virtual worlds

Article

Interaction Design Strategies for Socio-Spatial Embodiment in Virtual World Learning

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Abstract

Desktop Virtual Worlds (DVWs) offer unique spatial affordances for education, yet understanding of how these environments support meaningful learning experiences remains limited. This study introduces the Socio-Spatial Embodiment Model, a novel framework conceptualizing learning in DVWs as shaped by the interconnection of embodied presence, place-making, and community formation. Through semi-structured interviews conducted with 14 experienced educators from the Virtual Worlds Education Consortium, we investigated how these dimensions intersect and what design strategies facilitate this integration. Thematic analysis revealed that strategic design employs cognitive offloading techniques and biophilic metaphors to enhance embodied presence, balance familiar elements with spatial innovations to create meaningful places, and leverage synchronous engagement with institutional identity markers to facilitate learning communities. Our findings identified design strategies that facilitate stronger perceived student connections to the learning environment and community, when DVW designs address spatial, emotional, social, and cultural factors while reinforcing both cognitive and perceptual processes. This research advances understanding of embodied learning in virtual environments by identifying the dynamic interdependence among presence, place, and community, providing practical strategies for educators in creating more meaningful virtual learning experiences.

Keywords: socio-spatial embodiment model; desktop virtual worlds; embodied presence; sense of place; sense of community; learning communities; interaction design; human-computer interaction; affordances; educational technology; virtual learning environments

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1. Introduction

Desktop Virtual Worlds (DVWs) offer unique spatial affordances for educational experiences that cannot be readily replicated on other online platforms. These spatial qualities enable diverse and multimodal interactions, supporting multiple learning methodologies including experiential, exploratory, and active learning approaches [1,2]. These platforms are distinguished by two fundamental characteristics: a sense of presence and a sense of place. The sense of presence refers to the psychological state where a person experiences a virtual environment as if they were genuinely situated within it, perceiving stimuli, objects, entities, and interactions as sharing the same reality as themselves, despite knowing they exist in a mediated experience [3]. A sense of place refers to the transformation of virtual spaces into meaningful places through human interaction and experiences. It develops when users form emotional attachments, cultural associations, and shared memories within these digital environments, giving them significance [4].

In addition to these qualities, our engagement with educators in the Second Life (SL) Virtual World Education Consortium (VWEC) community underscored the significance of a sense of community in sustained engagement with DVWs. A sense of community is defined as feelings of belonging, identity, connection, and attachment among participants in online environments [5]. Despite the usability challenges of SL and its continued steep learning curve [6], educators persist in using it primarily because of the unique communities they have built or joined within these places over time. This observation suggested that while presence and place are fundamental characteristics of DVWs, social presence and community formation play a crucial role in creating meaningful and enduring learning experiences.

The persistence of educational communities in platforms like SL, despite newer technological alternatives, demonstrates that the sense of community in spatial virtual environments offers additional educational advantages. Consequently, we identified community as a crucial third dimension that operates synergistically with presence and place within our research framework. To establish the scope of our investigation into these three dimensions, we focused on DVWs rather than immersive virtual reality (VR) environments because DVWs represent the most available and widely adopted form of virtual world education. DVWs provide crucial advantages for educational contexts including operation on standard computing equipment that students already have access to and are familiar with, extended learning sessions without physical discomfort, convenient integration with other digital learning tools, and superior support for sustained engagement and community building. While immersive VR may offer advantages for applications requiring high-fidelity spatial manipulation or embodied skill training, most educational contexts benefit more from DVWs' practical affordances. This aligns with empirical evidence from Marks and Thomas [7], who found that despite 71.5% of students reporting VR enhanced learning outcomes, 36.3% experienced physical discomfort, highlighting barriers to sustained educational use.

While the significance of these dimensions in DVWs has been acknowledged in educational research [3,8–10], limited research examines their intersection. Previous research has extensively examined these dimensions in pairs—exploring presence-place relationships through spatial cognition theories [11–13], place-community connections through social learning frameworks [14], or presence-community interactions through social presence models [15]—but few have examined how they interact synergistically to create conditions for meaningful learning experiences. Understanding how these dimensions dynamically influence each other within learning environments will provide crucial insights for understanding students' embodied experiences, their relationship to the virtual environment, and their connections with others in DVWs. These embodied experiences are grounded in embodied cognition theory, which suggests that cognitive processes arise from sensorimotor interactions with the environment rather than occurring as isolated mental activity [16].

These observations led us to develop the Socio-Spatial Embodiment (SSE) Model, a novel framework conceptualizing learning in DVWs as shaped by the interconnection of these three key dimensions. While the existing dual-concept models have primarily focused on linear relationships between dimensions, our SSE Model identifies how the simultaneous interplay of these dimensions creates qualitatively different learning experiences than any pair of dimensions alone could produce. This integration enables us to identify design strategies that leverage the synergistic relationships among embodied presence, place-making, and community formation, addressing the critical gap at their intersection.

To explore this integrated framework and understand these synergistic relationships, this study addresses two primary questions:

1. How do presence, place, and community intersect in desktop virtual world learning environments?
2. What design strategies do experienced educators use to facilitate this intersection to enhance students' learning experiences in these environments?

To investigate these questions, we conducted in-depth interviews with educators from the VWEC community who had substantial experience teaching in DVWs. Our thematic analysis identified patterns in how educators created learning environments that integrate presence, place, and community to enhance student learning. Our findings are organized into three main sections as follows: 'Experiencing Presence Through Environmental Design,' which examines cognitive engagement through offloading and interpolation, and embodied presence through biophilic metaphorical design; 'Meaningful Learning Places in the Intersection of Embodied Presence and Community,' which explores balancing familiarity with innovation and embedding knowledge through spatial scaffolding; and 'Cultivating Community Through Shared Presence in Meaningful Places,' which investigates varied social environments for inclusive interaction, temporal dimensions, and the role of identity in community formation.

Our research advances the understanding of how embodied presence, place-making, and community formation function as interconnected dimensions in DVWs. Our integrated theoretical framework explores their dynamic interdependence and practical applications. By identifying interaction design solutions that leverage this three-dimensional interplay, we provide strategies for educators and designers seeking to create more meaningful and engaging virtual learning environments. In the following sections, we first review relevant literature on these interrelated dimensions in virtual learning environments, then present our SSE Model and research methodology, followed by our findings, and conclude with theoretical and practical implications, limitations, and directions for future research.

2. Background

In this section, we review the literature on interaction design concepts in DVW learning environments, focusing on the interrelated dimensions of presence, place, and community. We examine research on space-to-place transformation, embodied presence, and evolving social dynamics, as well as how these dimensions interact within DVWs to create learning contexts. Drawing from environmental psychology, human-computer interaction, and educational research, we examine the theoretical frameworks that inform our SSE Model and guide DVW interaction design for educational purposes.

2.1. The Transformation from Virtual Space to Meaningful Place

Human-computer interaction (HCI) design fundamentally aims to make interactions more intuitive, efficient, and pleasant by adapting technology to human needs rather than forcing humans to adapt to technology [17]. Designers typically employ real-world metaphors to make technology comprehensible to users [18]. Rai et al. [19] reference Aristotle's definition of metaphor as "*Metaphorá*", the transfer of a name and its associated attributes from one domain (source) to another (target). This metaphorical approach is central to DVW interaction design, which relies heavily on real-world metaphors, from virtual gravity to human attributes of avatars [20]. These metaphors provide interactive spatial experiences that create immersion that goes beyond static viewing [21].

The concept of place extends beyond simple space [22]. Place development involves a complex combination of factors including physical attributes, experiential dimensions (such as presence and sense of self), and identity-related aspects (including gender, sexuality, ethnicity, and other cultural and psychological elements) [23]. Places exist as dynamic constructs that are simultaneously envisioned, comprehended, narrated, perceived, and felt [24]. The conceptualization of sense of place has evolved from individual to social phenomena. Building on Tuan's [25] foundational work on space-to-place transformation, Jaalama et al. [26] demonstrated how environmental design influences behavior through collective meaning-making processes. Nordback et al. [27] further developed this social understanding, showing that place attachment develops through shared cultural experiences rather than individual perception alone. This social construction of place becomes particularly relevant in DVWs, where virtual experiences can feel isolating in the absence of meaningful social interactions.

In online learning environments, establishing a sense of place presents challenges yet remains essential for educational experiences [28]. These environments influence where, how, and what students learn, similar to how designers create physical spaces for multiple uses [29]. In such places, education shifts from information transfer toward designing students' experiences and contexts for learning activities, creating a trend toward enriched learning experiences using active, exploratory, and experiential methodologies rather than passive knowledge acquisition approaches [30]. Architectural design metaphors play a crucial role in this transformation, providing familiar spatial frameworks that help users navigate and understand virtual environments, thereby facilitating the place-making process essential for virtual learning.

2.2. *Metaphors of Architectural Elements and Principles in Virtual Worlds*

Technological advancements enable designers to create virtual environments as symbolic, schematic, or multi-sensory representations of physical phenomena [31]. These DVW representations act as metaphors in students' mental models, facilitating intuitive understanding of complex spatial relationships in DVWs. DVWs transform abstract information into experiential knowledge through strong memory encoding. This transformation process aligns with how individuals naturally make sense of new environments by asking: "What is it? What does it mean? What can I do?" [32]. The alignment between human perception, the purpose of virtual places, and the feeling of presence connects these cognitive questions to architectural design principles.

Architectural elements and principles serve dual roles, functioning as both means and metaphors for understanding virtual learning environments [32]. These metaphors provide recognizable foundations for developing experiences within unfamiliar DVWs [33]. The organization of virtual space follows principles similar to physical architecture and environment design. As Tuan [25] explains, undifferentiated space transforms into meaningful places as we contribute value to it—if space facilitates movement, place is a pause. This principle explains why carefully designed architectural elements in DVWs create meaningful places that support learning through intuitive navigation, emotional connection, and collaboration.

For strategic implementation, Harrison [34] notes that collaborative environments benefit from thoughtful spatial organization. Any environment requires meaningful organization relevant to users [35], with Charitos [36] suggesting predetermined organization rules to establish spatial structures in DVWs, which lack inherent support for dynamic spatial rearrangement. These spatial organization principles directly influence how users experience presence within virtual environments, creating a foundation for social interaction and community development [37]. This connection between spatial design and community formation demonstrates the interconnected nature of presence, place, and community in perceived engaging and immersive virtual learning environments. Understanding how these architectural foundations cultivate community requires examining the psychological processes of presence, the subjective experience that bridges designed environments and social connection.

2.3. Presence, Social Presence and Community Formation

The transformation of virtual spaces into significant learning environments links intrinsically to presence. Turner and colleagues [38] establish this crucial connection, arguing that sense of place and sense of presence are fundamentally intertwined. Presence arises as a state of consciousness in which individuals attribute sensations to stimuli in their surrounding environment [39]. In DVWs, presence combines users' objective responses to the environment and their subjective perceptions of being within that space [40]. Lee [41] describes this experience—a concept originally coined by Minsky [42], how human operators might feel virtually transferred to distant work locations.

According to Hameed and Perkis [43], presence in DVWs is influenced by five key dimensions: 'Immersivity', the subjective feeling of being transported into the virtual environment; 'Interactivity', user ability to influence and control the virtual environment; 'Explorability', freedom to navigate and discover within the virtual space; 'Plausibility', believability and coherence of the virtual world and events; and 'Authenticity', sense of genuineness that supports the overall illusion. Their framework expands on earlier models by integrating both technological affordances and psychological factors that collectively shape the presence experience. These dimensions help facilitate what Lombard and Ditton [44] describe as different forms of transference: "You are there" (users feel transported to another location), "It is here" (objects are brought to the user), and "We are together" (individuals share a sense of being transported to a common destination).

The concept of 'we are together' conveys co-presence [45], which differs from social presence. The distinction between co-presence and social presence reflects different levels of social connection rather than fundamentally different phenomena. Biocca et al. [46] conceptualize co-presence as awareness of others' virtual presence, while Bulu [47] positions social presence as requiring deeper interpersonal connection and emotional intimacy. In virtual learning environments, these concepts exist on a continuum where co-presence provides the foundation for social presence [48]. This progression from spatial awareness to social connection becomes particularly important in DVWs, where sustained student engagement within shared virtual spaces facilitates the interpersonal bonds beneficial for collaborative learning [49].

