

Lessons Learned Teaching Virtual Reality in an Undergraduate Design Studio

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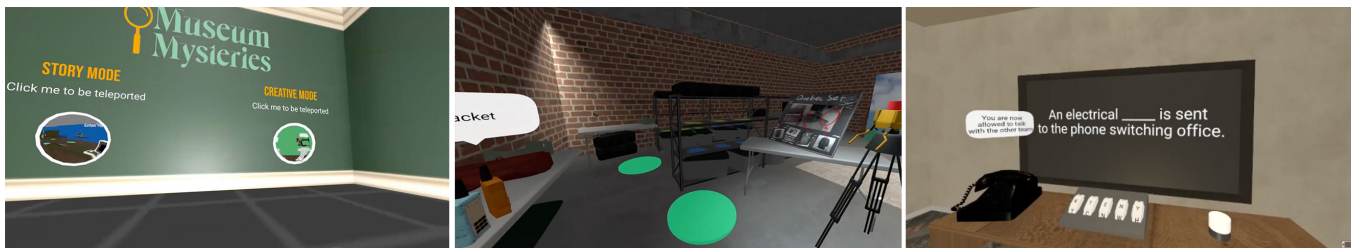


Figure 1: Three of the seven VR prototypes developed for a museum client in a 2024 undergraduate design studio. Left: an escape room to find virtual artifacts. Middle: a mini game where users create a movie set to match an image. Right: solving a puzzle by coordinating with others to find the hidden codes.

Abstract

As virtual reality hardware becomes more widely available, there is a critical need for pedagogical models that move beyond technical software training and toward better ways to teach human-computer interaction and accessible design for creating virtual experiences. This paper presents a longitudinal study of an undergraduate design studio in which students developed multi-platform, multi-user virtual reality prototypes over the course of a semester-long project. Across two years (the winter semesters of 2024 and 2025), we analyzed the development process of 45 student participants ($N_{2024} = 26$; $N_{2025} = 19$), creating 13 immersive learning experiences for clients in a museum ($N_{2024} = 7$) and new media

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arts ($N_{2025} = 6$) context. Through reflexive thematic analysis of the first year's 239 developer reflections, researcher observations, and a systematic codebook analysis of over 160 interaction instances, we identify five pedagogical challenges that hinder novice VR development. We subsequently validate these findings against data from the second year participants ($N = 19$) to ensure longitudinal consistency. Primary among these is "Platform Bias," a tendency for developers to prioritize desktop-based interfaces over immersive head-mounted display interactions due to development friction, and the "Accessibility Gap," where inclusive design is often treated as a secondary "optimization" rather than a core requirement. We illustrate these findings using two case studies from the 2025 cohort written by the students who developed them: *The Journey*, which used abstract aesthetics to overcome mobile hardware constraints, and *Echoes of the Mind*, which implemented novel multisensory brainwave visualizations. To address these pedagogical challenges, we propose five Teaching Considerations that prioritize "creator experience" and the transparency of the development frameworks. This work contributes to the limited literature on VR pedagogy by providing a data-driven foundation for training the next generation of developers to create usable and inclusive virtual worlds.

CCS Concepts

• **Human-centered computing** → **Virtual reality**; *Web-based interaction*; • **Social and professional topics** → **Adult education**.

Keywords

virtual reality, human-computer interaction, teaching, WebXR

ACM Reference Format:

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1 Introduction

Teaching the design and development of Virtual Reality (VR) applications poses a unique pedagogical challenge as it requires students to navigate a significant leap in spatial and interaction complexity compared to traditional 2D user interfaces (UIs). While 2D web and mobile development benefit from decades of established design heuristics and standardized layout frameworks, 3D user interfaces (3DUIs) require a multidisciplinary understanding of user agency, physical-virtual environmental conflicts, and multisensory feedback loops [20, 21, 24, 29]. This increased complexity in Human-Computer Interaction (HCI) means that creating a "usable" experience in VR involves far more than visual layout; it requires managing user comfort, spatial navigation, and accessibility as core technical constraints rather than secondary optimizations [13]. As VR matures into a viable medium for mainstream educational contexts [25, 29] and social platforms [4], there is an urgent need for active pedagogical models and standards to train developers to prioritize human factors.

This paper addresses this gap by presenting a two-year study of a design studio grounded in a Universal Design for Learning

(UDL) [7] approach to VR teaching and development. Students were challenged to consider VR accessibility and develop multi-platform, multi-user VR experiences for real-world clients: a science museum in the first cohort (2024) and a new media arts exhibitor in the second cohort (2025). By treating multi-platform compatibility as UDL's "multiple means of representation" [19, 30], students were required to confront the high-dimensional complexity of 3DUI design within the practical constraints of the GLAM sector (Galleries, Libraries, Archives, and Museums) [10]. However, this revealed a bias towards familiar non-immersive platforms, such as desktop, and towards visual-first design and development, with HMD development, accessibility, and sound treated as lower priorities. Through a reflexive thematic analysis of 45 student developers, we identify five Pedagogical Challenges (PCs) and offer five corresponding Teaching Considerations (TCs). These contributions provide a foundation for standardizing VR pedagogy and developing future teaching toolkits to support the creation of equitable, usable virtual worlds.

1.1 Study Context and Methodology

Over 12-week cohorts in 2024 and 2025, students in a third-year post-secondary design studio were tasked with developing multi-platform, multi-user VR prototypes (supporting desktop, mobile, and HMD). In the 2024 cohort, 26 students with minimal web programming experience and no prior VR development history formed 7 teams. To facilitate development across disparate hardware platforms, we used the WebXR-based frameworks A-Frame [2] and Circles XR [30], which provide native support for multi-platform, multi-user deployment [26, 31]. In the 2025 cohort, 19 students formed 5 teams.

