# Reclaiming VR Design Authority: Deaf Signers Shaping Immersive Classrooms

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## Abstract

Deaf students face a persistent visual attention split between signer and instructional materials. Although virtual reality (VR) is often promoted as an educational solution, it typically reinforces hearing norms (e.g., caption overlays or interpreter boxes onto hearing classrooms). Our work foregrounds Deaf leadership and reclaims VR design authority: in a mixed-hearing team led by Deaf scholars, we designed and evaluated a VR classroom prototype featuring three signer-placement modes: corner, parallel, and transparent. Twelve Deaf participants explored the prototype during a 15-minute lecture and participated in qualitative semi-structured interviews. Participants reported reduced attention split and improved visibility, and suggested VR may support flexibility and comprehension in Deaf learning. From these reflections, we introduce a five-dimension conceptual framework—proximity, customizability, visual efficiency, cultural fit, and task flexibility—that organizes how Deaf signers evaluate signer placements. This work moves Deaf Tech theory into practice, opening pathways for future Deaf-centered, culturally grounded HCI.

## CCS Concepts

• **Human-centered computing → Accessibility technologies**.

## Keywords

Accessibility, Deaf and Hard of Hearing, Virtual Reality, Visual Attention Split, Deaf Tech

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## 1 Introduction

Access to effective learning environments remains challenging for Deaf and Hard of Hearing (DHH) individuals who primarily use sign language [92], referred to in this paper as Deaf[1] signers. These challenges are especially visible in online and remote classrooms, where learning depends almost entirely on visual communication [66, 110]. Unlike hearing students, who can follow spoken lectures without sustained eye contact, Deaf students continually must split attention between the signing lecturer and instructional materials [87, 92]. This constant shifting of gaze leads to cognitive overload, eye fatigue, and information loss, making it difficult to engage with course content [108, 109].

Virtual Reality (VR) has shown potential in supporting Deaf education. Although much instructional content in VR is still presented in 2D, VR environments support three-dimensional configurations such as adjustable viewing distance and flexible spatial relationships between the signer and instructional materials, which offer possibilities not available in traditional 2D video interfaces [103]. Prior VR work has explored subtitling [1, 73] and captioning [69, 135], multimodal sound visualization [71, 96], and avatar-based sign language interaction [27]. While these studies demonstrate promise, most focus on hearing-centered, interpreter-mediated experiences [7, 104] or on sign language learning for hearing users [4]. Such approaches treat Deaf participation as an *after-the-fact* retrofit[2] [13, 59, 134], which, while helpful, often do not reflect the reality of Deaf life, require Deaf people to adapt to hearing defaults, and rarely address Deaf users' full needs [35, 41, 51]. Angelini et al.'s critical

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[1] Capital "D" Deaf refers to individuals who identify with Deaf culture and use sign language, whereas lowercase deaf denotes the physical condition of hearing loss without necessarily participating in Deaf culture [15, 102].

[2] After-the-fact retrofit refers to adding accessibility features to a system after it has been designed for hearing users, rather than building accessibility into the design from the start.

HCI work, *Speculating Deaf Tech: Reimagining Technologies Centering Deaf People* (CHI 2025 Best Paper), articulates a speculative and visionary agenda for reimagining technology through *Deaf epistemologies* [13]. Building on this precedent, our work extends this trajectory by reclaiming VR *design authority*, defined as the authority to make substantive design decisions rather than merely influence or use the final output [133]. In our collaboration, Deaf educators and researchers defined and articulated the requirements of a remote Deaf classroom and led the design and evaluation of immersive environments, supported by hearing colleagues and the broader community.

Despite prior work on VR in DHH education, it remains underexplored whether VR, when designed by and with Deaf communities, can be integrated into Deaf classrooms on their own terms. To address this gap, we investigate VR not only as a technical intervention but as a *sociocultural technology* [86, 114], examining whether VR applications featuring signed instruction align with Deaf pedagogical practices[3] and reduce the barriers associated with visual communication as the sole channel. We ask two research questions (RQs):

> **RQ1**: How do Deaf signers perceive VR as a sociocultural technology, and does it feel culturally and pedagogically aligned with their ways of learning?
>
> **RQ2**: How do Deaf signers experience different signer placements in a VR classroom, and what design preferences emerge from their feedback?

Guided by these questions, we present this work as an early-stage and exploratory participatory design study that lays the conceptual groundwork for future immersive learning tools. We developed a VR lecture prototype guided by four design goals: (1) flexible positioning of the signing lecturer, (2) minimizing visual attention shifts, (3) providing accessible instructional content, and (4) reducing distractions. Using a pre-recorded signed video to present an asynchronous lecture, the prototype supports three signer placement modes: *Corner Mode*, where the signer appears in one of four corners; *Parallel Mode*, where the signer is placed beside the instructional content; and *Transparent Mode*, where the signer is overlaid with adjustable transparency on lecture materials.

We conducted a qualitative study with 12 Deaf participants who communicate in American Sign Language (ASL) in their daily lives, using an ASL-first[4], Deaf-led approach. Participants reported that VR could support Deaf classrooms by reducing attention split, improving sign visibility, minimizing distractions, and allowing flexible arrangements for both students and instructors. These benefits were noted by both students and instructors, suggesting potential for supporting both teaching and learning. Our analysis also identified opportunities and limitations of each mode, which we synthesized into a five-dimension conceptual framework (proximity, customizability, visual efficiency, cultural fit, and task flexibility) that articulates the recurring evaluative reasoning our participants used when assessing signer placement in immersive classrooms.

Our work makes three contributions: (1) A VR prototype that prioritizes visual experience, cultural fit, and flexible spatial arrangements, laying groundwork for integration into live Deaf classrooms. (2) A five-dimension conceptual framework that makes visible the Deaf-centered evaluative considerations participants used when assessing signer placement and visual access. (3) A reframing of VR education as Deaf-centered, offering initial insights into how Deaf epistemologies can serve as foundations for VR design rather than adaptations to defaults.

As VR usage grows, we argue that it is time for the Deaf community to reclaim design authority over immersive classrooms. Deaf-centered VR classrooms point toward futures in which Deaf ways of learning define the design agenda for technologies used by Deaf people, rather than requiring them to adapt.

## 2 Background and Related Work

### 2.1 Deaf Community and American Sign Language

The Deaf community is a cultural and linguistic minority characterized by shared use of sign language and collective experiences. Deaf cultural practices, as illustrated in Fig. 1, foreground community connection and visual communication, relying on sign language, eye contact, clear sightlines, and direct engagement [17, 81]. Scholars advocate for frameworks that center Deaf experiences, moving beyond the traditional medical model of disability, such as *Deafhood*, which frames Deaf identity as a positive and collective journey [81], *Deaf gain*, which emphasizes the unique contributions of Deaf ways of being [17], and *DeafSpace*, an architectural and cultural framework where visual orientation, sightlines, and spatial arrangements are prioritized in daily life [47].

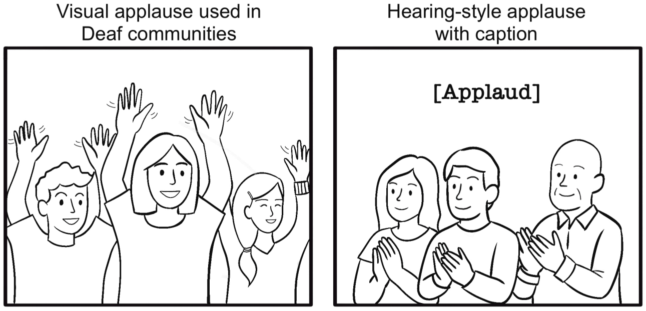

**Figure 1: Example of a Deaf cultural practice and how it differs from hearing environments with retrofit access. In Deaf cultural settings (left), applause is expressed visually, with the audience raising and waving their hands to create a shared, visible signal accessible to everyone in the space. In hearing environments (right), applause is expressed through sound-based clapping, here represented with a caption to indicate the technological retrofit access.**

The Deaf community is situated within the broader DHH category and may include individuals who are Deaf, deaf, or hard of

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[3] Deaf pedagogy is an educational framework that centers Deaf students' visual and multimodal resources, resists deficit models, embraces translanguaging, and intentionally develops critical consciousness by confronting the ethical and power-laden dimensions of Deaf education [119, 120, 126]. The goal is to provide an equitable and effective learning environment that addresses the unique needs and experiences of DHH individuals [126].

[4] By ASL-first, we mean working from the understanding that American Sign Language is our participants' primary language for daily communication, and thus the medium through which cultural knowledge and meaning are best expressed [44].

hearing, with differing levels of connection to Deaf identity [15]. This work focuses on Deaf individuals who use ASL as their primary language and actively participate in Deaf cultural contexts.

Sign languages are the primary mode of communication within Deaf communities worldwide [82]. They possess the same structural complexity as spoken languages [124]. ASL, the primary language of the U.S. Deaf community, is distinct from English and has its own grammar and lexicon [128, 132]. ASL also includes specialized vocabulary for science, technology, engineering, and mathematics (STEM), enabling comprehensive communication of technical concepts [136].