Students' social presence and group collaboration catalyze learning community formation by developing a "sense of community"—perceptions of belonging, interdependence, and mutual commitment in groups [50]. This community development is further enhanced when virtual interactions facilitate empathy and perspective-taking. Nguyen-Thi et al. [51] demonstrated that interactions with NPCs simulating diverse user personas and providing feedback enhanced students' empathy development, showing a 13.4% improvement in empathy scores compared to control groups, improving students' ability to understand and relate to different user perspectives and needs. Such empathy development strengthens the basis for substantive peer connections.

Through the sense of community and shared purpose, students feel connected, accepted, and valued, increasing their willingness to collaborate meaningfully with peers and participate more actively in learning activities, achieving improved academic outcomes and emotional well-being [52–54]. Quantitative evidence confirms these relationships, with Liman Kaban [55] finding in a study of 48 participants that high cognitive presence and social presence scores were associated with successful learning community formation and student satisfaction scores of 4.86 on a 5-point scale, demonstrating how cognitive and social presence work together to enable effective learning communities. This social dimension transforms DVWs from information delivery systems into dynamic learning ecosystems where knowledge is co-constructed through students' interactions [56].

Empirical evidence supports these interconnections, with Guo et al. [57] indicating that social presence components, particularly affective components, predicted 34% of variance in academic performance in online project-based learning. The study further revealed that cognitive presence exploration levels were equally predictive of performance outcomes, confirming the interdependent relationship between social and cognitive dimensions in virtual learning environments. Recent validation research reinforces these findings, with Alsayer and Lowenthal [58] surveying 413 online learners and finding affective expression, open communication, and group cohesion collectively explained 72% of social presence variance, while Eden et al. [59] identified real-time communication and group projects as essential for building supportive virtual communities. These collaborative knowledge-building processes depend significantly on how virtual environments are designed to support them, particularly through their interaction design affordances and signifiers. In the following sections, we examine these design elements and their impact on learning experiences.

2.4. Interaction Design in Virtual Learning Environments

DVW interaction design prioritizes creating experiences that facilitate embodied presence, socialization, and collaboration [60]. Building on this foundation, this section analyzes the key interaction concepts that shape student experiences in DVWs, contextualizing them within established modalities and classifications of interaction design.

Interaction modalities in DVWs primarily incorporate the WIMP (Windows, Icons, Menus, Pointer) interactions, using the display screen as the primary output source, often supplemented by audio and video streaming [61]. DVWs also offer multimodal interactions to support a wider range of student activities through affordances and signifiers [62]. These interaction modalities enable rich, multi-sensory engagement that supports diverse learning styles and pedagogical approaches.

In terms of classification, student interactions within DVWs fall into three main classifications: interactions with the world, with virtual objects, and with avatars [63]. Each of these classifications can include various interaction types as identified by Rogers [21]: conversing, instructing, manipulating, exploring, and responding. For example, when interacting with avatars, students might engage in conversing and instructing interaction types, while interactions with the DVW environments primarily involve instructing, manipulating, and exploring actions. In DVWs, instructing interactions predominate, with students instructing the system by typing, clicking, or pointing to interactive elements. To design these various interaction types successfully, understanding the foundational concepts of affordances and signifiers is essential, as they provide the theoretical framework for how students perceive and engage with virtual learning environments.

2.4.1. Affordances and Signifiers in the Interaction Design

The concept of affordances is central to understanding interaction design of virtual learning environments. Gibson [64] first coined the term in ecological psychology, defining affordances as what an environment offers to an animal, either beneficial or detrimental. This relationship implies a complementarity between environment and user. In educational psychology, Salomon [65] relates affordances to the perceived and actual properties of an object, particularly those functional aspects that determine how the object may be used. In HCI, Norman [66] defines affordances as the relationship between an object and a user; the perceived relationship between object properties and user capabilities that determines how the object can be used. Affordances are not properties, but relationships determined by the properties of both object and agent.

Affordances are provided through various cues, known as signifiers [67], which serve as perceivable indicators communicating suitable interaction behavior to users. Norman [68] categorizes signifiers into two types: deliberate signifiers made and used on purpose, and incidental signifiers that are unintentional byproducts of actions, occurrences, and events. Generally, affordances determine possible actions while signifiers communicate where actions should take place [66]. Both play crucial roles in helping users understand what actions are possible within virtual environments. In DVWs, affordances and signifiers create a bridge between physical and virtual, helping students transfer their real-world knowledge to virtual environments [69]. These theoretical foundations inform the practical implementation of interactive affordances in DVWs that shape students' learning experiences.

2.4.2. Interactive Affordances in Desktop Virtual Worlds

Building upon the affordances and signifiers framework, we explore how these concepts are applied in the interaction design of virtual learning environments. The interactive affordances in DVWs include a range of engagement possibilities, from environmental navigation to object manipulation and social interaction, creating integrated experiences that support learning through both spatial exploration and interpersonal communication.

Navigation represents one of the primary interactive affordances in virtual learning environments. In DVWs, navigation occurs through virtual spaces using avatars or through direct interactions with the environment [70]. These navigation methods include walking, running, flying, and other movements that mirror physical world mobility [71]. The standard navigation technique uses pointing devices and keyboards, with WASD or arrow keys providing essential motion control in first-person experiences [61]. These controls simulate real-world walking, with visual and audio cues such as footsteps functioning as signifiers for movement [72].

Students' perspectives can shift between first-person and third-person views, offering different relationships to the environment. First-person views are common in simulation activities, while third-person viewpoints enable students to perceive their digital representation in relation to surroundings and others [21]. This flexibility allows for various embodied experiences tailored to learning objectives. Most 3D DVWs permit switching between these perspectives, giving students opportunities to explore different perceptual angles.

Teleportation offers another significant navigation affordance in DVWs [33]. This feature allows students to instantly change locations, eliminating the need to navigate avatars through intermediate spaces. Teleportation transforms spatial experience, enabling non-linear exploration impossible in physical environments and saving time during learning activities.

Landmarks serve as crucial navigational aids by establishing reference points in virtual space [73]. They are distinguished by distinctive physical qualities—size, scale, spatial prominence, color, and contrast. When navigating, students typically identify the most prominent landmarks from their perspective [74]. Meaningful landmarks are recognizable, contrast with surroundings, remain visible from various locations, and often serve symbolic educational purposes. Signs complement landmarks by conveying environmental information necessary for navigational decisions, reducing cognitive load so students can focus on learning rather than wayfinding [75].

Beyond navigation, virtual objects offer another important category of interaction affordances, functioning as both content delivery mechanisms and creative tools. Interaction with objects includes engaging with both unmodifiable and modifiable elements. Unmodifiable objects often contain embedded course information or content, allowing instructors to integrate handbooks, presentations, or instructional materials into the learning environments [76]. Modifiable objects include students' presentations or posters that can be displayed in virtual classrooms or exhibitions and adjusted as needed [77].

Many DVWs provide content creation affordances. These platforms offer libraries of preset geometric objects that can be combined, manipulated, and customized to build desired environments and models [78]. Advanced affordances include lighting settings, texture application, sound integration, and interactive programming. These creation affordances facilitate building learning communities through students' shared creative work. As Dickey [70] emphasizes, collaborative participation in creating virtual learning environments strengthens social bonds within classes. This collaborative design process strengthens students' capacity to externalize knowledge, develop ownership, and engage actively with peers, enhancing problem-solving skills and deepening conceptual understanding [79].

Avatar-based interaction represents the third major category of affordances in DVWs. Avatars function as students' digital embodiments, enabling self-expression, identity exploration, and social presence. Avatar customization affordances (gender, pronouns, appearance, attire) enable students to gain agency and express identity [80]. Many environments also provide affordances for expressing emotions or thoughts, such as raising hands or clapping [81]. In addition to interacting with their own avatars, students can also interact with other human-controlled avatars, including those of peers and instructors such as following or adding them to their friends list [82]. With advances in artificial intelligence, interaction with AI-controlled avatars is becoming more common within virtual environments [83], exemplified by AI teaching assistants that guide and support students with course materials [84].

Other significant affordances of DVWs are related to communication. Communication affordances form the foundation of social learning in virtual environments, enabling students to share ideas, collaborate on projects, and build communities [85]. Providing learners with the means to interact with one another and with instructors represents a crucial aspect of learning environments. These communication affordances support collaborative learning, teamwork, and socialization through peer exchange [86]. DVWs offer enhanced computer-supported collaborative environments where embodied social presence makes remote interactions more similar to in-person engagement [87]. To facilitate this presence, DVWs implement various design elements promoting collaboration, such as group-specific avatar outfits or designated team spaces [88].

Communication in collaborative spaces operates through multiple channels. This occurs through public or private chat affordances [89], typically using text chat boxes. Communication modalities may include spatial audio and video communications [90], with proximity-based chat activated when avatars are within certain distances [91]. Visual signifiers like chat bubbles above avatars' heads indicate ongoing conversations.

Beyond basic communication, virtual environments provide collaborative affordances enabling joint creation and knowledge building: affordances such as building, screen sharing, and writing on whiteboards [92]. Collaborative creation includes creating 3D objects, displaying presentation posters, and exhibiting digital artwork [93]. Teams can archive conversation transcripts to document communications, or provide records for absent members. These collaborative affordances demonstrate how virtual environments support distributed cognition across individuals, artifacts, and spatial contexts. This distribution of cognitive processes through avatar-mediated interactions exemplifies the embodied nature of learning in DVWs, requiring a deeper examination of how embodied cognition theory applies to virtual learning environments.

2.5. Embodied Cognition and Learning in Virtual Worlds

Embodied cognition theory connects mental processes to physical experiences and environmental interactions, recognizing how thinking is shaped by bodily engagement with surroundings rather than occurring as isolated mental activity. In this research, we adopt

Wilson's [16] conceptualization of embodied cognition, specifically her view that "offline cognition is body-based"—where thinking remains grounded in sensorimotor experiences even when decoupled from immediate physical stimuli. In DVWs, this principle operates through metaphorical transfer: students draw upon their embodied schemas and sensorimotor representations from physical world experiences to make sense of avatar-mediated interactions [94,95]. When students control avatars that walk, fly, or manipulate objects, they activate these internalized sensorimotor patterns, creating cognitive bridges between physical and virtual experiences.

We define embodied presence as the psychological state where these metaphorical connections become activated—where students don't merely observe the virtual environment but experience it through their avatar as an extension of their sensorimotor system. This differs from general presence by specifically emphasizing how real-world bodily schemas inform and shape DVW interactions. For instance, when students navigate a virtual classroom, their embodied understanding of classroom spaces (the proprioceptive sense of sitting, the spatial relationships between desks, or the motor patterns of raising a hand) provides the cognitive framework for understanding and engaging with the virtual space.

For virtual environments, this perspective highlights how learning develops through the interplay between mind, virtual body, and virtual space [96]. In these environments, avatar representation and camera perspectives are key affordances for embodied cognition. Avatars function as users' virtual embodiments [97], while immersive environments provide affordances for virtual movements that create first-person experiences that enable embodiment [60]. Avatar customization, movement, and interactivity provide behavioral signifiers that offer psychological benefits such as agency and control [98,99]. Increased agency enhances students' sense of presence and positive emotional responses, driving learning engagement [100]. Research during the pandemic reinforces these engagement outcomes, with Alnagrat et al. [101] finding VR learners demonstrated 40% higher confidence and four times less distraction than e-learning, while Vázquez et al. [102] reported 80% of students believed virtual environments enhanced mathematics learning. These benefits create emotional and cognitive reinforcements.

Considering HCI principles, these embodied cognition experiences integrate perceptual processes through environmental and interface interactions [103]. This integration relies on the human cognitive apparatus that naturally employs object-oriented perception; people automatically distinguish contour-limited entities from the general environmental background. Kruzhilov [104] explains that the concept of object corresponds to the limited entities, while space corresponds to the general background. We divide the world into entities at human scale to facilitate manipulation in daily life [96], which in DVWs translates to avatars' sizes and proportions.

These perceptual processes become important when considering the social dimensions of virtual learning. Building on situated learning theory, which emphasizes context and social interaction in knowledge construction [105,106], our approach extends this by examining how avatar-mediated spatial experiences, social presence, and place-making intersect to create learning opportunities in DVWs. When DVW interaction design reinforces both cognition and perception through avatar-mediated actions while accounting for spatial, emotional, social, and cultural factors, students develop stronger connections to the learning environment and its community. This triadic relationship of presence, place, and community functions as interconnected dimensions rather than separate elements in our proposed framework. Drawing from this theoretical foundation, the following section introduces our SSE Model that addresses the identified knowledge gap at the intersection of these dimensions.