Our data collection was longitudinal and multi-modal, comprising weekly developer reflections, researcher observations of milestone presentations (Alpha, Beta, and Final), an end-of-term focus group, and participant-observer field notes recorded across 64 contact hours (16 four-hour sessions). In 2025, we repeated this study with a second cohort ($N = 19$) working with an arts organization client to cross-reference and validate our initial findings. Two student projects from the 2025 cohort are detailed as case studies, written by the student developers who created them, to illustrate the development process and the navigation of technical friction. This research is guided by a central exploratory question: *What pedagogical considerations can be derived from these studio-based experiences to standardize and enhance future VR instruction?*

The contributions of this paper are:

- (1) A longitudinal investigation into how students create multi-user multi-platform VR experiences.
- (2) Identifying five challenges in teaching multi-platform VR development.
- (3) Defining five educational considerations to address these challenges.
- (4) Adding to the existing corpus of VR teaching, an example of multi-platform, multi-user VR development using WebXR with real-world clients.

2 Related Work

Early VR pedagogy established foundational principles for classroom integration by emphasizing hands-on, project-based learning to navigate the medium's inherent technical complexity [6, 9]. While these works highlighted the need for curricula that nurture creativity alongside technical proficiency, they were largely developed for siloed laboratory environments. Contemporary XR¹ instruction has since shifted toward interdisciplinary and reflective practices, utilizing cross-disciplinary teams [11], design sketching [37], and scaffolded pathways for diverse learners [34] to mirror industry workflows and ethical considerations.

To overcome resource limitations and HMD equity gaps [25], recent methodologies prioritize accessible, web-based tools that support independent project progression and iterative feedback [13, 15]. Solutions such as WebXR [26], mobile AR [28], and economical hardware systems [3] enable multi-platform prototyping without the strict requirement of high-end headsets. However, despite these advancements in scalability [22, 23], significant hurdles remain regarding instructor readiness [32] and the seamless integration of creative and technical workflows [16].

This shift in pedagogy necessitates a transition from viewing VR as a "technical artifact" to focusing on the *Creator Experience* (CX)—the cognitive and technical friction between a novice developer and their spatial computing framework [31]. The high-dimensional complexity of 3DUIs creates a unique "logic gap" for learners that traditional 2D interfaces lack [16]. We argue that many high-level VR engines function as "black boxes," obscuring the spatial logic required for true VR+HCI innovation. Consequently, while accessibility is a common pedagogical goal, it remains under-theorized in classroom contexts. Following previous work [29], we define accessibility not merely as a feature set (e.g., subtitles), but as a *Universal Design for Learning* (UDL) requirement that also mandates cross-platform parity.

A critical gap thus remains in *HCI-grounded, multi-platform VR development conducted under real-world client constraints*. Our work builds on the client-focused studio model [11, 15] to investigate the "Accessibility Implementation Gap," where high design intent for inclusion fails to translate into technical execution due to workflow complexities. By framing VR frameworks through "Glass-Box" transparency [30], we offer pedagogical insights for standardizing inclusive social VR education.

3 The Study

We conducted a two-year longitudinal case study within a third-year undergraduate design studio ($N = 45$). This section details our methodological approach and analysis. By triangulating data from two distinct cohorts (*Museum 2024* and *New Media 2025*), we establish a foundation for the five proposed Pedagogical Challenges (PCs) and the subsequent Teaching Considerations (TCs).

3.1 Methodology

Here, we describe the course and study design, data collection, and analysis. This work was approved by the Algonquin College's Research Ethics Board (Protocol: 2024-Jan-Scavarelli).

¹Extended Reality (XR) serves as an umbrella term encompassing VR, Augmented Reality (AR), and various mixed-reality forms [27].

Table 1: Course Structure and Milestone Timeline

Week	Minor Milestone (Reflections)	Major Milestone (Deliverables)
4–5 6	Reflections 1–2 Reflection 3	Proposal / Concept Alpha Presentation
<i>Academic Winter Break</i>		
7–9 10 11–12	Reflections 4–6 Reflection 7 Reflections 8–9	Iterative Development Beta Presentation Final Polish / Optimization
13	Reflection 10	Final Showcase

3.1.1 Course Structure. This full-credit Algonquin College design studio (8 contact hours/ week) is a third-year requirement in the Bachelor of Information Technology: Interactive Multimedia and Design (BIT: IMD) program - a joint program between Algonquin College and Carleton University². The curriculum emphasizes an HCI perspective, specifically focusing on *interaction retargeting*, ensuring usability across desktop and HMD, and *user agency* within the constraints of web-based spatial rendering. The studio model transitions from foundational lectures on reality-based frameworks [17] to self-guided, agile group development. Foundational reference materials include works by Jerald [18], LaViola et al. [20], and MacKenzie [21]. The course assessment (see Table 1) balances individual technical proficiency (42%) with group-based project milestones (48%).

3.1.2 Study Design and Context. We conducted a two-year longitudinal study across the 2024 and 2025 cohorts. In 2024, students developed a "VR escape room" for a museum client to enhance engagement with 3D-scanned artifacts. In 2025, the study was replicated with an arts-organization client to validate the findings in a different GLAM (Galleries, Libraries, Archives, and Museums) context. To address hardware equity and accessibility, students had access to Meta Quest 3 HMDs for testing but were mandated to ensure multi-platform compatibility. To mitigate bias, Researcher 2 (R2) and Researcher 3 (R3) acted as neutral participant-observers, managing consent and anonymizing all data. The lead instructor (R1) remained blinded to the data until after final grades were submitted. This "Action Research" approach allowed R1's expertise as a framework contributor to assist in troubleshooting while ensuring the research analysis remained objective.

3.1.3 Participants. We utilized convenience sampling of students enrolled in the course. In 2024, 26 of 29 students consented; in 2025, 19 of 29 students consented, for a total of $N = 45$ participants. Data was not collected or analyzed from non-consenting students. Pre-study questionnaires characterized both cohorts as "heavy technology users but novice VR creators": 92–100% reported extreme comfort with digital technologies, yet 73–84% reported zero hours of prior HMD VR usage per week. Due to ethics board requirements for small-cohort anonymity, age and gender demographics were not collected.