## 2.2 Deaf Education and Direct Communication in Deaf-Led Classrooms

In Deaf-led classrooms, direct instruction in sign language is the norm and enables full participation [8, 76]. Teaching conducted in sign language is a standard practice and is often preferred by members of Deaf communities [8, 61]. In the United States, there are over 80 schools for the deaf [101], and nearly every state has at least one such school [43], where instruction is delivered directly in ASL.

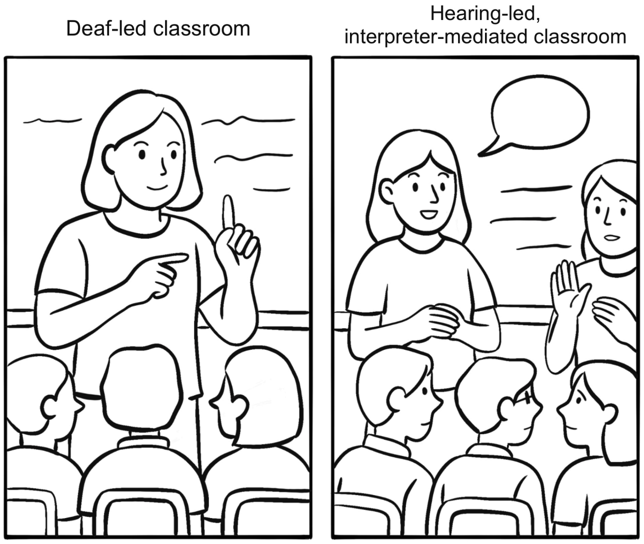

**Figure 2: Comparison of classroom dynamics in Deaf-led versus hearing-led and interpreter-mediated classrooms. Aside from instructional materials such as the blackboard, in the Deaf-led classroom (left), all students focus on the Deaf teacher. In the hearing-led and interpreter-mediated classroom (right), students' attention is divided between the hearing teacher, typically positioned at the center, and the interpreter, usually located to the side of the classroom.**

In hearing-led, interpreter-mediated classrooms, instruction prioritizes speech and translation rather than a shared language and culture. As a result, Deaf students are often denied the benefits of direct sign language communication, Deaf teachers' lived expertise, and teaching grounded in Deaf ways of knowing[5] (Fig. 2). Historically, Deaf children have often faced exclusion, ineffective instruction, and long-term trauma in educational settings [6, 41]. These issues are rooted in systems that privilege spoken language and auditory-centered pedagogy, while sidelining Deaf-led, sign language-based teaching [57]. By contrast, Deaf pedagogy centers visual and multimodal resources, incorporating visual–relational norms such as arranging classrooms for mutual visibility, using visual signals for turn-taking, and pacing lessons to match the rhythms of visual attention. It affirms belonging and transmits knowledge without translation or adaptation [8, 119, 120].

This work builds in that scope: *Deaf educators teaching Deaf students in ASL, with full access to both the content and the instructor.* We ground our study in Deaf pedagogical practices, visual-relational norms, and everyday Deaf life.

## 2.3 Discrimination and Audism

The Deaf community has experienced a long history of oppression, including ableism [116] and audism [16]—*"The notion that one is superior based on one's ability to hear or behave in the manner of one who hears [68]."* As both a disability group and a linguistic-cultural minority, Deaf people have faced systemic misunderstanding and exclusion [16, 116].

Within academic research, the majority of studies involving Deaf participants continue to be conducted by hearing, non-signing researchers (with exceptions such as [13, 45, 127]), while Deaf collaborators are often included only in limited feedback sessions [11, 93]. Without cultural competence or fluency in sign language, hearing researchers may lack the knowledge and sensitivity needed to engage ethically and effectively with the community [22, 40, 42, 45, 100]. This disconnect can lead to *harmful* outcomes, especially when researchers fail to ask, *Is this approach welcomed by the Deaf community [51]?* Community-led research offers a more ethical, respectful, and impactful alternative [13, 19, 40, 60].

In technology, Deaf communities have often been underrepresented in design and development processes. Tools intended "for" Deaf users are frequently created without substantial Deaf involvement and tend to reflect hearing-centric perspectives [9, 11]. This underrepresentation is both technical and epistemic: Deaf individuals are frequently positioned as end users rather than collaborators or knowledge holders. Consequently, many technologies intended to improve access fall short of community needs. In some cases, they may even perpetuate misconceptions. For example, *sign language gloves* [51] not only offer limited functional value, but also misrepresent the linguistic richness and embodied nature of sign languages. When developed without Deaf involvement, such technologies risk becoming forms of cultural appropriation, appropriating language and practices without engaging the communities to whom they belong [51, 64].

These reproduce a broader social pattern: Deaf communities rarely hold authority in defining technologies intended for them and are often forced to adapt to tools designed by and for the majority [19, 62, 90]. Scholars have responded by articulating and

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[5] Deaf ways of knowing refers to epistemologies that privilege visual-spatial modalities, embodied interaction, and community knowledge, resisting deficit framings [47, 81, 82]

advocating for *Deaf Tech*: technologies created by, with, and centering Deaf communities [10, 40, 77], emphasizing participatory design and cultural relevance. Our study extends this theoretical foundation by grounding Deaf Tech in practice through immersive classroom design.

## 2.4 VR Accessibility and the Broader DHH Community

While this work centers Deaf signers, we recognize the diversity within the broader DHH community. Individuals who identify as deaf or hard of hearing often use residual hearing and navigate between hearing and Deaf worlds [15], employing varied communication strategies such as speech, lipreading, amplification technologies, and captioning [24, 50, 70]. Their accessibility needs in digital and immersive environments partly overlap with, yet also differ from, those of Deaf signers, particularly regarding auditory cues, sound visualization, and multimodal feedback [50, 70, 71]. These diverse communication strategies have informed a range of accessibility approaches in immersive environments [73, 98].

Within HCI, accessibility in immersive technologies has become an important focus, with growing attention to DHH users. Research has investigated barriers and inclusive design guidelines for mixed reality systems [37, 38, 46, 72], such as captioning [135] and subtitling [2, 69], interpreter integration [7, 104], sound modifications [28], and visual or haptic sound representations that enhance environmental awareness [34, 55, 73, 85, 95]. Together, these efforts outline key directions for inclusive immersive design that support multimodal perception and situational awareness across the DHH spectrum.

While this body of work has significantly advanced VR accessibility for DHH users, it largely conceptualizes accessibility through a hearing-centered paradigm. For example, a common approach in VR accessibility involves adding captions or inserting an interpreter view into an otherwise unchanged lecture environment [104]. These approaches broaden access to hearing pedagogies but do not interrogate how immersive systems might instead be designed from Deaf epistemologies and cultural practices [54]. Critically, these systems often treat Deaf, deaf/hard of hearing experiences as *interchangeable*, overlooking the cultural and linguistic dimensions of Deaf life. Our work extends these efforts by focusing on Deaf-centered approaches that integrate epistemological knowledge into technology design. We contribute a complementary lens to VR accessibility, one that shifts from accommodation of auditory norms to the design of environments that align with Deaf ways of knowing and learning.

## 2.5 Sociotechnical and Sociocultural Perspectives on Technology

HCI has long emphasized that technologies are not neutral artifacts but sociotechnical systems, shaped by and shaping the communities in which they are used [86, 114, 123]. Recent work highlights how accessibility technologies, in particular, carry cultural and political assumptions that influence whether they are embraced or resisted by the communities they intend to serve [11, 42, 53, 59]. This perspective shifts evaluation beyond functional usability or efficiency, foregrounding how technologies align with cultural practices, values, and epistemologies.

Within disability studies, access is increasingly understood not as an add-on but as a cultural and relational practice [134]. Technologies that overlook these dimensions risk reproducing deficit framings or enforcing dominant norms [36, 90]. In response, community-led approaches emphasize that cultural acceptance is as important as technical feasibility [36, 39]. For underrepresented and underserved groups such as the Deaf community, this sociocultural framing is particularly vital: a technology's success depends not only on its interface design but on whether it resonates with Deaf norms of interaction [13].

Building on this scholarship, we approach VR not as a neutral learning tool but as a sociocultural technology whose value depends on whether it resonates with epistemic practices. This perspective motivates our inquiry into whether VR is culturally acceptable for Deaf signers and capable of supporting teaching, participation, and learning in Deaf classrooms.

## 2.6 Visual Attention and Digital Learning Platforms

For Deaf students, visual attention split creates persistent barriers in both physical and digital settings [87, 92, 111]. In videoconferencing platforms, students must continually toggle between signers and instructional materials, leading to cognitive overload, visual fatigue, and missed content [108, 112]. This issue arises across various contexts, including interpreter-mediated classrooms and Deaf-led settings, and becomes especially pronounced in digital platforms with limited spatial control and screen real estate [66, 109]. Researchers have proposed various strategies to reduce attention shifts, including gaze cueing [78] and notifications for slide transitions or speaker changes [29]. Semi-transparent video overlays have also been explored to support visual integration [94]. Similar goals have been explored in mixed reality environments, as outlined in Section 2.4. However, these systems remain grounded in audio-default infrastructures [74, 115]. These examples illustrate a common limitation: across both physical and digital classrooms, Deaf communities have been positioned as peripheral users rather than epistemic leaders. Prior work has either patched existing technologies or "fixed" Deaf people in hearing environments. Our study addresses this gap by centering Deaf agency and leadership, showing how immersive learning changes when it begins from Deaf epistemologies.