3. The Socio-Spatial Embodiment Model

The SSE Model conceptualizes learning in DVWs as shaped by the dynamic interconnection of three key dimensions: embodied presence, place-making, and community formation. The model addresses how these dimensions function as an integrated system rather than as independent elements, revealing design strategies that leverage their synergistic relationships. Building on the embodied cognition framework discussed in Section 2.5, the model adapts these concepts to desktop virtual environments where embodiment occurs through avatar proxies. Following Ottmar et al. [107], we ground conceptual learning in embodied spatial interactions. However, our framework extends beyond individual avatar control to examine how embodiment intersects with place-making and community formation, creating socially and spatially mediated learning.

3.1. Model Development and Evolution

The SSE Model evolved from traditional dual-dimension frameworks through our analysis of educator practices. While our interview protocol initially explored each dimension individually, analysis revealed that educators' most impactful strategies simultaneously addressed all three dimensions. This finding challenged linear approaches and led to our integrated framework positioning the intersection of all three dimensions as the foundational design space. Our analysis also refined how we conceptualize presence. General presence concepts proved insufficient for avatar-based interactions in DVWs, leading us to adopt embodied presence—how students experience virtual environments through avatars as extensions of their cognitive and perceptual systems rather than merely feeling present in space.

3.2. Framework Structure

Unlike frameworks examining these dimensions in isolation or pairs, our model emphasizes their interdependence. Embodied presence through avatar affordances establishes a foundation for spatial and social engagement; learning places develop through architectural design metaphors that support purposeful space design while enabling social connections; learning communities develop through shared presence experiences in these meaningful places.

The diagram in Figure 1 illustrates this triadic relationship. The intersection of three overlapping circles forms the integrated design space where students experience embodied presence within meaningful places while engaged in community interactions. This triadic relationship operates through three essential properties:

- Unified Triadic Relationship: Presence, place, and community operate as an integrated whole where each element continuously shapes and is shaped by the others.
- Dynamic Interdependence: The three dimensions exist in mutually reinforcing relationships creating a dynamic system rather than linear progression.
- Emergent Learning Experience: At the convergence point, transformative educational results emerge that cannot be reduced to individual components or pairs.

For practitioners, this model offers an actionable framework: rather than focusing on dimensions individually, designers should seek solutions reinforcing all three simultaneously. For example, when designing a virtual classroom, considering how the seating arrangement (place) facilitates avatar navigation (embodied presence) and group interaction (community). This integrated approach moves beyond feature checklists toward holistic environment design, supporting students' relationships with their avatar representations, spatial context, and learning community. In the following section, we present our methodology for investigating how students experience virtual learning environments through this integrated framework.

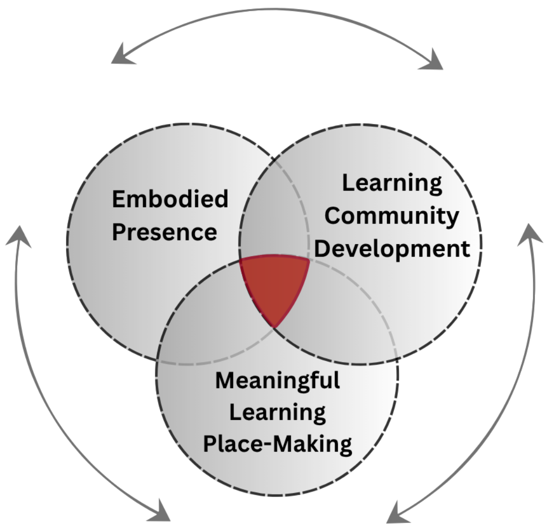


Figure 1. The Socio-Spatial Embodiment Model for learning environments in Desktop Virtual Worlds. The three overlapping circles represent embodied presence, place-making, and community formation, with their central intersection indicating the integrated design space where meaningful learning experiences emerge. Bidirectional arrows represent the mutually reinforcing relationships among all dimensions.

4. Methods

This section details our approach to investigating the interplay of presence, place, and community in DVW learning environments through the experiences of educators who designed or facilitated learning in these spaces. We conducted a qualitative study using semi-structured interviews to capture contextual insights from experienced DVW educators.

4.1. Participants

We interviewed 14 educators from the VWEC community in SL, selecting participants with substantial DVW experience. We deliberately focused on experienced rather than novice instructors, as those new to DVW environments typically replicate physical classroom designs with conventional objects. Given this common approach among less experienced practitioners, we sought to understand what seasoned educators—who have progressed beyond direct replication—consider essential for successful virtual learning environments.

The demographic profile included eight active full-time professors and six retired faculty members, primarily from four-year public institutions, representing diverse academic disciplines, with particular concentrations in sciences, education, and arts. The majority (9) were aged 55 or older, corresponding with extensive DVW experience—seven participants had over 15 years of experience. SL was identified as the dominant platform (used by 13 participants), followed by OpenSimulator (6 participants) with some educators also using newer platforms like Spatial. Most participants (8) developed their expertise through practical experience rather than formal training. Some educators taught synchronous courses in DVWs while others delivered asynchronous instruction, with teaching contexts spanning multiple educational levels, the highest concentration being in undergraduate education. For additional information on the participants' demographics, refer to Figures A1–A3 in Appendix A.

4.2. Data Collection

Our data collection strategy employed an interview protocol specifically designed to elicit detailed insights into educators' experiences designing or facilitating learning in

DVWs. Through carefully structured yet flexible conversations, we gathered rich descriptions of what they perceived as successful design approaches, challenges, and observations about student engagement across the dimensions of presence, place, and community.

4.2.1. Interview Protocol Development

We developed a comprehensive interview protocol based on our model for classifying interaction design in DVW learning. The initial protocol underwent rigorous development and refinement through multiple stages. First, questions were drafted based on our literature review and theoretical framework. The protocol was then pilot-tested with two experienced educators through expert cognitive walkthroughs to assess question clarity, relevance, and comprehensibility. During these pilot sessions, we evaluated whether questions properly captured insights related to our research questions and identified areas needing clarification or restructuring. Based on the feedback from pilot testers, several questions were refined for improved clarity and relevance before conducting the actual study. This iterative refinement process ensured our protocol would properly capture educators' experiences across all three dimensions of our framework. The final protocol consisted of 37 open-ended questions organized around five thematic categories:

- Teaching Context: Exploring educators' pedagogical philosophies and objectives
- Platform Comparison: Examining advantages and limitations of DVWs versus video conferencing
- Interface Utilization: Understanding how educators leveraged DVW user interface elements and functionalities
- Design Adaptations: Investigating how real-world elements and metaphors were utilized in virtual spaces
- Experiential Dimensions: Analyzing how platforms supported presence, place, and community

For complete interview questions, refer to Appendix B. This paper does not include analysis of the data collected from the platform comparison category of the interviews. This structured progression allowed educators to build upon their reflections as they moved from general teaching approaches to specific platform features, while maintaining flexibility for identified themes and unexpected insights.

4.2.2. Interview Process

Participants first completed an online Qualtrics survey to provide informed consent and demographic information, including data about their most-used avatars. Semi-structured interviews were conducted via Zoom, lasting approximately 60–180 min across one to three sessions per participant. Interviews were audio-recorded and initially transcribed using Zoom's automated captioning system.

4.3. Data Analysis

Following Braun and Clarke's [108] reflexive thematic analysis methodology, we conducted analysis to identify patterns across the dataset. Our analytical approach was primarily deductive, guided by our SSE Model to examine the dynamic interplay among three dimensions. However, we remained open to inductive insights that arose from the data.

4.3.1. Analytical Scope and Focus

While the initial analysis identified diverse themes about DVW education, our final thematic structure deliberately focused on findings that illuminate the SSE Model. Themes that fell outside this intersection—such as technical platform comparisons or general online teaching strategies—were noted but not included in the final analysis, allowing us to contribute novel insights about how presence, place, and community interact in DVW learning environments. This focused approach aligned with our research questions and theoretical framework while maintaining analytical depth.

4.3.2. Analytical Framework

We adopted an experiential orientation, prioritizing participants' lived experiences and meaning-making in DVWs. Our analysis was grounded in a critical realist perspective, acknowledging that while participants' experiences were valid and significant, they were also shaped by the technological affordances and constraints of DVWs. The analysis focused primarily on latent themes, interpreting underlying meanings and assumptions rather than remaining at the semantic level.

4.3.3. Data Preparation

Recognizing the limitations of Zoom's automated transcription, the first author manually reviewed each transcript against original recordings to correct errors, preserve nuances, and remove identifying information. This intensive preparation ensured data accuracy and facilitated deep familiarization with participants' narratives.

4.3.4. Coding Process

The first author conducted all coding using ATLAS.ti (version 25.0.1) for code management. The decision to use a single coder was made to maintain interpretive consistency given the experiential nature of the research questions, which required deep contextual understanding of participants' DVW experiences. Initial coding involved a systematic review of all cleaned transcripts, generating both concept-driven codes based on our theoretical framework and data-driven codes identified from participants' experiences. The coding process was iterative and evolved over nine months, with multiple rounds of refinement as patterns were identified and theoretical connections became clearer. Early iterations focused on broad categorization, while later iterations increasingly centered on the intersection of presence, place, and community. A total of 9218 codes were generated across all interviews, with no data segments left uncoded to ensure comprehensive coverage.

4.3.5. Theme Development

Themes were constructed through active interpretation of how codes related to each other and to our model, rather than relying solely on frequency counts or automated clustering. We used ATLAS.ti as an organizational tool for managing and retrieving coded segments, but theme identification occurred through interpretive analysis and reflection on patterns across the data. The first author's deep familiarity with the data through transcription verification, multiple readings, and iterative coding enabled the recognition of recurring patterns and conceptual connections. Themes were developed through systematic analysis of relationships between codes, focusing on how they illuminated the intersection of presence, place, and community in virtual learning environments.

4.3.6. Qualitative Rigor and Validation

To ensure analytical rigor, we implemented validation strategies. Weekly peer debriefing sessions among authors took place throughout the analysis phase to discuss patterns, interpretations, and theoretical connections. These sessions provided critical feedback on theme development and helped refine analytical interpretations. The iterative coding process over nine months, with multiple rounds of refinement, ensured thorough pattern identification. Additionally, we achieved theoretical saturation when patterns became clearly defined across the full dataset. Table 1 provides representative examples of our thematic structure with participant quotes to illustrate the analytical process. Additionally, Appendix C includes interview questions linked to themes with coding examples for methodological transparency.

Table 1. Thematic analysis: Representative examples from 9218 codes generated across all participant interviews.

Level 1	Level 2	Level 3	Level 4	Code Example	Quote Example
Embodied Presence	Cognitive Offloading & Interpolation	Sensory Integration	Visual-Spatial Processing	3D environment affordance enables natural spatial cognition in virtual world	*"We know what we're doing pedagogically, but because the way that our minds work. That we're optimized to live in a 3D world."*
	Biophilic Design Metaphors	Restorative Elements	Stress Reduction	Biophilic elements enable improved wellbeing outcomes	*"I wonder how much more comfortable you would feel in a virtual space if you recreated this idea of green and more natural environment than the classroom environment."*
Meaningful Places	Familiarity vs. Innovation Balance	Comfort Zone Calibration	Architectural Recognition	"At-home" feeling intentionally created through recognizable spatial organization	*"She wanted a world that the students were familiar with. So she had the building. She had offices, that's large atrium which is kind of a nice structure if you're building something on a campus."*
	Spatial Knowledge Scaffolding	Landmark Systems	Visual Anchors	Unique architectural elements mark important locations	*"They recreated the color of the brick that the campus had. that was their goal. I think that was a very smart."*
Learning Community	Varied Social Environments	Interaction Contexts	Formal Learning	"Real part of the class" signifies students authentic participation in virtual world classes	*"I actually discovered Second Life, or became interested in it, when I was the director for online course development. We were looking for ways to help online students feel like they were a real part of the class."*
	Temporal Community Dimensions	Synchronous Interactions	Real-Time Collaboration	"Being there together" signifies social presence	*"We used to meet there once a week, and we were definitely together in that space. We all remember that about Spatial... even though we were all at home, trapped in our own homes, we certainly felt connected."*
		Asynchronous Continuity	Persistent Evolution	"Pixel versions" of objects in Second Life specifically provide unique persistence advantages	*"The fact that you have these persistent albeit pixel versions of things that are manipulatives"*
	Identity & Place Formation	Personal Identity Development	Self-Concept Evolution	"Being yourself" signifies authentic expression in VWs	*"There's more freedom in the in the virtual environment. You can be yourself."*
		Place Attachment	Emotional Connection	"Connection to it" signifies students personal investment in their built objects in VWs	*"So they've started to build right then, and they made that and that's theirs and they have a connection to it."*

4.3.7. Researcher Positioning and Reflexivity

The first author, who conducted the analysis, brought a unique interdisciplinary background combining architectural design and human-computer interaction expertise. This positioning created a distinctive analytical lens for examining virtual learning environments, with the architectural perspective enabling enhanced sensitivity to spatial design elements such as proportion, wayfinding, and place-making principles, while the HCI background directed attention to interaction affordances, signifiers, cognitive load, and interface design impacts on user experience. This interdisciplinary background was particularly valuable for analyzing how educators translate physical world metaphors into DVW interfaces and how spatial design elements could accommodate the technical constraints while supporting embodied experiences. The research team's collective experience with DVW education provided additional interpretive context during theme refinement discussions, particularly regarding pedagogical strategies and community formation dynamics. We acknowledge that this positioning influenced our analytical lens and interpretation of data, particularly our focus on design-oriented solutions and spatial metaphors.