3.1.4 Software and Tooling. Students utilized the *Circles XR* learning framework, built upon A-Frame [2]. Unlike closed-source alternatives, Circles was chosen for its "Glass-Box" transparency, which

²<https://bitdegree.ca/>

Table 2: This table presents the supported VR platforms for each group project in the 2024 cohort: desktop VR (DVR), mobile/tablet VR (MVR), and HMD VR (HVR). Additionally, the table indicates whether accessibility or social features beyond Circles’ specific implementation were fully implemented () or only partially implemented (*) in the 2024 cohort.**

Group	DVR	MVR	HVR	Accessibility	Social
1	**		**	**	*
2	**	**		*	**
3	**				*
4	**	**	**		
5	**	**		**	**
6	**	**		**	
7	**				*

makes the entire framework accessible and modifiable, enabling students to explore, modify, and understand the underlying codebase. Other common VR development frameworks, such as Unity and Unreal, were also considered, but since developing multi-platform VR experiences for learning contexts was a core requirement, we decided that creating build targets, installs, and code-signing for each respective platform (e.g., desktop, mobile, HMD) would increase testing and tooling development frictions beyond the scope of the class. WebXR frameworks such as A-Frame and Circles, by comparison, support a build-once, deploy-everywhere model, available in any supporting browser, such as Chrome. Students also used GitHub for version control and Visual Studio Code as their IDE. These tools were selected to align with professional WebXR specifications [40] and to require students to confront the technical challenges of web-based networking and multi-platform interactions.

3.1.5 Data Collection and Analysis. Data collection comprised of weekly text-based reflections ($N = 10$ per student), transcriptions of milestone presentations, researcher field notes (64 contact hours per year), and a concluding semi-structured focus group. We employed *Reflexive Thematic Analysis* (TA) [8], moving through iterative phases of familiarization, coding, and theme development. R1 and R2 coded the 2024 data independently to establish a thematic framework; R3’s 2025 data were then used for *temporal triangulation*, cross-referencing Year 2 reflections, and the Section 4 case studies, against Year 1 themes to ensure findings remained stable across different clients and student cohorts through a deductive coding approach. Due to the lower number of students who consented to the study in 2025, we acknowledge that the identified themes in this cohort are weaker than in 2024, but the process was still meaningful as the codes and themes that emerged remained similar to the larger dataset of the 2024 cohort.

3.2 Study Results

Our findings are derived from a reflexive thematic analysis of 45 student developers across two cohorts [8]. While $N = 45$ students were studied in total, the initial thematic framework and deep-dive interaction analysis focused on the 7 projects from the 2024 cohort (as shown in Fig. 1 and Table 2). To ensure longitudinal consistency and the stability of our findings, data from the 2025 cohort ($N =$

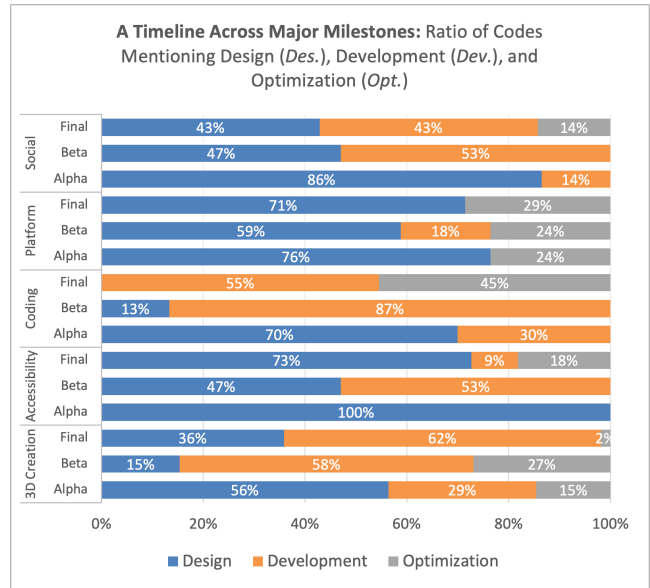


Figure 2: A normalized visualization showcasing the ratio of codes noting 3D creation, Accessibility, Coding, Platform, and Social Development were found in the minor milestones (participant reflections) where work was completed for each major milestone (alpha, beta, and final presentations) of the 2024 cohort. The high-level codes were thematically grouped into the design (Des.), development (Dev.), and optimization (Opt.) phases, illustrating how priorities shifted over time throughout the project.

Table 3: Mapping Pedagogical Challenges (PCs) to Student Reflections across 2024 and 2025 Cohorts.

Pedagogical Challenge	2024 Student Reflection (Museum)	2025 Student Reflection (New Media Arts)
PC.1: Platform Bias	"Developing on a laptop made it easy to ignore how the UI felt in the headset. We only realized the buttons were too high once we did the final VR export."	"The lag on the mobile headset was a shock compared to the desktop preview. We had to strip away half our lighting effects just to make it playable."
PC.2: Expectations vs. Exploration	"The client wanted a very literal 'museum' look, but we felt that just placing 2D pictures on 3D walls was a waste of what VR can actually do."	"I felt stuck between making a 'safe' project that met the brief and trying a more abstract interaction that I wasn't sure would work by the deadline."
PC.3: Workflow Paralysis	"We spent three weeks just trying to get the 3D models to export correctly with textures. By the time they were in, we had no time left for the actual coding."	"The technical hurdles of asset optimization were constant. It felt like the creative design part was always being pushed aside to fix broken glTF files."
PC.4: Glass-Box Logic Gap	"The framework handled the 'grabbing' but I didn't understand how. When I wanted to change the distance of the grab, I was totally lost in the black box."	"I finally understood how 'parenting' worked in A-Frame. Before that, every time I moved the camera, my UI disappeared and I didn't know why."
PC.5: Accessibility Gap	"We planned to add audio narration, but it became a 'nice-to-have' feature that we ran out of time for because the visual bugs were more urgent."	"Accessibility felt like a checklist we had to do at the end. We didn't really design with it in mind from the start, so it felt like an afterthought."

19) were used for temporal triangulation, cross-referencing Year 2 reflections against Year 1 themes. From this analysis, we identify five primary Pedagogical Challenges (PCs) (Table 3) that characterize the tension between HCI intent and technical execution (Table 4).