# 3 Methods

## 3.1 Ethics Considerations

*3.1.1 Positionality.* Our research team comprised six members: three Deaf and three hearing. The first author is a Deaf doctoral student with prior experience as a lecturer. The other two Deaf coauthors include a senior professor with extensive experience teaching and mentoring Deaf students, and a junior faculty member who also teaches in Deaf educational settings and serves as the last author of the paper. All three Deaf authors have taught in Deaf institutions where ASL and written English are primary, and the project emerged directly from needs *we observed in our own classrooms*.

Together, the Deaf authors conceptualized the research questions, guided the study design, and led data interpretation grounded in their lived experiences as Deaf signers and educators. Their perspectives shaped how accessibility, cultural alignment, and visual attention were understood within the context of immersive learning.

The three hearing coauthors contributed complementary expertise. One hearing coauthor supported the qualitative analytic process through ongoing discussions and peer debriefing. The remaining two hearing coauthors are VR specialists: one led prototype development and the other provided VR equipment and technical consultation related to usability, visual comfort, and affordability.

*3.1.2 Community Approach and Procedural Ethics.* Our study design was guided by trauma-aware [6] and culturally grounded research practices [21, 62]. In line with recommendations for ethical engagement with the Deaf community [39, 100, 118], we prioritized participant autonomy, agency, and comfort throughout the sessions. All study sessions were conducted in ASL by Deaf researchers. To avoid reproducing test anxiety or hearing-normed evaluation pressures, we did not include performance-based tasks or standardized usability tests [30, 56]. Instead, our approach centered participants' embodied experiences and reflections in their primary language to ensure full linguistic and cultural alignment [105].

This study was approved by the institution's IRB. All participants provided informed consent in ASL or written English and received $25 as compensation for their time.

## 3.2 Participants

We recruited 12 participants using a combination of relevant email lists (e.g., DHH students in STEM programs) and snowball sampling [113]. Eligibility criteria included identifying as DHH[6], fluency in both ASL and English, familiarity with sign language instruction, U.S. residency, and age 18 or older. Nine participants had prior experience with VR. Eight were college students, three were teachers in related fields, and one was a staff member. All reported a basic understanding of computer technology. All participants indicated experience with remote classrooms, especially during the COVID-19 pandemic. Participant demographics are summarized in Table 1.

All participants viewed a 15-minute ASL-based VR lecture on *binary search* (see Section 3.5 for details and rationale). Three teacher participants were already familiar with the topic, while the remaining nine student and staff participants were not.

## 3.3 Instruments

Data were collected using three instruments: orientation materials, a semi-structured interview protocol, and researcher field notes. These instruments were administered by three Deaf researchers.

**Orientation Materials:** At the start of each session, the research team provided a standardized orientation explaining the study goals and demonstrating how to use the VR prototype, ensuring that all participants received the same information before interacting with the system.

**Semi-structured Interview Protocol:** The semi-structured interview was the primary data collection instrument. This format allowed participants to reflect freely on visual comfort, fatigue, and personal preferences [21]. Interviews were video recorded upon consent. Each interview began with a brief set of demographic questions (age group, role, Deaf or hard of hearing identity, first and primary language(s), prior VR experience, and familiarity with the topic of binary search). The protocol then guided discussion across six areas: overall experience, evaluation of each signer placement mode, comparisons to Deaf-led remote classrooms, moments of visual comfort or strain, challenges during the session, and suggestions for improvement or broader applications. The full interview guide is provided in the appendix.

**Researcher Field Notes:** Throughout the session, the team took field notes documenting observations such as participant questions or visible reactions to specific signer modes. These informal notes served as a lightweight supplement to the interview data.

## 3.4 Study Design

The user study sessions comprised three components: orientation, prototype interaction, and a semi-structured interview, described in Section 3.3. Before recruitment began, we conducted an internal pilot to identify potential obstacles and ensure a smooth study process. The pilot helped us refine the session flow, prepare the study environment, set up equipment, and organize materials such as consent and video release forms.

At the start of each session, the research team obtained informed consent by providing the written English form or translating it into ASL upon request. The team then assisted participants with headset calibration and introduced the prototype's interactive features, including switching between signer placement modes and adjusting signer distance and opacity. Participants were encouraged to explore these features and personalize their settings.

Following the orientation, participants viewed the full 15-minute VR lecture. As part of the study procedure, they were asked to try all three signer placement modes during the lecture. The research team remained available for support while ensuring participants could engage with the system comfortably.

After the lecture, the team conducted the semi-structured interview. The overall study process centered cultural comfort, reduced evaluation pressure, and supported visually oriented, ASL-native meaning making [39, 62].

## 3.5 Apparatus

*3.5.1 Design Goals.* The prototype was designed to support a visual-centered learning experience grounded in Deaf cultural norms around access and visual attention. Building on prior research (Section 2) and our lived experience as Deaf signers and educators, we identified the following design goals:

(1) **Providing accessible and appropriate instructional content.** To ensure the lecture was both comprehensible and concise, we limited it to 15 minutes to balance depth with

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[6] Participants variously identified as Deaf, deaf, or hard of hearing. All were signers and participated in classrooms conducted through ASL. For clarity and consistency, we use the term "Deaf" to emphasize culture, language, and pedagogy rather than audiological status.

**Table 1: Participant demographics. Note: SL indicates sign language (e.g., Nigeria SL). HH indicates hard of hearing.**

| ID | Age | Role | Identity | Gender | First lang. | Primary lang. | VR experience |
|---|---|---|---|---|---|---|---|
| P1 | 18–24 | Student | deaf | M | English | ASL | Owns VR device |
| P2 | 25–34 | Student | Deaf | F | ASL | ASL | First time |
| P3 | 25–34 | Student | deaf | M | English | mixed | VR gaming |
| P4 | 18–24 | Student | Deaf | F | ASL | ASL | VR gaming |
| P5 | 55–64 | Professor | Deaf | M | Nigeria SL | ASL | General VR use |
| P6 | 35–44 | Professor | deaf | M | English | mixed | VR gaming |
| P7 | 35–44 | Student | Deaf | F | Spanish SL | ASL | Not stated |
| P8 | 45–54 | Student | Deaf | M | Spanish | ASL | General VR use |
| P9 | 25–34 | Student | HH | Not stated | ASL | ASL | Not stated |
| P10 | 35–44 | Staff | Deaf | M | English | ASL | General VR use |
| P11 | 25–34 | Professor | Deaf | M | English | ASL | General VR use |
| P12 | 25–34 | Student | Deaf | M | ASL | ASL | VR gaming |

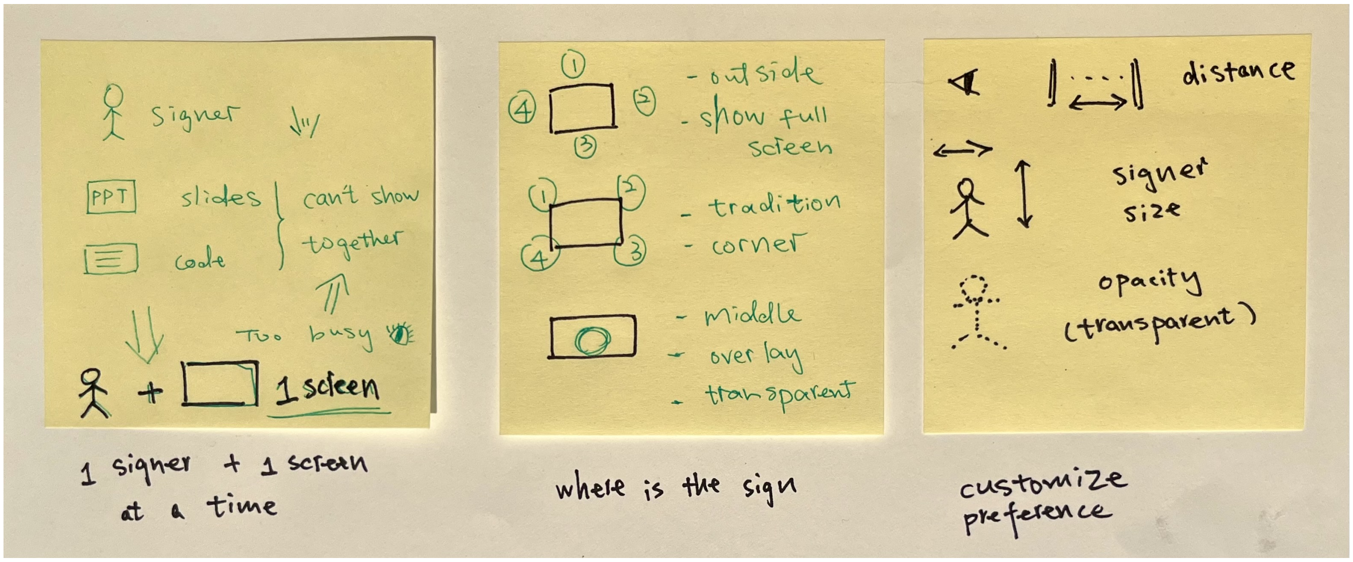


**Figure 3: Early sketches we used to think through possible VR classroom designs. We explored how to reduce visual attention split, test different signer placements, and identify what parameters should be customizable. These sketches shaped the prototype that followed.**

attention and minimize fatigue [30, 39, 65, 108]. We chose *binary search* as the topic of the prototype because our team includes computer science educators, and the topic is both widely taught and visually demanding, making it well suited for exploring how VR can support visual attention. Additionally, *binary search* is a standard topic in introductory programming courses, requires little prior experience, and remains intellectually engaging [58].