5. Findings

Our analysis of educator interviews identified three interconnected themes that demonstrated practical applications of the SSE Model. These findings illustrated specific design strategies educators employed to create integrated virtual learning environments where cognitive, spatial, and social elements worked synergistically.

5.1. Experiencing Presence Through Environmental Design

Our SSE Model frames DVW presence as an interaction between perception, cognition, environment, and social factors. Analysis of educator interviews highlighted embodied presence as multifaceted, influenced by spatial design and community interactions. We examine how this presence evolves into place-making and facilitates learning community development in virtual environments.

5.1.1. Cognitive Engagement Through Offloading and Interpolation

To enhance embodied presence in DVWs, interaction design elements should be immediately perceptible and cognitively accessible. When students expend mental effort to interpret or navigate the environment, their sense of embodied presence diminishes. Participants consistently emphasized that strategically designed environments free students' attention and minds for learning. This effect is especially crucial for novice users unfamiliar with DVW interfaces. One method for achieving cognitive efficiency was creating predictable environments that leverage students' familiar mental models:

> *"This facility looks very predictable; classroom space off the main space... nice couches down on the main floor... windows that you can see through, and see the surrounding landscape which also looks quite predictable."*

We identified several design strategies that reduce cognitive load. Educators have created predictable one-directional navigation patterns and signifiers throughout their virtual spaces, creating pathways that reduce the mental effort required for basic wayfinding.

> *"As you walk up it... you're always turning in the same direction... you're always turning left. You always know the next ramp is going to be on the left."*

This navigational clarity was complemented by careful control of information density, where educators balanced the number of objects against spatial dimensions, recognizing that virtual environments require different proportions than physical spaces:

> *"The fact that most of our working spaces here are relatively small... each of the floors of the towers is 20 by 20 and so there's a certain amount of stuff within that space; so I think it makes it less overwhelming."*

To further accommodate movement limitations inherent to virtual interfaces, educators deliberately oversized spaces to support the constraints of mouse-based navigation:

> *"Notice how big the spaces are in this building. In a virtual world where you're using your mouse and 'mouse look' and everything, you need great big spaces... so you can navigate, and that's been demonstrated."*

Underlying these spatial adaptations, educators consistently recognized hardware limitations of students' computers as significant barriers to their learning experience in DVWs:

> *"Many students don't have access to high-graphic or high-power computers, so simplified objects help them to experience the world better... otherwise lagging and not rendering good enough won't let them have a good experience."*

To address these common technical constraints, one of the educators described the use of simplified modeling while maintaining educational value. The educator observed that the human brain naturally compensated for technical limitations in virtual environments, creating presence through cognitive interpolation even with basic graphics. Cognitive interpolation as presented by Kellman et al. [109] refers to the mental process of filling in gaps in information based on surrounding context and prior knowledge:

> *"To me that was a real revelation when I first started looking into this, that it's like 90% of really being there; even with the crappy 2D graphics and same old keyboard, and so on, so forth, still your brain interpolates over all these imperfections, and you have the subjective sense of actually talking to a real person."*

This natural cognitive capability had important implications for designing inclusive virtual environments. These findings suggested that presence developed not only from technological realism but also from environments aligned with fundamental cognitive processes. When educators prioritize simplified geometric structures and reduced complexity, learners can engage through cognitive interpolation without technical disruptions, ultimately enhancing inclusion for students with limited resources.

5.1.2. Embodied Presence Through Biophilic Design Metaphor

An important theme identified in our research is the psychological importance of natural element metaphors in DVW learning environments. We use the term "biophilic design metaphors" to refer to the incorporation of nature-inspired visual and auditory elements in virtual learning environments. From an interaction design perspective, these elements function as signifiers that communicate environmental affordances—for example, grassy areas signifying walkable surfaces, or water features indicating boundaries. Students recognize these cues based on their real-world experiences with nature. From a learning design perspective, these same elements provide signifiers for emotional regulation and cognitive restoration during learning activities. Rather than serving a dual function, these elements offer multiple affordances: they simultaneously support navigation, orientation, and psychological comfort, distinguishing them from purely decorative nature representations in DVWs. While educators in our study did not explicitly use the term biophilic design, their consistent emphasis on incorporating natural elements for psychological comfort aligns with biophilic design principles adapted for virtual environments. As one educator articulated:

> *"If any of us want to feel better, what do we do? We go out into nature. We go to the sea, we go to the forest... nature makes us feel good because we are of nature... virtual spaces are also man-made, digitally created, and they're not natural to our system... plants help to make it less virtual and more familiar."*

Throughout our analysis, we identified various natural element metaphors—including water features, plants, trees, and natural lighting—that operate as design metaphors by referencing real-world phenomena while existing as digital representations. Even when users remain cognitively aware of the artificial nature of these elements, they still evoke physiological responses. One educator described this phenomenon:

> *"When you walked towards this wall where you could see the water, it was like a sort of a grounding. It stopped people from feeling uncomfortable and it was quite powerful. So your brain is telling you that it's not real, but your eyes are saying this is what you need to make you feel okay."*

This grounding effect is particularly beneficial for neurodivergent learners, as one participant explained:

> *"I often have to explain to people about how so many man-made things are so difficult for neurodiverse people because you know we are not attuned to fluorescent lighting or neon lighting or all these man-made things. It's not natural to us."*

Some of the identified design solutions leveraging biophilic elements in DVWs include strategically placing natural element metaphors in the learning environments and creating psychological comfort zones, using transparent structures to provide visual connections to surrounding virtual landscapes, and implementing smoothly animated natural metaphors such as waves, wind in the trees, or water fountains with moving water that create perceptions of responsive environments.

These findings demonstrate how environmental design establishes embodied presence as the foundation for student engagement in DVWs. Building on this foundation, the following section explores how embodied presence combines with spatial design elements to transform virtual spaces into meaningful learning places.

5.2. Meaningful Learning Places in the Intersection of Embodied Presence and Community

A place is a meaningful space [4]. The concept of presence, often defined simply as *being there*, inherently references place through the spatial notion of *there*. This linguistic connection reveals that place and presence function as interdependent, co-constructed experiences. Beyond individual experience, meaningful places also provide the foundation for community formation, creating shared contexts that support students' collective interactions and experiences. In this section, we present our findings on how meaningful learning places form at the intersection of embodied presence and community, facilitating both individual students' sense of immersion and the social connections that support learning experiences.

5.2.1. Balancing Familiarity with Innovation in Virtual Place Design

The transition from physical to virtual learning environments presents most students with a significant adaptation challenge. One strategy experienced educators employed to address this issue was carefully balancing familiar and novel interaction design elements in learning places. By implementing a progressive approach, educators helped students overcome the initial learning curve while simultaneously introducing the unique affordances of DVWs. This method created learning environments where students could develop both embodied presence and community connections with peers and others.

While replicating real-world classroom settings is common among novice virtual world educators, our interviews indicated that purely replicated spaces often remain unused (Figure 2).

(**a**) Unused virtual office in SL (**b**) Office of an interviewed professor in SL

Figure 2. (**a**) An example of a virtual office place in SL that remains unoccupied and unused by students and faculties. (**b**) One of the professor's virtual office incorporating biophilic design elements to create a calming atmosphere for students.

However, familiar elements do establish important psychological and social functions. Specifically, certain recognizable classroom metaphors form behavioral expectations in learning contexts:

> *"Like we were discussing, the idea of when we had a room in [name of the university]; put together as a classroom with seating and like a podium at the top. So they're things that instantly are recognizable to a student as being a place where we should be quiet, have respect, sit down. Somebody is going to stand at the top of the class, give a lecture, so it's instantly recognizable."*

These familiar elements connect to students' existing understanding of educational places, and help them recognize appropriate behavior without explicit instruction. This approach addresses the common problem of behavioral uncertainty in the virtual environments where in their first encounter, students often wonder: *"What are the rules? You know, what is okay, and what is not okay?"*

To support students as they move beyond initial orientation and toward active exploration, educators used additional psychological anchors. One of the educators used the home affordance as a navigation safety net, providing a reliable return point for students and encouraging them to explore their virtual campus. They mentioned how this method helped reduce students' anxiety about becoming lost in the virtual space:

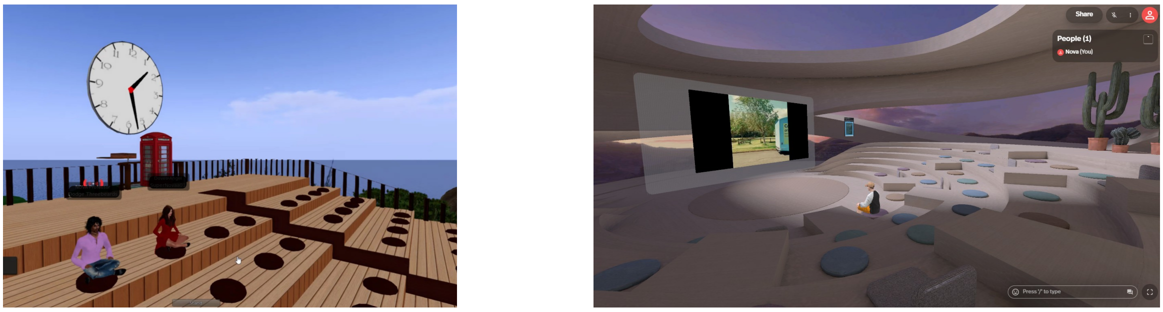
> *"I always bring them down here and I always ask them to make their home to this place... when you click on the home icon, then it takes you back... you don't ever get lost."*

As students developed comfort with these familiar anchors, educators adapted other physical world metaphors to better suit the virtual medium. A critical insight was identified regarding proportional relationships among objects, spacing, and environmental elements. These proportions needed careful reconsideration relative to avatar size, similar to how real-world proportions relate to the human body:

> *"It's really more about setting up an area where they feel comfortable... and I changed this one area around quite a bit. Right now, I have a very large class, so I have more chairs, but often I remove them... so less chairs for a small group is more intimate."*

When designing spaces in DVWs, educators made strategic choices about which physical world elements to keep or modify. They deliberately eliminated unnecessary physical world elements like walls, creating open or semi-open structures. Some environmental elements persisted as functional necessities across both familiar and novel designs. Seating was identified as important, as educators consistently noted that seated avatars reduced distractions from flying or standing avatars and helped maintain student focus. Two of the professors selected pillows in their virtual classroom due to their rendering simplicity and easier usability as seating objects (Figure 3). This design choice made interactions easier for students with limited financial resources, which is an important factor for DVW interaction design as discussed in the Section 5.1.1. This consideration was particularly important for the community colleges, where many students face economic challenges and often work with lower-performance computing systems:

> *"You might have done that with your bodies down on the floor, and so we take those chairs out. There are no chairs you have to worry about. You cannot mess up sitting on those pillows... so that's the sort of thing you're working for that... as you're in a community college. We have students who don't have much money. they have really poor computers."*



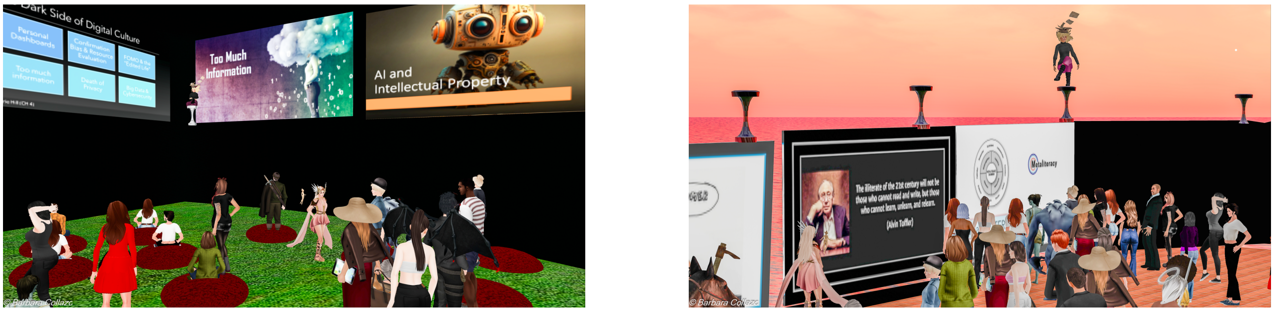
(**a**) Open classroom in SL using floor cushions as seating (**b**) Semi-open conference hall in Spatial with similar seating

Figure 3. (**a**) An open classroom in SL where traditional chairs have been replaced with floor cushions to simplify student interactions and reduce rendering demands. The space includes a prominently placed clock toward podium for instructor time management during lectures and a teleporter providing students with instant access to the learning environment. (**b**) A semi-open amphitheater in Spatial VWs featuring a tiered layout with cushioned seating. This design pattern exemplifies a configuration for presentations and lectures in virtual environments.