(PC.1) Platform Bias: Participants prioritized desktop VR workflows because of their familiarity with development environments. While all 2024 teams ($n = 7$) achieved desktop functionality, only 28% successfully implemented HMD support (Table 2). This "Desktop Trap" led to deferred testing; as one student noted, they assumed "locomotion... will remain consistent across platforms," failing to account for the unique spatial requirements of HMDs.

(PC.2) Expectations Versus Exploration: Balancing "client authenticity" (e.g., high-fidelity museum scans) with performance-constrained creative exploration. Students reported feeling "less incentive to go farther" when restricted by narrow client prompts, leading to a focus on compliance rather than innovation.

(PC.3) Workflow Paralysis: 3D modeling and glTF optimization consumed disproportionate effort. The friction of "fiddling" with textures to support mobile performance crowded out time for HCI-specific interaction design, as seen in the low frequency of "Optimization" codes in Figure 2. Though higher-level frameworks such as Unity and Unreal have more feature-rich 3D importers that support and convert multiple 3D formats automatically, optimization of the 3D models so that work well across different VR platforms suggests challenges beyond the development framework chosen (e.g., Circles, A-Frame, Unity, or Unreal) and more knowledge required on 3D formats and construction and how best for VR designers and developers to create 3D assets that are high-fidelity and performant.

(PC.4) Glass-Box Logic Gap: While high-level coding was sparse, students struggled with the underlying spatial logic of A-Frame. The transition from "black-box" usage to "Glass-Box" tinkering (e.g., understanding camera parenting within the development frameworks) was the primary threshold for technical breakthroughs. However, in some cases, additional guidance from instructors was required (e.g., ad hoc lessons on 3D computer graphics fundamentals) to support student learning.

(PC.5) Accessibility Gap: Despite client mandates, visual design consistently took precedence. Only 57% of the 2024 groups (4/7) implemented accessibility features beyond default settings (Table 2). Audio and inclusive UI were frequently "delayed" in reflections, prioritized only after visual aesthetics were finalized.

3.2.1 Longitudinal Stability (2024 vs. 2025). While the primary thematic framework was derived from the 2024 cohort, data from the 2025 cohort ($N = 19$) were analyzed using a deductive thematic approach to evaluate the stability of these Pedagogical Challenges, using the 2024 codes as a starting point. Despite the shift in client context (from Museum to New Media Arts), 100% of the 2025 student reflections mapped directly to the five identified PCs. The most persistent challenges across both years were *PC.1 (Platform Bias)* and *PC.3 (Workflow Paralysis)*, appearing in 84% and 79% of reflections respectively. This continuity suggests that these frictions are inherent to the novice 3D development cycle rather than specific to a single project type, and that many challenges can be generalized across varying development contexts, thereby also offering opportunities to generalize VR teaching methodologies.

4 Case Studies

The following two case studies were authored by the student developers (Authors 4–13) as part of their final project post-mortems. These narratives provide a qualitative, autoethnographical view of the design and development process, highlighting how the pedagogical challenges (PCs) identified in previous sections were navigated within specific creative contexts. Note that the student case-study authors were not involved in any analysis or writing outside of these case studies.



Figure 3: At the beginning of "The Journey" and meeting the virtual guide - Gea, a question is posed to the user on the path, and the Final statue gallery with users viewing the saved avatar of another user who has completed The Journey.

4.1 "The Journey": Virtual Self-Reflection

Overview: Virtual Reality (VR) is a powerful tool for exploring embodiment [14], learning [29], and self-reflection [5]. Similar to Bahng et al.'s work on VR as a reflexive storytelling medium and the identified dimension of "The Use of Abstract and Minimal Aesthetics" [5], we built "The Journey" as a multi-user, multi-platform interactive experience in which individuals journey through abstract environments and define their avatar's appearance. The Journey explores personal narratives, guiding the user along a path but allowing them to influence an outcome (how the avatar appears). The choices made and the resulting shapes the user embodies as their avatar are intended to prompt self-reflection both within and beyond the VR experience.

At the beginning of the experience, the user encounters a godlike character named Gea, who introduces the user (Figure 3). The user walks down a path containing several personal questions. Along the path, they are confronted with questions such as "What is success?" and "When you are thinking, where do you spend the most time?" As the user makes these choices, they will be rewarded with an abstract shape representing that decision, which will attach to their avatar. The user will experience several of these trials and, in the process, become a walking piece of unique abstract art, representing how their choices have shaped their body shape and colour.

Once the user has completed their journey on the path, they can add themselves to a gallery alongside other users who have similarly walked the path (Figure 3). This social VR element allows users to share their unique experiences with others. The Journey was developed using the learning VR framework Circles [30], which

allows us to focus on simple individual and social interactions that scale across multiple VR platforms, such as mobile phones and standalone VR headsets (e.g., the Meta Quest 3). Building for lower-powered mobile platforms inspired an abstract visual approach that aligned well with Bahng et al.'s observation that abstract visuals "allowed people to project their feelings and thoughts onto the piece with some emotional distance" [5].

Design: As *The Journey* was created for educational contexts, it was important to us that it be accessible and available on a variety of devices, with each device having a control scheme that fits its hardware. We implemented several accessibility options, including keyboard and mouse controls for PC players, tap-to-move controls for mobile, and teleportation pads for VR. The teleport pads also help avoid cybersickness commonly experienced in VR, though joystick "smooth locomotion" options were also available for advanced users. Beyond platform-specific controls, we also included narration for all questions and answers to help visually impaired individuals better understand the questions.

The *Journey* is intended as a metaphor for self-discovery. The main draw of the experience is that your choices are reflected in your avatar as you progress. It's an explicit way to show how our choices define who we are, not only to the world around us but also to ourselves [35].

It is essential that the questions affect your character's outcome, but they don't always end the same way. For example, the output is partially random, ensuring that every individual who passes through the experience will be at least slightly different, whether it's a subtle hue shift or a stretched or squashed shape; every user's avatar is unique, even if multiple users have the same answers. Once the user is finished, they enter the gallery, which is filled with statues, allowing them to observe the different outcomes of others who have also completed *The Journey*. At the end of the path, users will finally see the artwork they have become as a result of all their choices. However, they may not fully understand what that means. By the end of the path, your character is left behind in the gallery as evidence of your journey, and how the choices you made, though different, led you to the same place as everyone else.