(2) **Flexible positioning of the signing lecture.** Previous research has shown that individuals may have varying recognition abilities depending on different areas of their visual field [63, 125]. This led us to consider whether Deaf individuals might have distinct preferences for signer placement around the screen. Inspired by this possibility, we designed our system to allow users to adjust the signer's position according to their preferences.

(3) **Minimizing visual attention shifts.** A major challenge for Deaf individuals is the need to divide their visual attention between multiple resources simultaneously [92]. Reducing the distance between key visual elements may help mitigate this issue. Prior research has explored semi-transparent video interfaces as a potential solution [94]. Inspired by this, we designed an overlay mode, where the signer appears semi-transparent over instructional materials such as slides and an IDE for live coding demonstrations.

(4) **Reduce visual distractions.** Previous research has shown that DHH individuals may be more susceptible to visual distractions in the learning environment compared to their hearing peers [18, 109]. Instead of replicating a traditional

classroom environment, we designed the lecture space with a solid blue background, intentionally free of visual details, to minimize distractions and support sustained visual attention.

Building on these goals, we sketched ideas to think through the problem of visual attention split and our possible classroom design (Fig. 3). Three directions emerged: (1) show only one signer and one screen at a time, limited to either slides or code; (2) explore different signer positions on or around the screen; and (3) allow customization of distance, size, and opacity. These sketches guided the prototype design and development described next.

#### 3.5.2 *Prototype Development.*

Inspired by these goals, we developed a VR-based lecture application with three signer placement modes. Users could switch between these modes at any point during the lecture. All instructional content was presented against a solid blue background to reduce distractions and support visual focus (Goal 4).

**Corner Mode** supports flexible signer positioning within the four corners of the screen: top-left, top-right, bottom-left, and bottom-right (Fig. 4 (A)). In this mode, the signer is placed directly on the virtual screen (Goal 3). Users can toggle between the different positions by pressing the *"C"* key on the board at any time during the lecture (Goal 2).

**Parallel Mode** places the signer adjacent to the left side of the virtual screen rather than on the virtual screen itself (Fig. 4 (B)). Instead of being embedded within the instructional content, the signer is positioned against the blue background on the left side of the screen, providing a separate and clear visual reference (Goal 2).

**Transparent Mode** overlays the signer semi-transparently in the center of the virtual screen (Fig. 4 (C)). Users can adjust the opacity of the signer throughout the lecture by pressing the *"["* and *"]"* keys, allowing them to fine-tune visibility based on their preferences (Goal 2 and Goal 3).

Additionally, users can pause and play the video by pressing the *space bar*. The left and right *arrow* keys are configured to allow them to skip forward or rewind by five seconds. Users can exit the video by pressing *Escape*. In all three modes, users can adjust the distance of both the screen and the signer by pressing the up and down *arrow* keys on the keyboard, allowing them to move the content closer or further from their eyes.

We recorded a *binary search* lecture delivered by a Deaf instructor. The instructor was familiar to many participants, having taught or interacted with them in previous educational contexts. The video incorporates multiple forms of instruction, including sign language, slides, and live coding (Goal 1). We processed the footage using *DaVinci Resolve*. To integrate the signer into the VR environment, we separated the original recording into two video files: one for the webcam feed and one for the screen recording. We then applied a chroma key to remove the webcam background, creating a clean and adaptable overlay. Finally, we used *Shutter Encoder* to convert the videos into a Unity-compatible format that supports transparency. Although the instructional materials were presented in 2D, the VR environment allowed the signer and content to be positioned within a three-dimensional space. This spatial configuration enabled learners to adjust distance and placement in ways that 2D video interfaces cannot support, helping reduce visual attention switching, providing flexible screen size and arrangement, and minimizing background distractions.

The VR application was developed using *Unity Game Engine* (version 2022.3.47$f$1). We ran the system on a *Razer Blade 16* laptop equipped with an Intel Core $i$9-14900$HX$ processor, Nvidia GeForce RTX 4080 GPU, 32 GB RAM, and a 1 TB SSD, using *Oculus Link* to connect to a *Meta Quest 3* headset. We implemented interactive features such as video playback controls and signer opacity adjustment using Unity's video tools and C# scripting. We selected *Meta Quest 3* for its technical capabilities, ergonomic design, and affordability. While research prototypes are often tested on high-end devices, we prioritized hardware that could realistically be deployed in near-term classroom settings to support Deaf learners.

## 3.6 Data Analysis

Our qualitative analysis was informed by principles of *Constructivist Grounded Theory* [31–33], which emphasizes the co-construction of meaning between participants and researchers. Figure 5 illustrates our iterative five-stage analytic process; we describe each stage in detail below.

1. **Data collection and translation.** The interviews were conducted and recorded by the first author and two Deaf research assistants. The first author translated each ASL recording into English for analysis, with the research assistants proofreading the translations. The translation intentionally prioritized preserving the signing voice, tone, and discourse features of ASL rather than producing standardized written English, recognizing translation as an interpretive analytic act.
2. **Initial coding.** The first author (Deaf) and second author (hearing) independently conducted line-by-line initial coding of the translated transcripts using an inductive approach grounded in thematic analysis [25, 26]. This stage generated a wide range of descriptive codes reflecting visual comfort, spatial awareness, cultural alignment, and interactions with the prototype.
3. **Axial coding.** The same two authors met weekly via video chat, with ASL interpreters present, to compare interpretations and merge their codebooks. When the hearing coauthor was unsure about participants' intended meaning, the Deaf coauthor provided clarification based on linguistic and cultural knowledge. Any disagreements were discussed collaboratively, with the Deaf coauthor making the final analytic decisions. This iterative process continued until data saturation was reached [5], resulting in a combined set of 111 codes. Similar codes were clustered into preliminary themes that captured salient patterns across participants. These themes were collaboratively reviewed with the senior Deaf senior faculty member to refine and validate their boundaries.
4. **Selective coding.** The same two authors then examined how the emerging themes addressed the research questions. As they compared themes across participants, they also analyzed why participants evaluated the modes in particular ways, identifying higher-level concepts that captured participants' underlying reasoning. These concepts extended

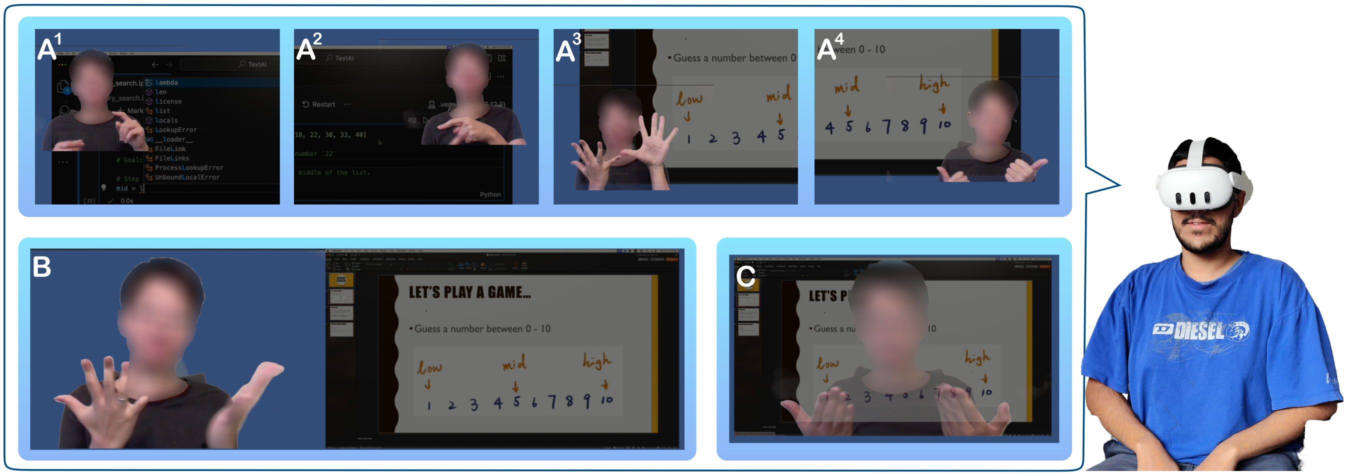


**Figure 4: Screenshots of the three signer placement modes in the VR prototype. (A) Corner Mode, showing all four possible corner positions for the signer. (B) Parallel Mode, with the signer placed adjacent to the virtual screen. (C) Transparent Mode, with the signer overlaid on top of the instructional content. Note that these images are 2D representations and do not fully capture the immersive experience of wearing a VR headset.**