They also took advantage of spatial affordances that exceed physical world limitations. Some educators transformed educational content into navigable space: *"It's kind of like a textbook you can walk around in."* Others reimagined content presentations (Figure 4):

> *"Instead of using slideshows, we produce big panels... then your avatar can sit in different parts of that panels that relate to the particular topic you're talking about... so people can get an overview of it."*

This section presented our findings on the balance between familiar elements and innovative design in DVWs. The analysis revealed that while replicated physical spaces frequently remained underutilized, strategic use of recognizable classroom metaphors established clear behavioral expectations for students. Experienced educators employed psychological anchors such as *home* functions to mitigate navigation anxiety, carefully adapted spatial proportions to accommodate avatar scale, and made deliberate decisions regarding which physical elements to preserve (such as simplified seating) and which to eliminate (such as walls or desks). Virtual learning environments that deliberately combined unique virtual affordances, showed what educators perceived as enhanced engagement by transforming educational content into navigable spatial experiences that function as immersive learning resources beyond physical constraints.



(**a**) Spatial presentation of lecture slides in SL (**b**) Similar spatial presentation in alternate environment in SL

Figure 4. (**a**) Turning presentation slides into spatial elements allows students to move through the content for an overview. The professor's avatar would position at the top of each presented slide progressively, creating a spatially navigable lecture. The environment theme also is modified to match the presented topic—in this figure, the professor enhances learning about the dark web by immersing students in a deliberately darkened virtual space, reinforcing conceptual understanding through environmental design. Image courtesy of Barbara Collazo. (**b**) Similar spatial presentation format where the professor's avatar is positioned at the top of slides, but in a different virtual environment addressing a different topic. Image courtesy of Barbara Collazo.

5.2.2. Embedding Knowledge in Place Through Spatial Scaffolding

A particularly innovative approach to virtual learning place-making was identified in how educators embedded disciplinary knowledge structures directly into spatial organization, creating environments where conceptual relationships became navigable places. This approach transforms abstract knowledge into embodied spatial experiences that students explore through their avatar movement. One educator created a vertical learning tower that organized biological concepts from foundational to complex:

> *"This goes from DNA structure up to chromosome structure, and then up to... you can see the comparison between human chromosomes and other species here."*

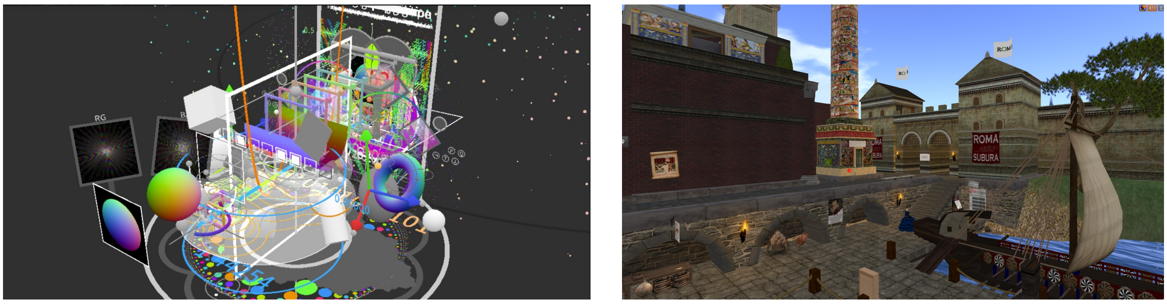
This vertical arrangement used virtually unlimited vertical space to create layered content placement. The vertical dimension became a meaningful organizational principle reinforcing conceptual relationships through spatial positioning.

Similar disciplinary-specific spatial metaphors appeared across subject areas. In chemistry education, one professor created an interactive periodic table where *"atoms get bigger as we go up,"* allowing students to develop embodied understanding of atomic properties through spatial relationships. Geography educators designed simulations where climate transitions were embodied through changing landscape features, while history professors created environments where time periods were spatially organized for students' chronological exploration.

These approaches created powerful alignments between conceptual structure and spatial organization. As students moved through these environments, their avatar navigation simultaneously became conceptual navigation. The movement itself became a learning process. These disciplinary adaptations influenced design priorities:

> *"The included objects really could depend on the teaching subject... there was a successful outer space environment for learning math; the environment itself was very minimal and the objects were the point of the space which students loved... so what this does is, it draws their attention to the interaction, rather than the environment itself. That was my point... however, this is different from learning history where the replication of a historical era could give an immersive experience of that time of history."*

Figure 5 shows examples of both approaches described by this educator.



(**a**) Learning math in VRChat (**b**) Learning history in SL

Figure 5. (**a**) A minimalist outer space platform in VRChat featuring interactive mathematical objects with deliberately reduced environmental complexity. This design approach emphasizes functional learning elements while minimizing visual distractions, demonstrating how abstract subjects like mathematics benefit from simplified virtual environments that focus student attention on conceptual understanding. (**b**) A detailed recreation of ancient Rome in SL designed for history education. In contrast to the minimalist approach used for mathematics instruction, this environment employs rich historical detail and architectural accuracy as the primary learning medium, illustrating how subjects centered on contextual understanding benefit from immersive, content-rich DVW designs.

This spatial scaffolding approach went beyond information visualization by creating environments where knowledge structures were not just represented but enacted through avatar-mediated movement. Rather than students simply viewing conceptual relationships, they navigated them through their avatars, potentially creating deeper understanding through embodied interactions with knowledge structures. The impact of these place-based experiences persisted across contexts, blurring the boundaries between virtual and physical interaction design. One educator shared an example of how virtual places support natural memory continuity between virtual and physical places. They described how a conversation that began in a virtual environment continued naturally when they unexpectedly met at an academic conference:

> *"And I haven't seen him in real life for several years. So we would have conversations in our virtual [Name] institute; and then at some real life scientific conference, I ran into him, and we just continue conversations from previous day, as it was the same thing."*

This cohesive continuation suggested that memories formed in virtual environments resembled those formed in physical spaces, differing qualitatively from other digital communications:

> *"A number of people notice that if you're exchanging ideas or having a conversation with somebody, it stores the memory of that conversation better if it was done in a virtual world, in the same place, if you will, as the real-world conversation... as opposed to if it was on the phone or by email."*

This section demonstrated how educators used innovative spatial design approaches to transform abstract disciplinary concepts into navigable virtual environments where students navigated them by controlling their avatars, potentially creating deeper understanding through mediated spatial experiences with knowledge structures. These embodied interactions demonstrated how meaningful learning places form when spatial design aligns with disciplinary subject matter.

5.3. Cultivating Community Through Shared Presence in Meaningful Places

The embodied nature of avatar co-presence combined with meaningful context and shared purpose evolves into social presence. As one educator explained: *"There is social presence which involves interaction amongst several people in the same place."* This social presence involves cognitive and emotional processes that enhance students' personal presence in learning environments. In this section, we examine how this social presence develops into student communities through shared experiences in meaningful virtual places.

5.3.1. Creating Varied Social Environments for Inclusive Interaction

Several educators created dedicated social spaces to support student collaboration and group interaction, facilitating the development of learning groups. They configured spatial elements and communication affordances to adjust social intensity according to different pedagogical requirements. A key design strategy involved leveraging spatial audio and text chat affordances with customizable activation thresholds. One educator described creating differentiated student group communication zones in SL where these affordances enabled simultaneous but separate group conversations without interference. The positioning of these zones creates an environmental architecture that inherently modulates social interaction intensity:

> *"You can make parcels on the region... you can make voice [areas] that are limited to that parcel."*

> *"On our campus there are just lots of possible spaces for students to meet and they're far enough apart that the chat won't interfere with each other."*

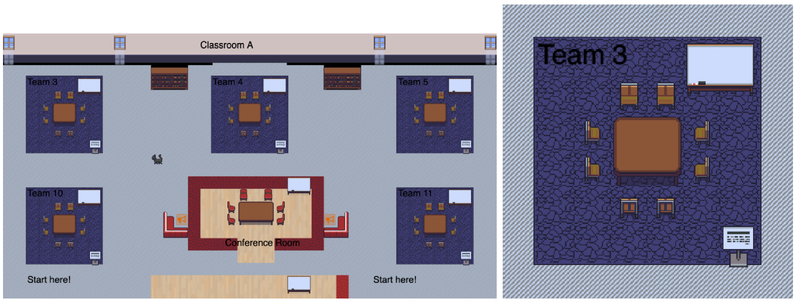
Other virtual platforms such as Virbela and Gather.Town implement more explicit visual indicators for collaborative zones, as illustrated in Figure 6. These platforms use distinct spatial signifiers to clearly communicate the boundaries and purpose of areas designated for group activities.

In addition to communication and space management, educators emphasized creating varied atmospheric qualities to support different learning community functions. Complementing the biophilic design metaphors discussed in the Section 5.1.2, educators valued the creation of specialized sensory environments for collaborative work:

> *"It would be lovely to have a breakout room that is absolutely set up as a sensory space like a quiet space."*

These natural elements created visually attractive gathering spaces for collaborative learning while providing calming environments for students' emotional regulation. The incorporation of dedicated sensory breakout spaces served important functions for managing group dynamics, particularly in educational contexts with diverse cultural backgrounds:

(**a**) Private group tables in Virbela



(**b**) Group work areas in Gather.Town

Figure 6. (**a**) Private group tables in a lounge area of a campus in Virbela. The blue circular indicators surrounding each table function as visual signifiers marking spatial boundaries where private audio and text communication occur. These visual thresholds communicate to students which conversations remain isolated to specific groups, supporting collaborative learning activities while maintaining audio and text privacy within the shared virtual environment. (**b**) Student collaboration zones in Gather.Town, using rugs as visual signifiers to indicate dedicated areas for group work.

> *"Sometimes in social situations when you're dealing with people from different parts of the world, different religions, different cultural expectations, I think it's good maybe*

> *to have that little breakout room every now and again for a teacher to be mindful of their students."*

In cross-cultural settings, culturally neutral design was identified as significant for inclusive participation. By creating environments that didn't privilege particular cultural or political perspectives, educators enabled students from diverse backgrounds to feel included and participate fully in class activities:

> *"I think it's inclusive and that goes back to not putting your ideology in the system. Don't put anything in the system that is going to offend or make people even think twice."*

> *"But I think that schools shouldn't take or environments shouldn't take a stance. So don't put [a political figure] posters on the walls of the classroom that you design in second life."*

Environmental design choices also directly shaped social interaction patterns. Different spatial arrangements signified specific types of social dynamics. Some educators implemented hierarchical layouts with a podium and rows of cushions, establishing traditional teacher-centered interactions. Others preferred circular arrangements to facilitate non-hierarchical discussion. *"I think when we meet in the [Name]... they're used to sitting around tables and I talk to the students."* These varied spatial configurations enabled different learning methodologies. Within these spaces, interactive objects structured and enhanced social interactions. One educator created an object placed in the center of a discussion circle; when students wanted to talk, they would interact with this object to signify their turn. These interactive objects provide signifiers that shape expectations for behavior and interaction while facilitating co-learning among students.

