaluate cognitive, social, and teaching presence within platforms such as Learningverse and MeILE (Singh et al., 2024; Song, Cao, Wu, et al., 2023). The use of multimodal learning analytics (MMLA) was common, leveraging data types such as gaze, movement, communication logs, and object manipulation to understand learner behavior and collaborative dynamics.

3.2 Data Visualization and Immersive Context

Studies in this cluster focused on the technological affordances of immersive environments for representing learner data. Tools like PLUME (Javerliat et al., 2024) and Mozilla Hubs (Yano, 2024) visualization platforms enabled post-hoc analysis through heatmaps, 3D trajectory visualizations, and gaze path overlays. However, these implementations were primarily retrospective, with few studies incorporating visualization during runtime or integrating it into the instructional process (Song, Cao, Lei, et al., 2023).

3.3 Key Findings

Potential of metaverse environments for generating diverse and granular multimodal data is widely recognized across the literature. Post-hoc analysis tools like PLUME are capable for analyzing the data with great control but are researcher oriented. These tools often lack suitability for instructors or learners for getting insights from the data on the field. There is a trend towards developing specific educational metaverse platforms (e.g., Learningverse) or adapting existing ones (e.g., Spatial.io for MeILE, Mozilla Hubs) with built-in considerations for data logging and sometimes basic visualization, aiming for more integrated ecosystems. From low-level interaction logging in Second Life to multi-view visualizations of simulated data in CAVE (Neto et al., 2015) systems and heatmap generation in Mozilla Hubs, there are many proof-of-concepts from the literature that show that the underlying technological building blocks are feasible. The intersection of metaverse & descriptive LA or educational data visualization remains largely in its discovery phase. Much of the literature includes system descriptions, framework suggestions, or pilot work with small numbers and brief intervals. Although there are tools for post-hoc visualization or runtime display of descriptive plots, there is a significant lack of tools that enable instructors or learners to interactively navigate, filter, manipulate, or query visualized data during an active learning session in the metaverse.

4. Implications

The literature reviewed always emphasizes the ability of metaverse environments to produce unprecedented levels of multimodal, diverse learner data (MMLA) including spatial locomotion, interaction flows, gaze patterns, communication records, and physiological signals. And yet this very richness produces a large interpretation bottleneck. Bridging this gap between data capture and actionable insights is arguably the most pressing need for the field to move forward. One of the unique affordances of the metaverse is the ability to analyze and visualize data within the immersive 3D environment itself, a concept known as immersive analytics**.** However, the synthesis reveals that this potential is largely untapped in current runtime educational tools. Most studies featured short-term or small-scale deployments, and the application of more advanced educational data mining (EDM) techniques were rare.

5. Conclusion

The intersection of descriptive learning analytics and data visualization in metaverse-based learning is still emerging. This review highlights that the educational metaverse is seen as an evolution toward persistent, social, interactive 3D virtual spaces designed for learning, rather than just VR or XR applications. Current methods emphasize capturing multimodal data, including spatial tracking and interaction logs, using tools like PLUME for Unity. Analysis techniques primarily involve descriptive learning analytics and post-hoc analysis, with visualization methods using heatmaps, 3D trajectories, and basic dashboards. This review identifies the development of interactive immersive visualization dashboards for educational settings as a promising direction for future research, addressing the need for immersive analytics and interactivity in navigating complex multimodal learning analytics.

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