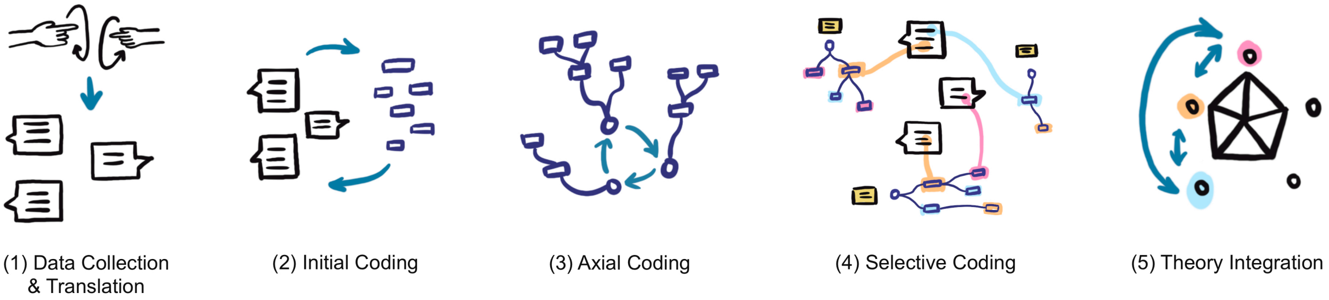


**Figure 5: Overview of our qualitative analysis process. Because our interviews were conducted in ASL, we began by (1) translating ASL video recordings into English transcripts for analysis. We then conducted (2) initial line-by-line coding of the translated transcripts, (3) axial coding to relate codes and group them into thematic clusters, (4) selective coding to synthesize cross-cutting categories across themes, and (5) theory integration, where these categories informed the development of our five-dimension conceptual framework.**

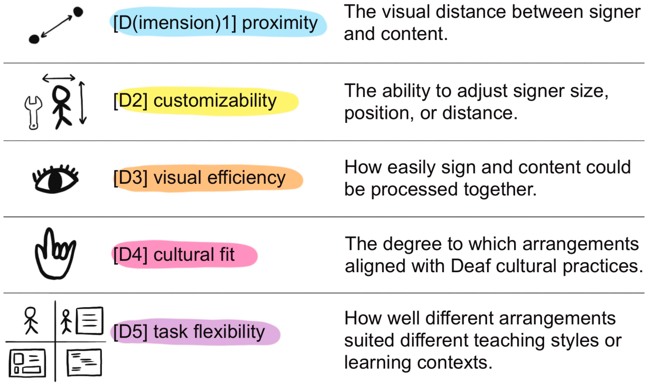
beyond answering the research questions and formed the foundation for subsequent theory-building. All analytic decisions were made through discussion and consensus, supported by ongoing review from the senior Deaf senior faculty member.

(5) **Theoretical integration.** Finally, all three Deaf coauthors met to interpret and integrate these higher-level concepts. Through collaborative discussion grounded in Deaf experience, they synthesized these concepts into five interrelated dimensions—proximity, customizability, visual efficiency, cultural fit, and task flexibility—which form our five-dimension conceptual framework. These dimensions represent theoretical constructs that emerged from sustained engagement with the data instead of pre-defined categories. In the Results section (Section 4), we explicitly annotate each participant quote with its corresponding dimension to make transparent how raw data, themes, and theory connect.

## 4 Results

In this section, we present the results of our study, organized around the two research questions. For RQ1, we describe how participants perceived VR as a sociocultural technology, summarizing *themes* related to reduced visual attention split, improved coherence of the visual experience, and alignment with Deaf pedagogical practices, alongside additional observations about accessibility, comfort, and usability. For RQ2, we compare the three signer placement modes and examine their respective strengths and challenges in supporting visual comfort and attention management.

Although RQ1 and RQ2 address different aspects of the VR classroom experience, participants drew on a shared set of evaluative considerations when reflecting on both the overall value of VR and the tradeoffs of each signer placement mode. These considerations cut across and extended the RQ1 themes and RQ2 comparisons. During analysis, we identified these recurring considerations across interviews and used them as the analytic basis for inductively synthesizing five interrelated dimensions (Fig. 6). These dimensions appear inline throughout the Results as analytic markers that make visible the reasoning participants used to evaluate spatial and cultural aspects of the VR classroom. **We return to these dimensions in Section 5.1**, where we elaborate how they form an emerging conceptual framework that organizes Deaf-centered evaluation considerations.



| | |
|---|---|
| [D(imension)1] proximity | The visual distance between signer and content. |
| [D2] customizability | The ability to adjust signer size, position, or distance. |
| [D3] visual efficiency | How easily sign and content could be processed together. |
| [D4] cultural fit | The degree to which arrangements aligned with Deaf cultural practices. |
| [D5] task flexibility | How well different arrangements suited different teaching styles or learning contexts. |

**Figure 6: Five interrelated dimensions synthesized from participants' evaluations of signer placement in VR classrooms.**

## 4.1 RQ1: VR as a Sociocultural Technology

Our findings indicate that participants viewed the VR learning experience positively and evaluated it through both usability and cultural lenses. Rather than focusing solely on ease of use, they considered whether the VR classroom aligned with Deaf pedagogical norms and communication practices. Participants identified several benefits of VR for remote learning, including reduced visual attention split, increased flexibility and physical comfort, and fewer visual distractions. In the sections that follow, we examine these *themes* in detail, showing how VR's immersive and visually oriented design can support Deaf signers' engagement and comprehension while also highlighting limitations and potential barriers. Importantly, participants compared the VR classroom not to interpreted or captioned instruction, but to their own experiences in Deaf-led remote classrooms. Taken together, these reflections suggest that participants saw VR as a promising sociocultural technology, one that could extend and strengthen direct signed instruction.

*4.1.1 VR helps reduce visual attention split.* Participants reported that VR reduced visual attention split and lessened eye fatigue, making it easier to follow the lecture. Unlike traditional remote learning, where students must frequently shift their gaze between the signer and instructional materials, VR places all key visual elements within a single immersive space, naturally guiding the user's focus. In a 2D video-based class, students often divide their attention between multiple, separate visual sources, such as a signer in a small video window and instructional materials in another window. In contrast, VR centralizes these elements, enabling students to view everything within their field of vision without excessive head or eye movement. This centralization was experienced as more than a usability improvement, and it may also be interpreted as supporting classroom practices where visual access is expected to be integrated rather than fragmented. In this way, students could more intuitively determine where to look during a lecture, as P3 noted: *"Remote lectures were so hard. Often, I didn't know where to look [...] but VR is so nice! Things are close to me [...] it feels natural to know where to look. When the lecturer signs, I look at the teacher, and the slides are right there (visual efficiency)."*

Participants likened this integrated viewing experience to *shadow interpreting* in accessible theater, where interpreters perform alongside the actors rather than off to the side of the stage [14]. P9 explained that this method minimizes the need for constant eye movement, making the experience feel more natural: *"That was always a good experience. Much better than having interpreters on the side of the stage, where you have to move your eyes a lot the entire time. Instead, I could watch the performance itself, and access was built into it (proximity)."*

The integrated VR classroom reduced the need for frequent pausing, a common strategy employed by DHH individuals in video-based classes. P2 highlighted this benefit, stating, *"It feels so much better. Usually, in video classes, I had to pause a lot to see the interpreter/signer and read slides or code, but with this, everything can go in parallel."* They further emphasized the improved experience with VR, explaining, *"I feel like I didn't miss anything (visual efficiency)."*

*4.1.2 VR enhances visual accessibility for Deaf learners.* Beyond reducing visual attention split, VR also improves visual accessibility by removing the physical screen limitations commonly found in traditional remote learning environments. In standard video-based platforms, the size of the teacher is constrained by the display screen, often making it difficult to perceive facial expressions and the fine details of sign language. Many participants noted that having the screen closer to their eyes in VR significantly improved visibility, expanded their field of view, and enhanced their ability to read the lecturer's signs. As P5 shared, *"I really like it. I can see more widely in VR, see better, and feel less tired (visual efficiency)."* P11 echoed this sentiment, stating, *"At first I was like, why do you need VR? [...] But when I started using the device, I got the point. The screen is so near my eyes. It indeed is a different experience. I do like it better than a regular computer screen."* P4 then further emphasized the cultural value of VR: *"VR is better, more visual, fits Deaf better (visual efficiency and cultural fit)."*

Participants also emphasized the limitations of traditional screen setups for remote learning. P9 pointed out, *"Your laptop only has one small screen."* Similarly, P11 described their experience with Zoom lectures: *"(With Zoom) The screen is so small. Everything is so small. Hard to read."* By removing this constraint, VR provides greater control over screen size and placement, enabling a more adaptable and personalized learning experience. As P9 concluded, *"You can decide how many screens you have. Not limited by the number of hardware screens [...] I feel VR fits us well (visual efficiency and cultural fit)."* By allowing students to customize their visual environment, VR creates a more immersive and accessible learning experience, reducing eye strain while improving engagement.