Overall, this section examined how educators created social environments in DVWs to support inclusive student interactions. They designed spaces with customized communication thresholds using spatial audio and visual signifiers (like Virbela's blue circles or Gather.Town's rugs) to enable simultaneous but separate group activities. Our analysis identified how biophilic elements and dedicated sensory spaces supported emotional regulation and cultural inclusivity, while different spatial configurations—from hierarchical to circular arrangements—facilitated diverse teaching methodologies and structured student interactions through interactive objects.

5.3.2. Temporal Dimensions of Community Formation

Building upon the spatial design considerations discussed previously, our research also identified significant temporal factors that affect the development of learning communities in DVWs. Synchronous interaction was identified as a critical factor in developing virtual communities. Through our thematic analysis, we identified patterns indicating a relationship between synchronous versus asynchronous class formats and community development. As one educator emphasized:

> *"For the sense of community, it is important to have synchronous classes. It is very hard to create a sense of community in the asynchronous classes."*

Synchronous engagement enabled shared experiences that form the foundation of community. These real-time interactions created opportunities for co-exploratory and collaborative learning:

> *"I mean just to be able to explore together. I curate a list of places for each field trip. I curated a list of educational spaces. We go to those educational spaces, and students will explore, and they will tell each other, 'Oh, look at this, and how do you do that?' And then they try to figure things out together."*

In developing these synchronous co-experiences, one educator emphasized that consistent structure and regular meeting and event patterns were essential components for successful community development. Educators who successfully built communities did so through scheduled, consistent events ranging from educational activities to recreational gatherings:

> *"So I think you need some kind of regularity in order to make that kind of thing work regularly."*

> *"So, I sponsor a dance for the class; they could dance with each other... you see that's the common experience where people sort of get to know each other."*

Educators also used multiple communication affordances to enable inclusive student community development, recognizing the diversity of student communication preferences and social comfort levels. This multimodal approach created more flexible social environments by offering various interaction options (typing, speaking, or passive presence), that accommodate diverse student needs. This includes respecting students' autonomy to abstain from social interaction when desired:

> *"Features that enable a sense of community would be to create events... and definitely to have functionalities like being able to type or to be able to speak or neither; sometimes you meet people who just don't say anything."*

This communication flexibility created inclusive pathways for student participation, while enhancing their agency and control over social interactions. In contrast, asynchronous classes face significant challenges in developing both social presence and community. The continuous availability of DVWs, while seemingly advantageous, can paradoxically inhibit community formation when students rarely encounter each other:

> *"Students' schedules vary, [so] it is very hard to develop a sense of community in the virtual world, as they don't come to the world at the same time."*

These scheduling difficulties are particularly pronounced for community college students who have work and family commitments. For asynchronous students, communication typically defaults to leaving messages rather than real-time interaction.

> *"We didn't do that, simply because this is a community college; most of them are working jobs and stuff like that... and they're coming to college at certain times when they can take a class... that's the time they can do it. They can't be doing it other times; they might have kids at home and stuff... so rather than have them collaborate, they can just come in and do it whenever they have the time to do it... that's kind of our thinking on that."*

Across these temporal considerations, our findings highlighted synchronicity as a critical factor in developing virtual communities. Regular, scheduled interactions created shared experiences essential for community building, while asynchronous formats presented significant challenges for meaningful connection, particularly for students with competing commitments. Despite continuous, unrestricted access, community formation was hindered when students rarely encountered each other in real-time.

5.3.3. Identity and Place in Community Formation

Meaningful places with institutional themes were identified as important facilitators of community formation. Place-based interactions enabled a qualitatively different type of community compared to other online platforms due to their embodied presence:

> *"When I was teaching using this platform [Zoom], at the end of the semester, we had a bit of a community. But it just wasn't the same. We didn't interact with each other physically. The sense of community stopped at the screen, the photo, the picture, the image on the screen... in 3D worlds, we're not stopped by the image."*

Building on our earlier discussion of transitions between physical and virtual contexts, we found that the transition between physical and virtual identities also significantly affected social connections. Educators created airlock spaces where students first land in the environment before engaging in social interaction. These threshold spaces incorporated avatar customization zones. These identity connections were further strengthened through familiar institutional branding, and architectural elements, and landmarks at entry points. Some professors enhanced this by providing students with pre-customized avatars featuring the institution's branding on their outfits:

> *"Yeah, I will say one thing everybody did was to make a t-shirt. So we definitely had a university [university's name] t-shirt. Some students would wear them. That was kind of cool."*

One professor's strategy of positioning familiar buildings and institutional identifiers at arrival points helped remote students immediately connect with the institutional space, establishing initial links between physical and virtual campuses:

> *"So that little tiny piece just made me feel good that they felt like they were really at [university's name]... they were really a [university's name] student and she (a remote student) literally said that: 'it's the first time I felt like I'm a real [university's name] student.'"*

As virtual communities matured, their shared spaces transformed into expressions of educational institution identity. Educators designed gathering areas showcasing permanent displays of student-created content and builds. These displays preserved institutional virtual history and bridged the connections between successive student cohorts. Over time, these communities developed their distinctive practices and cultural norms:

> *"There's a kind of social code that you acquire as you interact with people here, and I think that helps to contribute to the sense of community."*

These design decisions demonstrated how identity and place facilitate community formation in DVWs. Educators created threshold "airlock" spaces and incorporated institutional branding to help students transition between physical and virtual identities. Institutional architectural elements and landmarks as well as branded avatars strengthened institutional connections, particularly for remote students. As communities matured, shared spaces became expressions of institutional virtual history while distinctive social practices were developed.

6. Discussion & Conclusions

In this study, we introduced the SSE Model as a framework for approaching interaction design in DVW learning environments. Based on interviews with experienced educators, our model extended embodied cognition theory by showing how learning develops from the interconnection of three key dimensions: presence, place, and community. This research addressed two primary questions: How do presence, place, and community intersect in DVW learning environments? And what design strategies support this intersection that enhances students' learning experiences? While existing literature has often treated these dimensions separately, our integrated approach provided educators with both theoretical understanding and practical strategies. The intersection of these three dimensions shapes students' personal embodied experience, their relationship with the virtual environment, and their interactions with others, creating a foundation for meaningful learning in DVWs.

6.1. How Presence, Place, and Community Intersect in Desktop Virtual World Learning Environments

Our research shows that achieving presence in DVWs relies more on cognitive management than on technological sophistication alone. The phenomenon of cognitive interpolation [109] in the virtual environments, where the human brain compensates for their technological constraints, is important. Instructors observed that *"90% of really being there"* occurs through cognitive processes despite *"crappy 2D graphics."* This insight suggests that presence develops not primarily from technological realism but from environments aligned with fundamental cognitive processes. This challenges assumptions that high-fidelity graphics are essential for engaging virtual learning and instead emphasizes cognitive inclusivity as a critical factor.

This cognitive interpolation phenomenon has significant implications for equity in virtual learning environments. Our findings on simplified design approaches directly address concerns about students experiencing digital divide challenges. Educators deliberately used simplified objects and streamlined environments to reduce technical barriers. This approach uses the brain's natural ability to interpolate meaningful experiences from minimal cues. As demonstrated by the community college educator who replaced complex chairs with simple cushions, these design choices can equalize the learning experience for students regardless of their hardware capabilities. This suggested that well-designed DVWs can provide equitable experiences across different technological resources, making virtual world education more inclusive than previously assumed.

This inclusive approach is important given infrastructure challenges revealed during COVID-19. Attallah et al. [110] studied 19 universities that adopted DVWs to address remote learning gaps when institutions lacked online infrastructure. They found that while virtual environments offer educational opportunities, effective implementation requires substantial infrastructure investments. Despite these challenges, students demonstrated positive attitudes toward virtual learning. Similarly, recent Metaverse studies revealed barriers for disadvantaged students lacking high-speed internet access. However, Rojas et al. [111] found 73.08% still expressed positive engagement attitudes despite technical limitations, suggesting well-designed DVWs can partially address technical limitations through design strategies.

Building on these cognitive foundations of presence, the psychological importance of natural element metaphors in DVWs contributes significantly to our understanding of virtual environment design. While biophilic design has been extensively studied in physical architecture [112], its application in virtual environments has received limited attention. Our findings suggest that natural element metaphors in DVWs facilitate embodied presence through alignment with innate human environmental preferences. The physiological responses triggered by these elements, such as the grounding effect described when students encountered virtual water features, extend Gall et al.'s [113] claim that virtual environments can activate embodied responses similar to physical environments. The observation that natural element metaphors function not merely as aesthetic enhancements but as components for students' psychological comfort, represents an important theoretical insight, particularly for understanding how different student populations experience virtual environments. The particular value of natural elements for neurodivergent students highlighted important insights for accessible and inclusive educational design [114]. By aligning virtual environments with human evolutionary preferences for natural settings, educators can create environments that accommodate diverse cognitive processing styles.

Our findings on the transformation of virtual space into meaningful place expand Lewicka's [4] definition by identifying design strategies that support this transition in educational contexts. The balance between familiarity and innovation address the paradox identified by Turner [115], where purely replicated physical spaces often remain unused despite their familiarity. This finding aligns with the neurophysiological evidence presented by Stavroulia et al. [116], showing that fictional virtual environments can produce stronger immersion than realistic replicas, with participants demonstrating increased occipital lobe engagement and alpha state synchronization in imaginative spaces compared to traditional classroom designs. This suggests that traditional, lifelike classroom environments may not always offer the most effective conditions for learning.

A particularly innovative finding concerned spatial scaffolding of knowledge structures—the transformation of abstract disciplinary concepts into navigable spatial arrangements, such as vertical learning towers organizing biological concepts from foundational to complex. This approach aligns with Jetter's [96] work on blended interaction but extends it by showing how knowledge structures themselves can be spatially organized to facilitate embodied learning. The persistence of place-based memories across contexts, as noted by educators who continued conversations begun in virtual environments when meeting in physical settings, suggests that DVWs create qualitatively different types of social interactions compared to other online platforms. This finding both supports, and extends Turner et al.'s [38] assertion that sense of place and sense of presence are fundamentally intertwined by demonstrating processes through which this connection emerges in educational contexts.

In addition to spatial considerations, the connection between place and community becomes more evident when examining how virtual spaces support social presence and interactions. Temporal dynamics and institutional identity appeared as critical factors shaping community development in DVWs. Our interviews revealed synchronicity as crucial to community formation, as one educator emphasized: *"it is very hard to create a sense of community in asynchronous classes."* While continuous access appears advantageous [117], our findings show this paradoxically impedes community formation as students seldom encounter peers simultaneously. This challenges assumptions about temporal flexibility in online learning, suggesting scheduled events remain essential for community formation in virtual contexts. As one educator noted, *"you need some kind of regularity in order to make that kind of thing work."* This consistency creates shared experiences, whether educational activities or recreational gatherings like virtual dance events, that form community bonds. These findings extend Finch et al.'s [118] research on how structured events promote connection and enhance well-being in the communities.

Complementing the temporal factor, institutional identity is identified as a powerful force in social connections. Placement of institutional branding and architectural elements at entry points creates immediate connections for remote students with their educational institutions. One remote student captured this emotional impact: *"the first time I felt like I'm a real [university's name] student."* These place-based identity elements transform abstract institutional affiliation into embodied experience.

Our findings regarding culturally neutral design reveal how the SSE Model operates in culturally diverse educational contexts. While our model presents place-making as resulting from the intersection of presence, place, and community, the emphasis on cultural neutrality indicates how students from different backgrounds may indeed form a sense of place in different ways—what resonates as meaningful for one cultural group might feel alienating to another. This aligns with our theoretical grounding that place transformation inherently involves cultural and identity-related aspects [23]. The model's focus on the intersection of all three dimensions, rather than treating them in isolation, accounts for these cultural variations by recognizing that successful virtual learning environments should simultaneously negotiate diverse meaning-making processes across all dimensions.

6.2. Design Strategies That Facilitate This Intersection

Educators consistently reported that purposefully designed environments reduce students' cognitive load, freeing their attention for learning rather than navigation and environment interpretation. As one educator noted, creating *"predictable environments"* helps students develop embodied presence by leveraging their real-world familiar mental models. The educators' emphasis on predictable navigation patterns, appropriate information density, and proportional spacing demonstrates how environmental design directly influences cognitive load, supporting Hutchins's [119] concept of distributed cognition. As he suggested, cognitive processes are distributed across individuals, artifacts, and the environment, rather than being confined to the individual mind.