Figure 4: The main hub environment of "Echoes of the Mind." The coloured spheres are placed in cylinders near each of the three experience doors (Alpha, Delta, Gamma) and serve as voting tools to asynchronously communicate to other users what you thought of each experience.

4.2 "Echoes of the Mind": Learning about Brainwaves Through Visual Analogy

Overview: In neuroscience, brain waves are electrical signals associated with different cognitive states [38], yet they are typically presented only as diagrams or text. To make learning more engaging and accessible, we developed *Echoes of the Mind*, a prototype virtual reality (VR) experience that uses visual metaphors and social interactions. The VR medium was chosen for its ability to boost engagement through shared learning activities [29, 36]. *Echoes of the Mind* includes three environments representing Delta, Alpha, and Gamma waves, each with unique audio-visual interpretations and social interactions. This multisensory approach lets users explore brain waves while fostering collaborative learning. Persistent visualizations of collective user emotions, as a voting system, encourage reflection through shared emotional footprints.

Echoes of the Mind comprises three brainwave environments and a central hub that connects users to each experience. It supports mobile, desktop, and head-mounted display (HMD) VR devices, with accessibility considerations tailored to each platform. The central hub is an abstract representation of a neuron, where users first spawn and configure accessibility settings, such as guiding text, post-processing effects, and teleport pad opacity (Figure 4). The central hub's purpose is to allow users to explore brainwave environments and to display visualizations of users' felt emotions.

Design: Each brainwave environment and the central hub include social interactions that support collaborative learning affordances [12]. Interaction styles match brainwave frequencies: lower-frequency environments encourage reflection through simpler activities, whereas higher-frequency environments involve more active engagement. In Delta, users observe avatars interacting with and releasing memory orbs; in Alpha, they search for books together; in Gamma, they collaboratively guess shapes, tracking others' selections to maintain focus.

After visiting an environment, users return to the hub, choose an emotion—joyful, peaceful, sad, unsettled, or focused—from a dispenser, and place it into a visualization tank (Figure 4). Persistent visualizations in the central orb and next to each environment's entrance scale proportionally to reflect votes. This emotion-voting system encourages reflection and fosters a connection to the collective emotional footprint of past participants.

To illustrate the multisensory mapping of neurological signals, the experience features three distinct environments (Fig. 4):

- **Delta (Deep Sleep/Consolidation):** A low-frequency, dark neural dome with an ambient soundscape and a pulsating "heartbeat" memory core [1]. Users pick up fallen "short-term memories" and release them to trigger fading memory sounds, representing the fragility of memory consolidation.
- **Alpha (Relaxation):** A middle-frequency environment set in a warmly lit library with a fireplace and rain Foley. To elicit alpha-band EEG patterns [39], users search for books to place on lecterns, triggering layers of Mozart's K. 448.
- **Gamma (High Focus):** A high-frequency, sterile white hall with walls pulsating to a fast-paced polyrhythmic soundtrack [1]. Users must click brightly coloured geometric shapes in a specific patterned order, simulating the high-demand information processing associated with this brainwave state.

Table 4: Mapping Observed Themes to Pedagogical Contributions

Pedagogical Challenge	Teaching Consideration
PC.1: Platform Bias	TC.3: HMD-First Milestones
PC.2: Expectations Versus Exploration	TC.5: Transdisciplinary Reflection
PC.3: Workflow Paralysis	TC.2: Aesthetic-Hardware Alignment
PC.4: Glass-Box Logic Gap	TC.4: Framework Transparency
PC.5: Accessibility Gap	TC.1: Early Scaffolding

4.3 Case Study Results

The thematic tensions and pedagogical challenges identified in Section 4 are most visible in the divergence between early student prototypes and these final artifacts. These two projects specifically illustrate a successful navigation of the identified constraints through distinct HCI strategies.

Navigating Platform Bias (PC.1): "The Journey" team initially struggled with a desktop-centric development workflow, leading to performance lag on HMD and mobile hardware. However, by embracing an abstract, low-poly aesthetic, they achieved a functional "Aesthetic-Hardware Alignment." This style allowed them to maintain a stable frame rate across all three target platforms without sacrificing the "reflexive storytelling" goals they prioritized in their early reflections [5]. This case suggests that when students are forced to confront multi-platform parity early, they move from "visual-first" design to "performance-aware" HCI.

Overcoming the Logic Gap (PC.4): "Echoes of the Mind" serves as a primary example of overcoming the friction inherent in the WebXR coding ecosystem. While many teams found the framework components limiting, a developer in this group noted a significant technical breakthrough in understanding the "Glass-Box" logic of the engine:

"A breakthrough came with my ability to understand and implement parenting and preparenting of objects to cameras... I was able to figure out a way the user can pick up the object and put it down."

By mastering these underlying spatial relationships rather than relying on pre-built "black-box" scripts, the team moved beyond standard UI patterns. They successfully addressed the Accessibility Gap (PC.5) by implementing a custom multisensory interface where spatialized audio and haptic-visual analogies (the "memory orbs") served as primary navigational cues, rather than relying on traditional 2D text overlays.

Synthesis of Findings: Both cases demonstrate that, although the *3D Workflow* (PC.3) initially paralyzes novice developers, a transparent, modifiable framework enables students to bypass technical friction. These examples validate that a client-driven studio environment, when supported by appropriate scaffolding, can encourage students to prioritize human factors and universal design even within highly complex 3DUI development.

5 Discussion

The findings of this two-year study reveal a persistent tension between high-level pedagogical goals—accessibility, multi-platform parity, and social interactivity—and the technical friction inherent in novice VR development. Our findings contribute to the emerging

field of Creator Experience (CX) [31] in a GLAM context, where accessibility, multi-platform development, and social considerations are significant. While previous studies also identify technical hurdles [16] and the value of multidisciplinary team-based practical projects [11, 13], we provide a structured mapping of how these hurdles (PCs) specifically distort HCI design intent—such as how Platform Bias (PC.1) directly leads to the de-prioritization of accessibility (PC.5). This study also provides further evidence for the importance of project-based teaching strategies to help enhance and encourage the multidisciplinary learning skills required for VR development. To lay a more concrete foundation for future VR course development, we propose five Teaching Considerations (TCs) derived from the observed Pedagogical Challenges (PCs) (see Table 4).