*4.1.3 VR supports visual and physical flexibility.* All participants appreciated the prototype for its flexibility, both in signer positioning and in supporting physical comfort. In traditional classroom settings, students are expected to maintain a fixed gaze on the instructor or screen, which can lead to discomfort over time. Signing instructors also face unique constraints compared to their hearing counterparts, as they are less able to move around freely while teaching. One participant who is a professor (P5) explained, *"Sometimes, hearing teachers walk around the classroom when they teach. But we cannot do that. We are limited by our language style. We cannot wander around when we teach in sign language. But our eyes can get really tired."* In contrast, VR offers greater flexibility in positioning visual content, which may help alleviate this issue. Beyond adjusting the signer's placement, students can also modify the distance between their eyes and the signer based on personal preference, further enhancing comfort and reducing visual strain. As P6 noted, *"Definitely more flexible, more options—I can move the teacher around myself. I like it (customizability)."*

Additionally, participants emphasized the physical flexibility and comfort provided by VR, particularly in reducing reliance on traditional computer setups. Unlike hearing individuals, who can listen to lectures through headphones while sitting in relaxed positions, DHH students must remain upright at a desk or hold a laptop, keeping their eyes focused on the screen for the entire duration of the lecture. Over time, this rigid posture can lead to physical fatigue. In contrast, VR serves as a visual equivalent to headphones for DHH students, enabling them to engage in learning from more comfortable positions without being confined to a desk or needing to hold a device (task flexibility). As P5 expressed, *"My body is comfortable, but my mind can still learn. Right now, we are mostly stuck in our chairs while learning. Our bodies get tired. It feels so limited."*

*4.1.4 VR minimizes visual distractions.* The simplified background and immersive nature of VR helps students minimize visual noise by eliminating external distractions that might otherwise draw their attention away from the signer or lecture content. One participant (P7) noted, *"In the classroom (in-person classes), wow, it's hard! Too much information all at once! Eyes busy! But in VR, I am more attentive, understand better, my eyes cannot go around."* Unlike hearing students, who can absorb spoken information while looking elsewhere, Deaf students must maintain visual attention on the lecture at all times. This makes them more susceptible to missing information when their gaze shifts. VR mitigates this challenge by creating an immersive environment that reduces visual noise and sustains students' focus. P1 described how VR reduced distractions compared to traditional remote learning, explaining that in Zoom, it was easy to be distracted by other screens or background elements, but in VR, *"I can only see the sign, the lecture, and a blue background. That's all I can see. So much less distracting (visual efficiency)!"* This simplified visual environment helped them remain focused, absorb information more effectively, and stay engaged throughout the lecture.

The reduced visual noise in VR also benefits instructors. DHH students are generally more susceptible to visual distractions in learning environments than their hearing peers [106]. As a result, instructors often worry about whether students are able to maintain attention throughout the lecture. Since watching a signed lecture requires continuous visual effort, it can be cognitively and physically demanding. When students look away, teachers may question whether the content is being fully understood, making it difficult to identify gaps in comprehension. In physical classrooms, instructors often rely on eye contact to gauge student engagement, but this becomes more challenging in large or remote settings. One teacher (P5) suggested that VR could help Deaf instructors feel more confident that students are paying attention: *"It helps the professor keep moving with the lecture without having to worry about whether students are looking at me or not."* VR provides a structured visual environment that minimizes external distractions, allowing instructors to feel more assured that students are engaged with the lecture (cultural fit). This, in turn, enables instructors to focus more on delivering content effectively. This reflects Deaf cultural norms that value visual clarity as a precondition for equitable learning, not just as a usability feature [12, 81].

*4.1.5 Potential limitations of VR and barriers to access.* Participants also noted several limitations of VR that may affect accessibility for DHH users. Some reported that the headset did not fit comfortably, especially for those who use cochlear implants or hearing aids. For example, one participant (P3) shared, *"I have cochlear implants, and they are near where the straps are. So I feel uncomfortable with my cochlear implants."* Others described the headset as heavy and physically uncomfortable to wear for longer periods.

## 4.2 RQ2: Signer Placement Preferences and Design Implications

We explored different placements for the signer in a VR-based Deaf classroom by presenting three modes in our prototype system: corner mode, parallel mode, and transparent mode. Participants expressed diverse preferences, with no single mode emerging as universally superior. Instead, participants valued having the ability to choose between modes based on different learning scenarios. As P6 explained, *"I like the 3 modes because they gave me options. [...] I like that flexibility."*

In the following sections, we evaluate each mode by examining its advantages, limitations, and the contexts in which it may be most effective. We also highlight how participant reflections connect to the five dimensions introduced earlier, which provides a foundation for the framework we return to in Section 5.1.

*4.2.1 Corner mode.* Corner mode (Fig. 4 (A)) was the most widely accepted option, with all participants either liking or tolerating it. One reason for its familiarity may be that it aligns with existing conventions (cutural fit). P9 noted, *"Disney has movies with ASL translation, and the interpreter is on the bottom right. So maybe I'm already used to that."* Another participant preferred the lower corners because they allowed for simultaneous viewing of captions and the signer. Since captions are typically displayed near the bottom of the screen, placing the signer in a lower corner reduced eye movement and visual attention split, making it easier to follow both sources of information (proximity).

Because corner mode offers four different positioning options (upper left, upper right, bottom left, bottom right), participants' location preferences varied based on several factors. Some preferred the signer to be positioned as close as possible to the instructional content without obstructing it (proximity). Others felt a stronger connection to a specific area within their visual field (customizability and visual efficiency), such as P3, who mentioned, *"I am a right person. I like people on the right when talking to me."* Some participants adjusted their preferences depending on the signer's actions, such as typing code, running code, or presenting slides (task flexibility). A few participants actively switched between corner positions to avoid occlusion with slide content or the code editor.

Overall, participants appreciated corner mode for its balance of visibility and flexibility, particularly in reducing visual attention split. Its familiarity, adaptability, and unobtrusive design made it a strong candidate for default implementation. Participants also expressed a preference for having more control over the signer's position and frame size.

*4.2.2 Parallel mode.* Compared to corner mode, parallel mode (Fig. 4 (B)) was more polarizing. Some participants felt that this mode introduced greater visual split, making it harder to follow both the signer and the instructional materials (lack of proximity). P8 described the challenge by saying *"My eyes work too hard. The signer is too far from the content. If I have to use parallel mode, I have to watch the sign first, then pause, then read the slides, then continue to watch the sign, then pause to see the slides [...]."*

Most participants agreed that parallel mode required greater cognitive effort because the signer and the instructional content were farther apart. However, a few participants found it beneficial for attentional focus, as the signer appeared larger and more prominent (visual efficiency). P5 noted, *"I can see the sign easily because the signer is big and clear. And I can adjust the frame size to my comfort level (customizability). The slides are there, far, but I can still read them."* P6 found it helpful for maintaining focus on the speaker's face. Others noted that parallel mode could be useful for long lectures, as P10 remarked, *"If the teacher just talk for a long time without slides, I will use parallel mode (lack of task flexibility)."*

Although parallel mode included some customization features, such as adjusting the signer's frame size, participants expressed a desire for additional controls. In particular, they wanted the ability to move the signer closer to the visual content, or in some cases further away, depending on the context (potential for more customizability).

In sum, while some participants valued the larger signer and focused layout of parallel mode, many found the increased visual separation challenging. Its effectiveness largely depended on the lecture style and the individual's preference for managing visual attention.

*4.2.3 Transparent mode.* Transparent mode (Fig. 4 (C)) was the most controversial of the three modes. Some participants appreciated its potential to reduce visual split, while others strongly disliked it. Those who favored it felt that it minimized eye movement, making it easier to follow the lecture (proximity and visual efficiency). P8 noted, *"I feel the transparent concept would solve a lot of challenges we used to have with Zoom classrooms."*

However, several participants found it difficult to see in transparent mode due to insufficient contrast between the signer and the background, which made it more mentally demanding to distinguish the signer from the instructional content (lack of visual efficiency). P9 also pointed out that facial expressions, a crucial feature of ASL [129], were harder to read in this mode. Participants expressed a desire for greater customization options, particularly the ability to adjust the theme and contrast of the instructional materials, as well as the position of the signer. Many emphasized that enhancing the contrast between the signer's skin tone and the visual content would significantly improve visibility (lack of customizability).