The psychological importance of natural element metaphors was identified as important for facilitating embodied presence. Educators strategically incorporated biophilic design elements that serve not merely as aesthetic enhancements but as critical components for students' psychological comfort. The particular value of natural elements for neurodivergent students highlights the importance of accessible and inclusive educational design approaches. By aligning virtual environments with human evolutionary preferences for natural settings, educators create environments that accommodate diverse cognitive processing styles.

Spatial scaffolding strategies transform abstract disciplinary concepts into navigable spatial arrangements. Examples include vertical learning towers organizing biological concepts from foundational to complex levels, and interactive periodic tables where atomic properties become spatially navigable. This approach extends beyond information visualization by creating environments where knowledge structures are enacted through avatar-mediated movement.

Community-building strategies address temporal and identity dimensions. Educators emphasized the necessity of synchronous interactions, implementing structured temporal events that provide regularity essential for community formation. Strategic placement of institutional branding and architectural elements at entry points creates immediate connections for remote students with their educational institutions. Cross-cultural considerations led educators to emphasize culturally neutral design for inclusive participation, creating environments that avoid potentially alienating cultural markers while maintaining social cohesion.

Theoretical Contributions: This research advances virtual learning theory through the SSE Model, which demonstrates how presence, place, and community function as interdependent dimensions rather than isolated factors. The study extended embodied cognition theory by showing how avatar-mediated interactions activate embodied schemas from physical world experiences, creating cognitive bridges between virtual and real environments. Additionally, the framework explains how spatial design and cognitive processes interact to create meaningful virtual learning experiences through mechanisms like cognitive interpolation.

Practical Contributions: For educators and designers, this study provides actionable strategies including cognitive offloading techniques that reduce navigation complexity, biophilic design elements that enhance psychological comfort, spatial scaffolding approaches that transform abstract concepts into navigable knowledge structures, and institutional identity integration methods for creating more engaging virtual learning environments.

6.3. Limitations and Future Research

Our study exclusively reflected the perspectives of experienced educators, which limits the generalizability of the SSE Model to novice DVW instructors who may use different design approaches. We are currently conducting focus group studies to understand students' perspectives on DVW interaction design and their learning experiences with presence, place, and community within these environments.

The SSE Model framework presented in this study was developed through qualitative analysis of educator interviews and has not undergone quantitative validation. To address this limitation, we are developing a psychometric scale to measure students' experiences of presence, place, and community in DVWs. This instrument will enable quantitative assessments of the three SSE Model dimensions and their interrelationships. Future empirical validation will include: (1) confirmatory factor analysis to test the three-dimensional structure of the model, (2) structural equation modeling to examine the dynamic relationships among presence, place, and community, and (3) experimental studies comparing environments designed using SSE Model principles with traditional environment designs. Such quantitative validation will strengthen the framework's theoretical foundation and provide educators with validated tools for evaluating their virtual learning environments.

Future research will also include comparative analyses of existing DVW platforms to identify which specific affordances and signifiers support socio-spatial embodied learning and highlight gaps in current implementations. These findings would provide practical guidance for DVW designers seeking to improve interfaces for educational adoption. Longitudinal studies tracking community development would provide insights into how these design approaches function over time. By expanding research across different stakeholders and time frames, we can develop a more comprehensive understanding of how the SSE Model functions in diverse educational contexts and how it might evolve with new technologies.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Cat Runden Institutional Review Board of University of North Carolina at Charlotte (protocol code 2024-001 and date of approval 15 March 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study consist of transcripts from audio recordings that cannot be shared publicly due to privacy and confidentiality agreements with participants. The audio recordings were transcribed verbatim and analyzed according to the methodology described in this paper. The codes developed for analysis are available upon request from the corresponding author. No new publicly available datasets were generated during this study. This approach aligns with MDPI's data availability policies regarding sensitive personal data.

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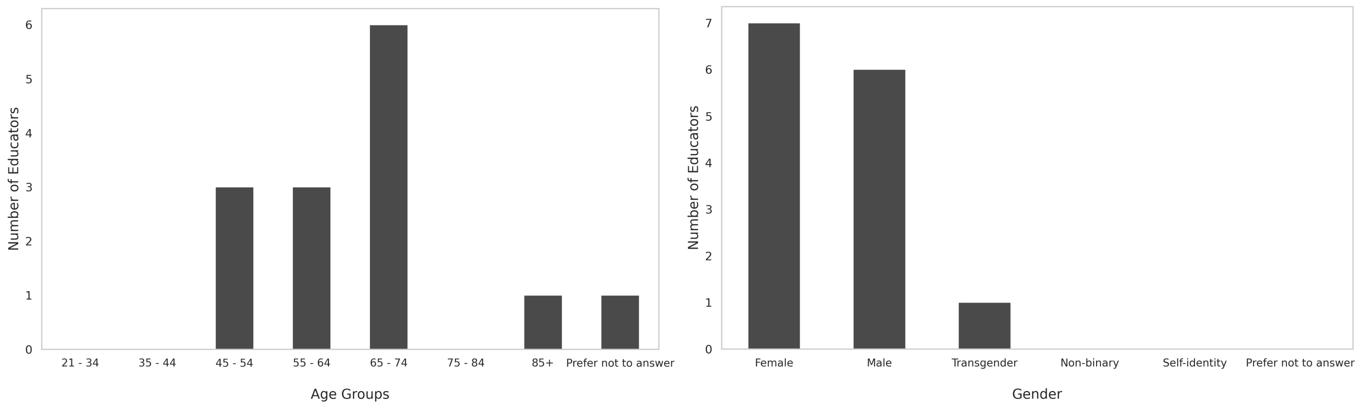
Abbreviations

The following abbreviations are used in this manuscript:

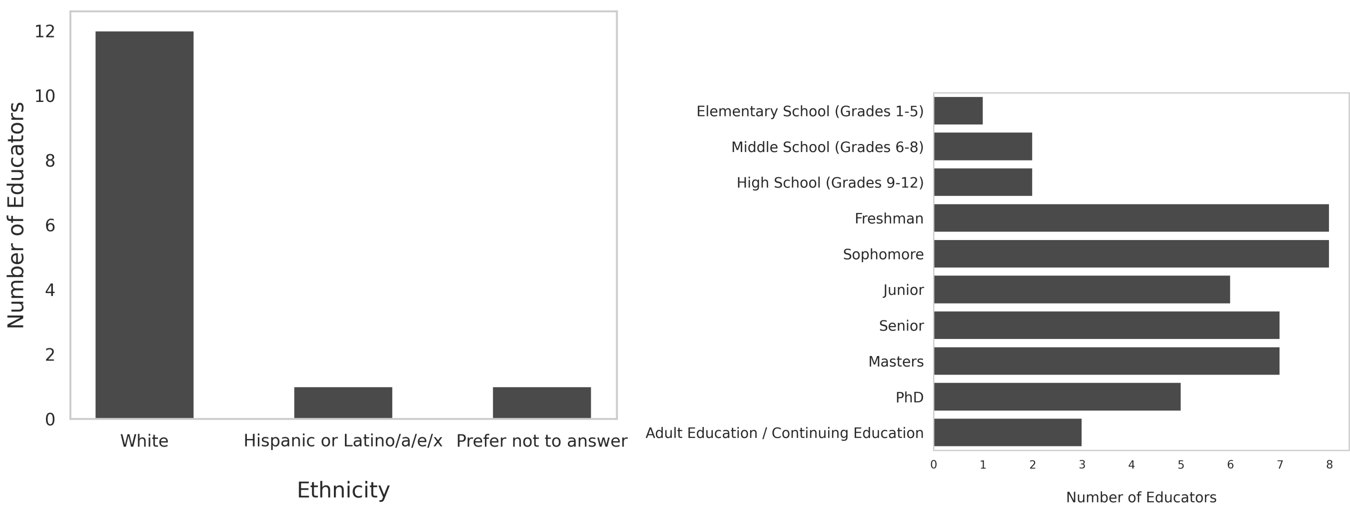
SSE Model	Socio-Spatial Embodiment Model
DVWs	Desktop Virtual Worlds
HCI	Human-Computer Interaction
VWEC	Virtual World Education Consortium
SL	Second Life

Appendix A. Demographic Information of Study Participants



(**a**) (**b**)

Figure A1. Basic demographics. (**a**) Age distribution; (**b**) Gender distribution.



(**a**) (**b**)

Figure A2. *Cont.*

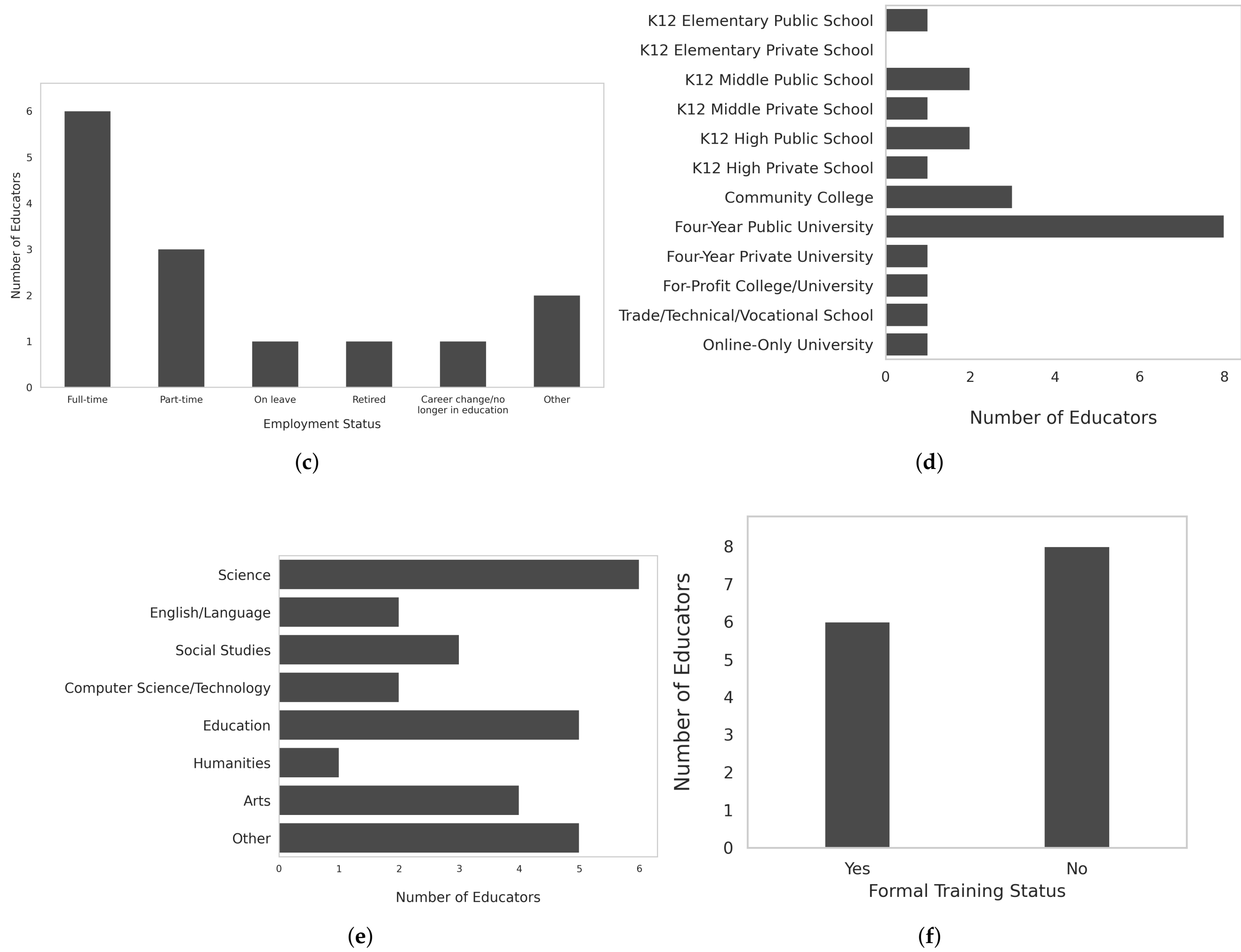


Figure A2. Academic and professional profile. (**a**) Ethnicity; (**b**) Teaching level; (**c**) Employment status; (**d**) Institution type; (**e**) Teaching subject areas; (**f**) Formal training for Using Virtual Worlds.