Countering Platform Bias (PC.1 → TC.3): Our data identified a significant "Desktop Trap," in which the convenience of 2D development biases students against immersive testing. This bias led to "interaction retargeting" failures, in which mouse-click logic did not translate into 6DOF trigger haptics. To counter this, we propose *HMD-First Milestones* (TC.3). By mandating weekly cross-platform demos and in-class HMD rotations, instructors can ensure that multi-platform parity is treated as an iterative requirement rather than a post-production fix.

Resolving Workflow Paralysis (PC.3 → TC.2): A recurring friction point was "3D Workflow Dominance," where the labour-intensive nature of modelling and gTf optimization reduced time for HCI logic. This friction often resulted in "Workflow Paralysis" that compromised mobile performance. We recommend *Aesthetic-Hardware Alignment* (TC.2), as demonstrated in "The Journey" case study. By guiding students toward "performance-first" aesthetics (e.g., low-poly or stylized environments), curricula can ensure stability across mobile VR and WebXR without sacrificing creative intent.

Closing the Glass-Box Logic Gap (PC.4 → TC.4): By prioritizing *Framework Transparency* (TC.4), curricula can leverage the "Glass-Box" nature of A-Frame and Circles, where the underlying HTML DOM and JavaScript codebase is visible to help novices explore and understand concepts such as spatial parenting, entity-component systems, and event-driven logic. For example, teams changed core components of the Circles framework that are normally inaccessible in other "black-box" frameworks, such as Unity, to enable networking features that are not built in. From the case studies described in this paper, this includes modifying the default avatars to replace them with geometric shapes in "The Journey" or attempting to add data persistence through Firebase in "Echoes of the Mind" so that modifications to the voting elements in the hub world remained even after the world was reloaded for all. These novel features required additional knowledge beyond the lecture components of this course, including data persistence, 3D scene graphs, and 3D parenting, which students were enthusiastic to self-teach and discuss with the instructor, now motivated by their own ideas and the open-ended nature of the design studio teaching format. As seen in "Echoes of the Mind", mastering this underlying logic is the primary threshold for moving from "making it work" to "making it usable."

Bridging the Accessibility Gap (PC.5 → TC.1): The "Visual-First" bias frequently led accessibility to be treated as a secondary

optimization. Because VR accessibility definitions remained vague to novices, implementation was often deferred or omitted. We propose *Early Accessibility Scaffolding (TC.1)*, integrating concrete universal design checklists (e.g., teleportation, audio narration, UI scaling) as graded checkpoints starting in Week 1. This shifts accessibility from a "feature to be added" to a "standard to be met."

Navigating Expectations Versus Exploration (PC.2 → TC.5): Finally, the "Expectations Versus Exploration" observations in 2024 highlight the difficulty of balancing client "authenticity" with universal design. We recommend *Transdisciplinary Reflection (TC.5)*, using peer critiques and client-integrated pitch sessions to broaden students' inclusive perspectives during the ideation phases.

5.1 Generalizability Across Contexts

We acknowledge that *PC.1 (Platform Bias)* is likely exacerbated by the web-based nature of our tools; since the prototypes run natively in a desktop browser, the friction of "switching" to an HMD may appear less necessary. In contrast, students using game engines such as Unity or Unreal may face additional frictions, including long build times, device installation, or tethering requirements. However, we argue that the core of Platform Bias, the tendency to prioritize the more comfortable, 2D development environment over the immersive target environment, is a universal hurdle in XR education regardless of the framework used. *Additionally, this is also an important consideration to note in any study discussing VR development, especially for WebXR, where it is not always clear what "VR" means - is it HMD VR, or mostly desktop VR? Increased transparency around this is critical.*

Also, our findings regarding *PC.2 (Expectations vs. Exploration)* are inherently tied to our studio's use of real-world clients. In a purely skill-based lab without external stakeholders, this tension might be absent. However, we believe this challenge is representative of "professional-track" HCI education, in which students must bridge the gap between client requirements and the unique affordances of immersive media.

Regarding *PC.4 (The Logic Gap)*, the manifestation of "Black-Box" frustration is specific to the declarative, component-based architecture of A-Frame. In a lower-level environment (e.g., Three.js or C++), the logic gap might instead manifest as "Mathematical Paralysis." However, our proposed *TC.4 (Framework Transparency)* remains generalizable: whether a tool is DOM-based or script-based, instructors must provide "Glass-Box" visibility into how high-level abstractions (like "teleportation" or "grabbing") translate into low-level transformations.

Finally, the team-based structure of our studio ($n = 14$ teams) naturally encouraged task specialization. While this mirrors industry workflows, it potentially masks individual learning trajectories. Future work should investigate whether *PC.3 (Workflow Paralysis)* is more or less severe in solo "micro-projects" in which a single student must bridge the gap between 3D asset creation and HCI logic without a teammate's support.

6 Limitations and Future Work

Generalizability and Researcher Positionality: While this study provides a two-year longitudinal perspective ($N = 45$), it was conducted within a single third-year design studio. The observed

Platform Bias (PC.1) and *Workflow Paralysis (PC.3)* may manifest differently in graduate seminars or professional workshops with greater hardware resources. Furthermore, although we employed de-identified analysis to minimize bias, the researchers' expertise in the *Circles* and *A-Frame* ecosystems may have influenced the thematic interpretation of students' technical "breakthroughs." Future work should involve multi-institutional studies to evaluate these pedagogical challenges across diverse instructional contexts.

Specialization and Individual Trajectories: The team-based nature of the studio ($N = 12$ teams) often led to task specialization, where individual students focused exclusively on either 3D modelling or logic. This division of labour can obscure individual learning trajectories. While this mirrors industry workflows [11], it complicates the assessment of how a single student navigates the transition from designer to developer. Future studies should employ "micro-projects" to isolate the acquisition of specific HCI skills versus team-managed design outcomes.