Additionally, some participants mentioned that they were unfamiliar with this type of visual presentation. As P10 explained, *"With the overlay, I understand what the teacher says, but I'm just not used to that kind of visual (lack of cultural fit)."* They further commented that transparent mode required them to process two different types of information within the same visual space, making comprehension more challenging: *"It takes a little more work for my brain. If it were a simpler topic, like art, I could probably follow through, but with code, it feels like too much work (lack of task flexibility)."*

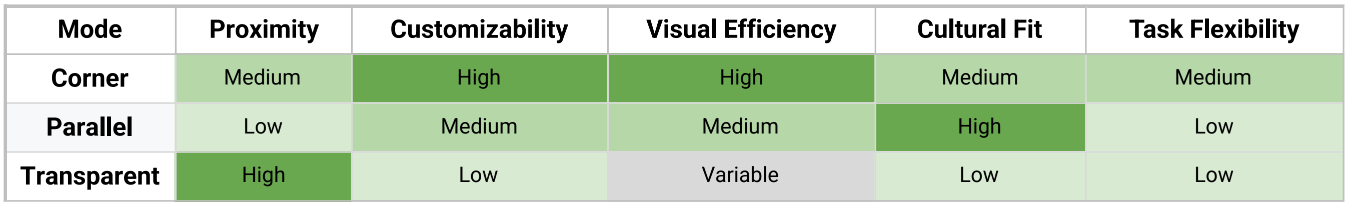
In general, transparent mode showed promise for reducing visual attention split, but its effectiveness was limited by visibility challenges and a lack of familiarity. Participants emphasized that without sufficient contrast and customization, this mode could increase cognitive load rather than reduce it.

## 5 Discussion

In this section, we reflect on the broader implications of our findings for Deaf-centered immersive technology design. Building on the participant perspectives reported in RQ1 (VR as a sociocultural technology) and RQ2 (signer placement preferences and design implications), we synthesize *recurring themes* into a five-dimension conceptual framework for evaluating signer placement: proximity, customizability, visual efficiency, cultural fit, and task flexibility. While these dimensions overlap with conventional notions of usability, they fundamentally express Deaf epistemologies: shared norms of visual attention and interaction, visual clarity, cultural resonance, and pedagogical flexibility essential to Deaf learning. What HCI often frames as "interface preferences" are, for our participants, evidence of whether a classroom affirms or fragments their ways of knowing [11, 59, 90]. From this perspective, VR was evaluated not only as a technical tool but as a sociocultural technology, one that resonates with Deaf norms around visual attention and spatial control. We then highlight the importance of designing with signing instructors as pedagogical leaders, challenge common visual hierarchies in interface design, and propose directions for research grounded in visual primacy and Deaf epistemologies.

### 5.1 A Deaf-Centered Conceptual Framework for Signer Placement

Our findings indicate that Deaf signers have diverse visual preferences, with no single display mode being universally preferred within our study. Participants described switching between modes depending on the learning context, influenced by factors such as content type, instructional materials, caption placement, and moment-to-moment attentional demands. Many emphasized the need for greater customizability within each mode, highlighting how Deaf learners employ diverse visual strategies to coordinate signing and instructional content. Prior work similarly documents



| Mode | Proximity | Customizability | Visual Efficiency | Cultural Fit | Task Flexibility |
|---|---|---|---|---|---|
| **Corner** | Medium | High | High | Medium | Medium |
| **Parallel** | Low | Medium | Medium | High | Low |
| **Transparent** | High | Low | Variable | Low | Low |

**Figure 7: Five-Dimension Framework for Evaluating Signer Placement Modes. The table summarizes trade-offs among the three modes in our VR prototype (Corner, Parallel, Transparent) across five dimensions: proximity, customizability, visual efficiency, cultural fit, and task flexibility.**

substantial variability in how Deaf individuals process visual information [23, 79, 97]. While prior work has examined access to interpreted spoken language, our study extends this understanding to immersive environments where signer placement becomes part of a broader ecology of attention and learning.

Our goal is not only to report observed preferences, but to clarify the underlying evaluative reasoning that shaped them. For participants, signer placement was not simply an interface setting. It required balancing visibility, cognitive effort, cultural familiarity, and moment-to-moment task demands—a pattern consistent with prior work showing that access needs shift with context [89]. This shift from reporting preferences to articulating evaluative reasoning is central to our contribution. Through qualitative data analysis, we synthesized participant reflections into five interrelated dimensions that characterize how Deaf learners make sense of signer placement across learning contexts (Fig. 6). The framework is organizational rather than prescriptive: it surfaces the considerations through which participants interpreted spatial arrangements and provides conceptual structure for reasoning about spatial, cultural, and visual relationships in signed communication.

**[D1] Proximity**: Prior HCI work has examined proxemics in co-located interaction [91]. Here, we define proximity in a Deaf-centered sense: *the visual relationship between signer and content*, including whether signing can be perceived without crowding, blocking, or distancing key information.

**[D2] Customizability**: The extent to which users can adjust signer position, size, opacity, or distance. Prior work on personalization and adaptable interfaces highlights how user control over spatial layout can reduce barriers [52].

**[D3] Visual Efficiency**: Participants described visual efficiency in terms of minimizing eye strain, effort, and unnecessary attention shifts. This dimension captures how efficiently signing and content can be coordinated within a single field of view.

**[D4] Cultural Fit**: We approach this dimension through a sociocultural lens, asking not only whether the prototype is usable but also whether it resonates with conventions, pedagogical practices and community values.

**[D5] Task Flexibility**: Learners frequently changed their preferences based on what the instructor was doing, such as typing code, explaining slides, or demonstrating visual materials. This dimension parallels prior HCI work on task-adaptive interaction design [117], capturing how spatial needs shift across instructional activities.

Throughout the interviews, participants described evaluating modes not one dimension at a time, but through their interactions. Each mode involved tradeoffs across the five dimensions: corner mode offered balanced support for customizability and visual efficiency, and its adjustability made it adaptable across tasks. Parallel mode strongly aligned with cultural norms and preserved the spatial logic of a classroom lecture, yet its fixed distance reduced proximity to content and limited flexibility. Transparent mode maximized proximity by placing signing directly over content, but this benefit was offset by limited control, potential contrast issues, and inconsistent visual efficiency across learners. These patterns reveal why no single mode emerged as universally preferred: each emphasized some dimensions at the expense of others. The table (Fig. 7) thus provides a conceptual map of these tradeoffs, illustrating how Deaf learners' evaluative reasoning is shaped by the dynamic coordination of spatial, cultural, and task-specific considerations.

During the theoretical integration stage of our analysis, we synthesized these interdependencies into a comparative summary of how participants evaluated each signer placement mode. The table above (Fig. 7) is an interpretive synthesis that models the evaluative considerations shared across participants, constructed from repeated reasoning patterns expressed in the interviews and collaboratively validated by the Deaf authors. The table distills the comparative judgments participants made implicitly as they described how each mode supported or interfered with their preferred visual strategies.

While the framework is most naturally applied in immersive 3D environments, where signer and content can be repositioned with greater spatial flexibility, the evaluative considerations it describes extend beyond VR. The five dimensions capture underlying reasoning that Deaf signers bring to any interface where signing and visual content must be coordinated. In 2D interfaces, the same concerns arise, though their expression may be more constrained because spatial relationships cannot be modified as fluidly. As such, the framework offers transferable concepts that can inform the design of signed media across immersive, augmented, and traditional digital platforms.

We present this framework as a conceptual structure that makes visible the Deaf-centered reasoning participants used when weighing tradeoffs in signer placement. The framework does not prescribe design rules; instead, it clarifies the epistemic commitments that provides a foundation for future Deaf-centered design work in immersive environments. By foregrounding Deaf ways of seeing, it encourages designers to begin not with accessibility retrofits, but with Deaf users' perceptual and cultural priorities.

## 5.2 VR as a Culturally Situated Sociotechnical Technology

One key implication of our findings is that the visual affordances of VR give it the potential to function as a *Deaf-centered sociocultural technology*. This reframes immersive learning design: its long-term value depends on how well it aligns with community epistemologies. Participants' reflections moved beyond basic usability, highlighting shared norms of visual rhythm, spatial attention, and the embodied flow of focus in signed classrooms [80, 81]. Many appreciated being able to adjust signer position, screen distance, and opacity, tailoring the visual layout to their own strategies. As one participant expressed, the experience felt "natural" because *"I didn't have to work so hard to know where to look."* Unlike physical classrooms with fixed seating or videoconferencing platforms constrained by limited screen estate, VR enabled learners to reconfigure their visual field dynamically. This adaptability reduced cognitive and physical fatigue and felt more congruent with Deaf classroom practices.

Transparent Mode was especially noted for its potential to integrate sign and content without dividing attention. This resonates with prior explorations of semi-transparent interfaces [94] and may prove particularly valuable for visually intensive or collaborative tasks such as code review and pair programming. Our work extends this scholarship by bringing it into immersive classrooms and examining its relevance to Deaf educational contexts. We invite further research to explore how semi-transparent interfaces can be adapted, refined, and evaluated in diverse Deaf educational settings.

Beyond transparent mode, VR may offer additional Deaf-centered possibilities worth exploring. Although our study did not investigate these capabilities, immersive systems could support features such as repositioning the signer based on the viewer's gaze to reduce visual switching and using room-scale layouts that better reflect Deaf classroom practices. These possibilities highlight directions for future Deaf-centered XR work.