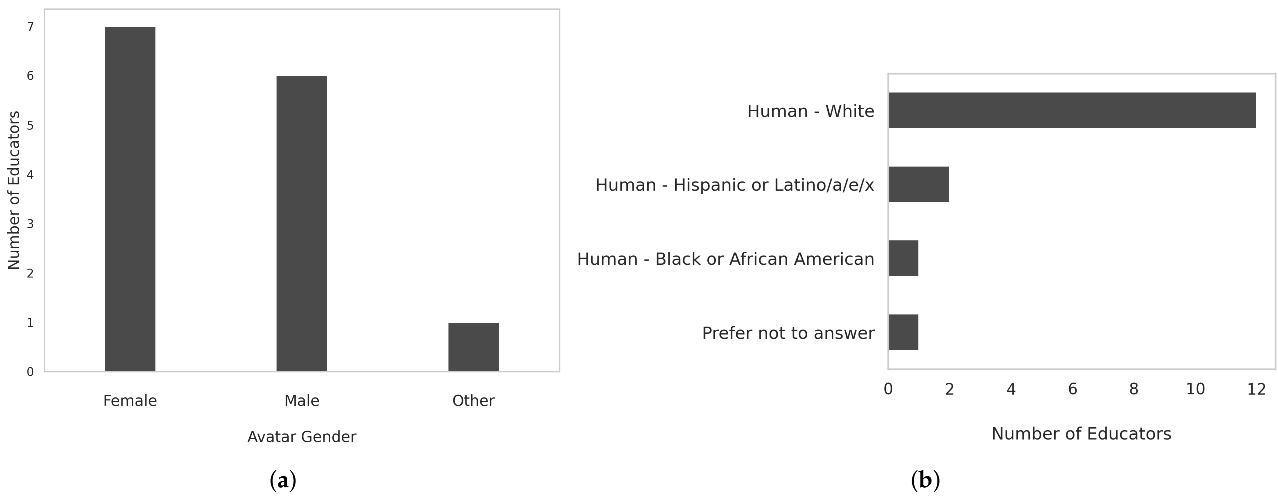
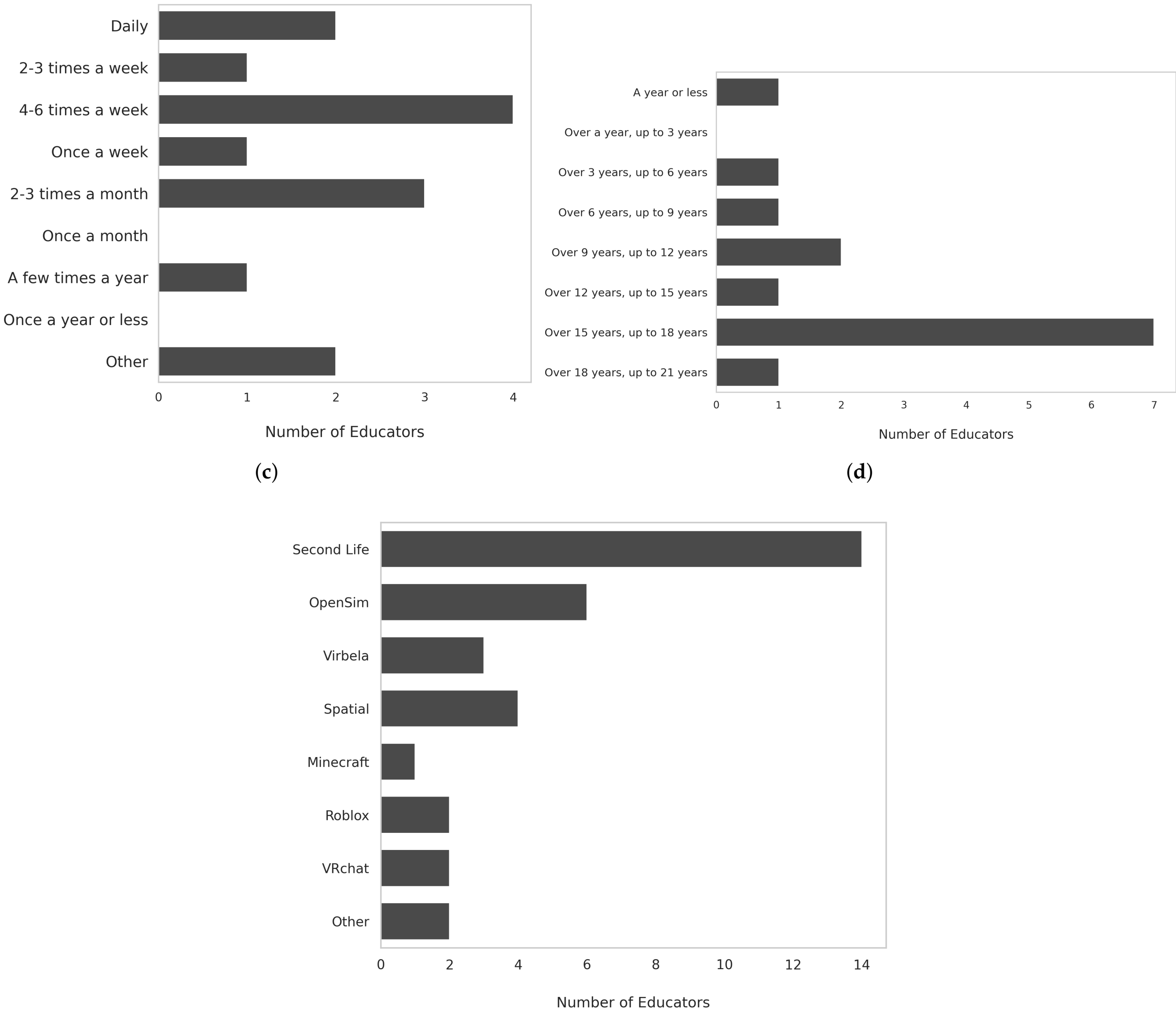


Figure A3. *Cont.*



(**e**)

Figure A3. Virtual world experience and avatar characteristics. (**a**) Participants' Avatar gender; (**b**) Participants' Avatar race; (**c**) VW Usage Frequency; (**d**) VW experience; (**e**) Used VW platforms.

Appendix B. Educator Interview Questions

Appendix B.1. Educators' Teaching Objectives & Strategies and Their Experiences with Virtual World Learning Environments

Appendix B.1.1. Objectives & Strategies

- What do you teach?
- What is your teaching approach/philosophy?
- What are your primary teaching objectives?
- Did you in general enjoy teaching?
- What are the primary teaching objectives that you aim to achieve by using a virtual world learning environment?
- What instructional strategies do you employ in your virtual world classrooms?
- What strategies do you use when setting up your virtual world classrooms to make it more engaging for students or enhance their participation?
- What tools/settings/educational objects do you use for implementing these strategies?

Appendix B.1.2. Experiences: Advantages & Challenges

- What do you perceive as the biggest advantages of using virtual world classroom compared to video conferencing ones?
- What do you perceive as the biggest challenges or drawbacks of using virtual world classroom compared to video conferencing ones?
- What are your expectations of a virtual world classroom experience compared to video conferencing ones?
- What challenges have you encountered when using virtual world classrooms over the past year compared to video conferencing ones? Please explain and provide examples if possible.
- What are your most memorable teaching experiences (both positive and negative) when teaching in the virtual worlds compared to video conferencing?
- How would you describe your ability to connect/interact with students in virtual world classrooms compared to video conferencing ones? What factors make it easier or harder to build these connections?
- If you had the opportunity to improve the design of virtual world platforms for designing your virtual world classroom, what changes or additions would you suggest?
- Please share any additional comments or feedback you may have regarding the use of virtual world classroom platforms for teaching.

Appendix B.2. UI Elements

- What user interface elements and functionalities do you use most often in your virtual world classroom (e.g., Second Life) that enhance your teaching and students' learning experience?
- How do you leverage the unique functionalities of 3D virtual world environments to facilitate learning experiences that differ from traditional online and video conferencing platforms?
- What specific student interactions, behaviors, or engagement patterns within the virtual world learning environments indicate high levels of engagement, participation, and effective learning?
- What role does the virtual world's user interface (UI) play in fostering student engagement and collaboration within the learning environment?
- What techniques have you found effective in using the virtual world platform's UI to support different instructional approaches (e.g., experiential learning, problem-based learning, collaborative learning)?
- Based on your experience, what are the primary challenges or limitations in effectively leveraging the UI and environmental design features of virtual world platforms for educational purposes, and how have you addressed these challenges?
- How do you envision the future evolution of virtual world platforms and their UI/environmental design to better support immersive and effective educational experiences?

Appendix B.3. Real-World Elements

- To what extent do you intentionally incorporate real-world scenarios, simulations, or contextualized learning experiences into your virtual classroom design?
- When designing your virtual classroom environment, what real-world elements or patterns do you intentionally incorporate or avoid to create an effective and authentic learning experience?
- How do you balance the incorporation of real-world elements with the unique functionalities of virtual world environments to create an optimal learning experience for your students?

- How would you describe the overall impact of virtual world classroom design, including the UI and real-world elements, on student motivation, engagement, and learning outcomes compared to traditional online or video conferencing environments?
- How do you use the customizable and flexible nature of virtual world platforms to design and adapt the classroom layout, objects, and interactive elements to support your specific pedagogical goals and student needs?
- How do you design the layout of your virtual world classroom to promote a comfortable and inclusive environment for your students?

Appendix B.4. How Instructors Create a Sense of Place/Presence/Community

- What features in Second Life most contribute to students having a sense of “being there”?
- How much did having an avatar in Second Life that students could customize to represent them add to students’ sense of having a presence in the virtual space?
- What objects, if any, in the Second Life virtual spaces helped orient students and make them feel grounded in a physical location?
- How do you create or modify virtual learning environments in Second Life to convey a sense of place and presence to enhance student engagement?
- What functionalities or features of Second Life do you use to enable a sense of community and facilitate meaningful interactions and communication between students and the instructional team?
- What interactive features in your Second Life classroom contribute to a collaborative and socially engaging learning atmosphere?
- How does the sense of place in Second Life influence the social aspect of co-learning environments, including students’ interactions with peers and the instructional team, compared to video conferencing platforms?
- What specific features or aspects of Second Life contribute to a different engaging learning experience for students compared to Zoom?
- How does the collaboration experience in Second Life differ from Zoom, and what role do virtual tools play in enhancing or hindering collaborative efforts?

Appendix C. Interview Question-Theme Mapping

Table A1. Sample Questions Contributing to Theme Development.

SSE Dimension	Theme	Interview Category	Sample Questions	How Responses Informed Theme
Embodied Presence	Cognitive Engagement Through Offloading and Interpolation	Interface Utilization	“What UI elements enhance teaching and learning experience?”	Revealed predictable navigation and simplified object strategies
		Experiential Dimensions	“What features contribute to students’ sense of ’being there’?”	Revealed cognitive interpolation phenomenon
	Embodied Presence Through Biophilic Design Metaphor	Design Adaptations	“What real-world elements do you incorporate to create effective learning?”	Revealed emphasis on natural elements for psychological comfort
		Experiential Dimensions	“What objects help orient students and make them feel grounded?”	Identified grounding effects of water, plants, natural lighting

Table A1. *Cont.*

SSE Dimension	Theme	Interview Category	Sample Questions	How Responses Informed Theme
Meaningful Place	Balancing Familiarity with Innovation	Design Adaptations	"How do you balance real-world elements with unique virtual functionalities?"	Identified balance strategies using real-world architectural patterns
		Teaching Context	"What strategies make classrooms more engaging for students?"	Revealed progressive adaptation approaches
	Embedding Knowledge Through Spatial Scaffolding	Interface Utilization	"How do you leverage unique 3D functionalities for learning?"	Discovered vertical learning towers, navigable content
		Design Adaptations	"How do you use customizable nature to support pedagogical goals?"	Identified disciplinary-specific spatial metaphors
Learning Community	Creating Varied Social Environments	Design Adaptations	"How do you design layout to promote comfortable, inclusive environment?"	Identified spatial audio zones, communication thresholds
		Experiential Dimensions	"What interactive features contribute to collaborative atmosphere?"	Identified social space configuration strategies
	Temporal Dimensions of Community Formation	Experiential Dimensions	"What functionalities enable sense of community?"	Identified synchronous vs. asynchronous importance
		Teaching Context	"What instructional strategies do you employ?"	Identified regular events and structured temporal patterns
	Identity and Place in Community Formation	Experiential Dimensions	"How does sense of place influence social aspects of co-learning?"	Revealed institutional identity and avatar customization effects
		Design Adaptations	"How do you create environments that convey sense of place?"	Identified entry points, branding, cultural neutrality

This table illustrates the relationship between themes identified through reflexive thematic analysis and the interview question categories that generated relevant data. The complete 37 interview questions are available in Appendix B.

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