Stakeholder Gaps in Inclusive Design: A significant limitation is the lack of direct participation by participants with disabilities in the co-design or testing phases. Consequently, the "Accessibility Optimization" instances recorded ($N = 2$) represent student *perceptions* of accessibility rather than validated inclusive outcomes. To move from "theoretical compliance" to authentic evaluation, future iterations of this studio must integrate participatory design sessions with disabled museum-goers and community stakeholders.

Toward an Open-Source VR Teaching Toolkit: The challenges identified in this work highlight a fragmented landscape in XR education. Future efforts should focus on developing *open-source VR teaching toolkits* that standardize interaction scaffolds and accessibility protocols, building on existing resources from the HCI community [33]. We intend to replicate this studio model across diverse departments (e.g., Fine Arts vs. Computer Science) to evaluate the adaptability of our Teaching Considerations (TCs). By formalizing these insights into shared, community-driven resources, we can lower the "entry floor" for novice instructors while raising the "innovation ceiling" for student creators in the immersive arts.

7 Conclusion

This two-year longitudinal study ($N = 45$) highlights the persistent tensions between technical implementation and human-centred design in novice VR development. By analyzing student progress through the lens of five *Pedagogical Challenges (PCs)*, we identified a systemic "Platform Bias" and an "Accessibility Implementation Gap" that relegate inclusive design to a secondary polish phase.

Our findings suggest that transitioning from a "Visual-First" to an "HCI-First" development model requires more than robust software; it demands a pedagogical shift toward "Glass-Box" frameworks and structured milestones that mandate early interaction testing on target hardware. The success of projects such as *The Journey* and *Echoes of the Mind* demonstrates that when students are provided with transparent, modifiable coding ecosystems, such as A-Frame and Circles, they can move beyond "black-box" constraints to create sophisticated, accessible, and social immersive experiences.

Moving forward, these results should inform the design of future VR curricula by prioritizing *Creator Experience (CX)* alongside user

experience. We propose that the next step for the immersive education community is to develop *open-source VR teaching toolkits* to standardize the fragmented landscape of VR pedagogy. By formalizing our *Teaching Considerations* (TCs) as shared, community-driven resources, we can better equip educators to train a new generation of developers to build equitable, inclusive, and usable virtual worlds for GLAM institutions and beyond.