Overall, our findings suggest that when designed with Deaf input and leadership, VR is not merely usable but welcomed as part of Deaf classrooms, functioning as a sociocultural technology rather than a technical add-on. This reflects broader calls in HCI for epistemic justice [60, 90, 122], where marginalized communities define the terms of technology design. **This is not Deaf people adapting to VR; this is VR adapting to Deaf people.**

## 5.3 Designing with Signing Instructors, Not Around Them

In Deaf-led classrooms, signing teachers are not edge cases or special accommodations; they are the *foundation* of instructional practice. Yet most educational technology research and development systematically treats spoken instruction as the default and frames signed instruction as a constraint to be worked around [16, 119, 121]. Prior work has primarily focused on access to interpreted spoken content through sign language interpreters [104, 131], and the perspectives and instructional needs of signing instructors have received far less attention. Our study challenges this framing by centering signing educators as pedagogical leaders and exploring how VR can be designed *with* their teaching strategies. Our participants highlighted several opportunities to rethink how immersive learning tools can support the work of Deaf educators, instead of making existing systems more accessible.

Student participants emphasized how VR influenced their ability to focus, navigate visual information, and remain physically comfortable. In contrast, instructor participants discussed the cognitive demands of teaching in signed environments. For example, instructors described how they often expend energy monitoring student gaze to ensure visual attention, something not typically required in spoken-language classrooms where students may continue listening while looking elsewhere. VR provided a sense of relief by helping students stay visually engaged within a structured environment, allowing teachers to concentrate more fully on content and delivery.

Importantly, instructor participants did not view VR as a replacement for in-person teaching but as a complementary tool that could extend their reach across classroom formats (P5 and P6). They imagined its application in flipped classrooms [3, 20], hybrid models, and asynchronous instruction, particularly for complex topics requiring sustained visual focus. By offering a consistent, immersive space where signing and content can be co-located and customized, VR has the potential to enhance clarity and reduce fatigue, for *both* students and instructors.

Designing for signing instructors is not an accessibility overlay. It is instructional design. Centering their perspectives can lead to more effective pedagogical tools for Deaf classrooms and for education more broadly. Our findings suggest that VR holds promise to support signed instruction. Future research should continue to explore how VR can be integrated into Deaf-led teaching models and how technology can amplify, rather than constrain, the strengths of signing educators.

## 5.4 Challenging Visual Hierarchies in Tech Design

Technology interfaces often reflect hearing-centered assumptions about what deserves visual priority. In many systems, slides or text are emphasized on screen while the signer is reduced to a small window or pushed aside, because hearing users do not rely on vision to follow spoken language. For Deaf signers, however, sign language is the *primary channel* of instruction, and diminishing its visual presence imposes hierarchies that conflict with how information is organized in Deaf classrooms [88, 130]. In those classrooms, vision is the central modality, and elements such as signing, facial expressions, slides, and diagrams carry equal communicative weight [83]. Designing for this context requires moving beyond an auditory-deficit framing and beginning with the embodied experience of Deaf users. Commercial head-mounted displays also reflect that DHH users were not considered in their design assumptions [53]. Our participants highlight how hardware itself can reproduce defaults that limit Deaf accessibility.

Participants described spatial preferences not as matters of convenience but as comprehension strategies. For example, P3 noted, *"I am a right person,"* expressing a consistent preference for receiving information from a particular direction. Such preferences reflect culturally grounded strategies of visual rhythm and attention distribution that are central to Deaf ways of learning. Rather than enforcing a fixed layout, our prototype allowed participants to construct their own visual experience, treating placement as both personal and cultural.

Prior studies have found that Deaf signers attend to different visual areas than hearing users and may show lateral preferences tied to visual processing [48, 49]. Yet little research has extended these insights to immersive environments. Concepts like Preferred Viewing Location (PVL), commonly studied in reading and spoken language [84, 99], remain largely unexplored in Deaf educational settings, despite signers' full reliance on visual information.

Our findings suggest that for Deaf signers, visual layout is not a technical detail but a cultural and embodied practice. Understanding how signers manage attention between equally weighted elements can help designers avoid reproducing hierarchies that do not reflect Deaf learning norms. Future research should examine how visual load, visual attention strategies, and signer–content relationships influence comprehension in immersive spaces. Designing for the Deaf body means centering visual primacy rather than treating vision as secondary [67]. This is not an accessibility adjustment, but points toward a paradigm shift in how immersive systems can be imagined.

## 5.5 Limitations and Future Directions

*5.5.1 Study scope and design limitations.* This study was designed as a qualitative, exploratory investigation grounded in Deaf epistemologies and cultural values. While the findings provide valuable perspectives on visual comfort, cultural alignment, and accessibility, they should be understood within the scope of early-stage participatory design.

*5.5.2 Hardware and prototype constraints.* Participants identified several practical barriers related to current VR hardware. Those who use hearing devices reported discomfort from headset straps, reflecting how commercial devices rarely account for diverse DHH bodies and assistive technologies. Others described the headset as heavy during longer use, consistent with prior research [69]. Although no participant reported difficulty reading text in our prototype, previous work documents resolution limits, eye strain, and text placement challenges in VR [75, 107]. These limitations illustrate that current VR design remains oriented toward default user bodies [53], highlighting the need for DHH accessible hardware and interface design that supports long term comfort and readability.

The prototype relied on keyboard input rather than hand tracking or gesture-based interaction. This decision supported rapid iteration and maintained accessibility during development, but future versions will explore more natural interaction methods, such as VR controllers or gesture recognition [127].

*5.5.3 Future directions.* All participants were based in the U.S. and used ASL. The extent to which these findings apply to signers who use other sign languages or participate in different educational and cultural contexts remains an open question. Future research should explore how immersive technologies can support a broader and more diverse global DHH population.

While our findings are specific to Deaf learners and signed instruction, the methodological approach used in this study may offer value for other underserved and underrepresented communities whose sensory or cultural practices are often overlooked in mainstream VR design. Centering community epistemologies, emphasizing cultural fit, and treating accessibility as the foundation of design rather than a later stage modification may support more inclusive immersive technologies. Exploring how culturally grounded, community led design frameworks can be adapted for additional populations is an important direction for future accessibility research.

Finally, we do not claim that a single small scale prototype resolves the challenges of Deaf education. Rather, we show that even within a fifteen minute lecture, Deaf ways of knowing reframe what immersive classrooms must consider and prioritize. Future studies will examine sustained classroom deployments, diverse subject areas, and quantitative measures of learning outcomes and engagement. Importantly, these extensions will proceed only with continued Deaf community support. We commit to culturally accountable research.

## 6 Conclusion

We presented a Deaf-led, ASL-first study of immersive classrooms, exploring how signer placement in VR shapes visual access, cultural fit, and pedagogical practice. Through Deaf-centered design and close collaboration with the community, we created and evaluated a prototype that reimagines classroom layouts through Deaf epistemologies. Participants emphasized that elements often treated as interface preferences—such as signer position, spatial arrangement, and opportunities for customization—are, in fact, fundamental to comprehension, cultural resonance, and Deaf ways of learning, teaching, and living. From these insights, we introduced a five-dimension conceptual framework (proximity, customizability, visual efficiency, cultural fit, and task flexibility) that captures how our participants reason about signer placement and visual access in immersive environments.

We aim to signal a broader shift for Deaf-centered HCI in which Deaf communities guide the development of emerging Deaf Tech. Deaf learners and educators are not peripheral users adapting to VR; they are epistemic authorities whose perspectives reshape what immersive classrooms must consider and prioritize. As a mixed-hearing team with Deaf leadership, we take an initial step toward reclaiming VR design authority. Immersive classrooms built from Deaf epistemologies are not accessibility retrofits; they are blueprints for Deaf futures.

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# A Study Session Protocol (60 minutes)

Each study session should be under 60 minutes and consists of three parts: orientation, prototype testing, and a semi-structured interview.

**Orientation (15 minutes)**

Welcome the participant, briefly explain the purpose of the study, and review the consent and video release forms (offer ASL translation if needed). Outline the agenda and collect demographic information, including age, gender, first and primary language(s) for communication, prior experience with VR, and prior experience with the topic of binary search.

Provide a short tutorial on using the VR equipment and assist the participant in getting comfortable with the setup.

**Prototype Interaction (15 minutes)**

Explain that the prototype supports three signer placement modes (corner, transparent, and side-by-side), and encourage the participant to explore each setting. Have the participant engage with the VR classroom prototype (a binary search lecture). Observe and take notes on their interactions, questions, challenges, and notable behaviors.

**Semi-Structured Interview Guide (20 minutes).**

After the prototype session, conduct a semi-structured interview using open-ended questions to elicit detailed feedback. Example prompts include:

- How did you find the overall experience?
- What are your thoughts on the three modes (corner, transparent, parallel)?
- Was the VR environment intuitive and easy to navigate?
- Did the VR setup help with visual attention? Were you able to look at slides/code and follow the ASL lecture? How does this compare to a regular online lecture with a Deaf teacher?
- Were there any difficulties or challenges you faced?
- This prototype focused on a programming course. Do you think this tool could be applied to other subjects? If so, which ones?
- What improvements or features would you suggest?

**Wrap-Up (10 minutes).**

Summarize key discussion points, thank the participant for their time, and provide information on next steps and how they can stay updated on the project.