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References

- [1] [n. d.]. The Science of Brainwaves – The Language of the Brain. <https://nhahealth.com/brainwaves-the-language/>
- [2] A-Frame. 2015. A-Frame. <https://aframe.io/>
- [3] Joel C. Adams and Joshua Hotrop. 2008. Building an economical VR system for CS education. In *ITiCSE*. ACM, Madrid Spain, 148–152. doi:10.1145/1384271.1384312
- [4] Wagner James Au. 2023. *Making a metaverse that matters*. John Wiley and Sons Inc., Hoboken, New Jersey.
- [5] Sojung Bahng, Ryan M. Kelly, and Jon McCormack. 2020. Reflexive VR Storytelling Design Beyond Immersion: Facilitating Self-Reflection on Death and Loneliness. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. ACM, Honolulu HI USA, 1–13. doi:10.1145/3313831.3376582
- [6] D. H. Bell. 1996. Teaching virtual reality. *ACM SIGCSE Bulletin* 28, 2 (June 1996), 56–61. doi:10.1145/228296.228306
- [7] Beatrice Hope Benton-Borghini. 2013. A universally designed for learning (UDL) infused technological pedagogical content knowledge (TPACK) practitioners' model essential for teacher preparation in the 21st century. *Journal of Educational Computing Research* 48, 2 (2013), 245–265. doi:10.2190/EC.48.2.g
- [8] Virginia Braun and Victoria Clarke. 2019. Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health* 11, 4 (Aug. 2019), 589–597. doi:10.1080/2159676X.2019.1628806
- [9] Grigore C. Burdea. 2004. Teaching virtual reality: why and how? *Presence: Teleoperators and Virtual Environments* 13, 4 (Aug. 2004), 463–483. doi:10.1162/1054746041944812 Place: Cambridge, MA, USA.
- [10] Freyja Catton and Laura Smith. 2021. Museums without walls: a temporal analysis of virtual exhibitions in GLAM institutions. *Pathfinder: a Canadian Journal for Information Science Students and Early Career Professionals* 2, 2 (May 2021), 72–85. doi:10.29173/pathfinder31
- [11] Daniel C. Cliburn. 2018. A cross-disciplinary course on virtual reality. In *2018 IEEE Frontiers in Education Conference (FIE)*. IEEE, San Jose, CA, USA, 1–5. doi:10.1109/FIE.2018.8659016
- [12] Barney Dalgarno and Mark J W Lee. 2010. What are the learning affordances of 3-D Virtual environments? *British Journal of Educational Technology* 41, 1 (2010), 10–32. doi:10.1111/j.1467-8535.2009.01038.x
- [13] Ralf Doerner and Robin Horst. 2022. Overcoming challenges when teaching hands-on courses about virtual reality and augmented reality: methods, techniques and best practice. *Graphics and Visual Computing* 6 (June 2022), 200037. doi:10.1016/j.gvc.2021.200037
- [14] Guo Freeman, Dane Acena, Nathan J. McNeese, and Kelsea Schulenberg. 2022. Working Together Apart through Embodiment: Engaging in Everyday Collaborative Activities in Social Virtual Reality. *Proceedings of the ACM on Human-Computer Interaction* 6, GROUP (Jan. 2022), 1–25. doi:10.1145/3492836
- [15] Polina Häfner, Victor Häfner, and Jivka Ovtcharova. 2013. Teaching methodology for virtual reality practical course in engineering education. *Procedia Computer Science* 25 (2013), 251–260. doi:10.1016/j.procs.2013.11.031
- [16] Ruslan Isaev and Ruslan Migranov. 2025. Designing a 3D and virtual reality course: integrating technology and creativity for immersive learning. doi:10.20944/preprints202501.1141.v1
- [17] Robert J K Jacob, Audrey Girouard, Michael S Horn, and Jamie Zigelbaum. 2008. Reality-Based Interaction : A Framework for Post-WIMP Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM. doi:10.1145/1357054.1357089
- [18] Jason Jerald. 2015. *The VR book: human-centered design for virtual reality*. Morgan & Claypool publishers and ACM Books. doi:10.1145/2792790
- [19] Margaret King-Sears. 2009. Universal design for learning: technology and pedagogy. *Learning Disability Quarterly* 32, 4 (Nov. 2009), 199–201. doi:10.2307/27740372
- [20] Joseph J. LaViola Jr., Ernst Kruijff, Ryan P. McMahon, Doug A. Bowman, and Ivan P. Poupyrev. 2017. *3D user interfaces: theory and practice (usability)*. Addison-Wesley.
- [21] Scott I. MacKenzie. 2024. *Human-computer interaction: an empirical research perspective* (2 ed.). Elsevier. doi:10.1016/C2022-0-02755-0
- [22] Bernardo Marques, Beatriz Sousa Santos, and Paulo Dias. 2024. Ten years of immersive education: overview of a virtual and augmented reality course at postgraduate level. *Computers & Graphics* 124 (Nov. 2024), 104088. doi:10.1016/j.cag.2024.104088
- [23] Maram Meccawy. 2022. Creating an immersive XR learning experience: a roadmap for educators. *Electronics* 11, 21 (Oct. 2022), 3547. doi:10.3390/electronics11213547
- [24] Martez Mott, John Tang, Shaun Kane, Edward Cutrell, and Meredith Ringel Morris. 2020. "I just went into it assuming that I wouldn't be able to have the full experience": understanding the accessibility of virtual reality for people with limited mobility. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, 1–13. doi:10.1145/3373625.3416998 Series Title: ASSETS '20.
- [25] Ville Mäkelä, Cayley MacArthur, Jieun Lee, and Daniel Harley. 2025. Integrating virtual reality head-mounted displays into higher education classrooms on a large scale. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–16. doi:10.1145/3706598.3713690
- [26] Vinh T. Nguyen, Kwanghee Jung, and Tommy Dang. 2019. Creating virtual reality and augmented reality development in classroom: is it a hype? In *2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. IEEE, San Diego, CA, USA, 212–2125. doi:10.1109/AIVR46125.2019.00045
- [27] Qualcomm. 2018. Extended Reality. <https://www.qualcomm.com/invention/cognitive-technologies/immersive-experiences/extended-reality>
- [28] Nancy Rodriguez. 2016. Teaching virtual reality with affordable technologies. In *Human-computer interaction. Theory, design, development and practice*, Masaaki Kuroso (Ed.). Vol. 9731. Springer International Publishing, Cham, 89–97. doi:10.1007/978-3-319-39510-4_9 Series Title: Lecture Notes in Computer Science.
- [29] Anthony Scavarelli, Ali Arya, and Robert J. Teather. 2021. Virtual reality and augmented reality in social learning spaces: a literature review. *Virtual Reality* 25, 1 (March 2021), 257–277. doi:10.1007/s10055-020-00444-8
- [30] Anthony Scavarelli, Ali Arya, and Robert J. Teather. 2024. Circles: a framework for creating inclusive virtual reality learning activities in social learning spaces. In *Immersive Learning Research - Academic*, Vol. 1. The Immersive Learning Research Network, Glasgow, Scotland, UK, 1–11. doi:10.56198/U6COWWZCX
- [31] Anthony Scavarelli, Ali Arya, Robert J. Teather, Rebecca Wakelin, Sarah Gauen, and Julie McCann. 2025. Exploring the inclusive design and use of social multi-platform virtual reality for a post-secondary gender diversity workshop. In *Immersive learning research network*. Vol. 2271. Springer Nature Switzerland, Cham, 272–283. doi:10.1007/978-3-031-80475-5_20
- [32] Michael Schwaiger, Mitja Krajinčan, Matej Vuković, Matija Jenko, and Daniel Doz. 2024. Educators' opinions about VR/AR/XR: an exploratory study. *Education and Information Technologies* 29, 18 (Dec. 2024), 24861–24880. doi:10.1007/s10639-024-12808-7
- [33] Valentin Schwind, Stefan Resch, and Jessica Sehr. 2023. The HCI user studies toolkit: supporting study designing and planning for undergraduates and novice researchers in human-computer interaction. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM, Hamburg Germany, 1–7. doi:10.1145/3544549.3585890
- [34] Ruchi Sembey, Roberto Martinez-Maldonado, and John Grundy. 2026. Considerations for VR integration into human-centered computing education. *ACM Transactions on Computing Education* 26, 2 (June 2026), 1–24. doi:10.1145/3795531
- [35] Daniel J. Siegel. 2020. *The developing mind: how relationships and the brain interact to shape who we are*. Guilford Publications.
- [36] Laura Simon, Lina Klass, Anton Benjamin Lammert, Bernd Froehlich, Jan Ehlers, and Eva Hornecker. 2024. Social VR activities should support ongoing conversation - comparing older and young adults desires and requirements. In *ACM Symposium on Spatial User Interaction*. ACM, Trier Germany, 1–13. doi:10.1145/3677386.3682089
- [37] Sarah Serman, Miriam Sturdee, and Angela Miguel. 2026. Sketching snapshots: reflecting on human-computer interaction education through sketching. *ACM Transactions on Computer-Human Interaction* 33, 1 (Feb. 2026), 1–53. doi:10.1145/3771924
- [38] Shao Kuo Tai and Yu Kai Lin. 2018. The influence of different kinds of music on brainwave signals. In *2018 IEEE International Conference on Advanced Manufacturing (ICAM)*. IEEE, Yunlin, 223–226. doi:10.1109/AMCON.2018.8614971
- [39] Walter Verruso, Evaristo Ettore, Edoardo Vicenzini, Nicola Vanacore, Mauro Cacciarella, and Oriano Mecarelli. 2015. The Mozart effect: a quantitative EEG study. *Consciousness and Cognition* 35 (Sept. 2015), 150–155. doi:10.1016/j.concog.2015.05.005
- [40] W3C. 2019. WebXR Device API. <https://www.w3.org/TR/webxr/>