A Qualitative User Study Investigating Designs to Reduce User Challenges in Cross-Reality Transitional Interfaces

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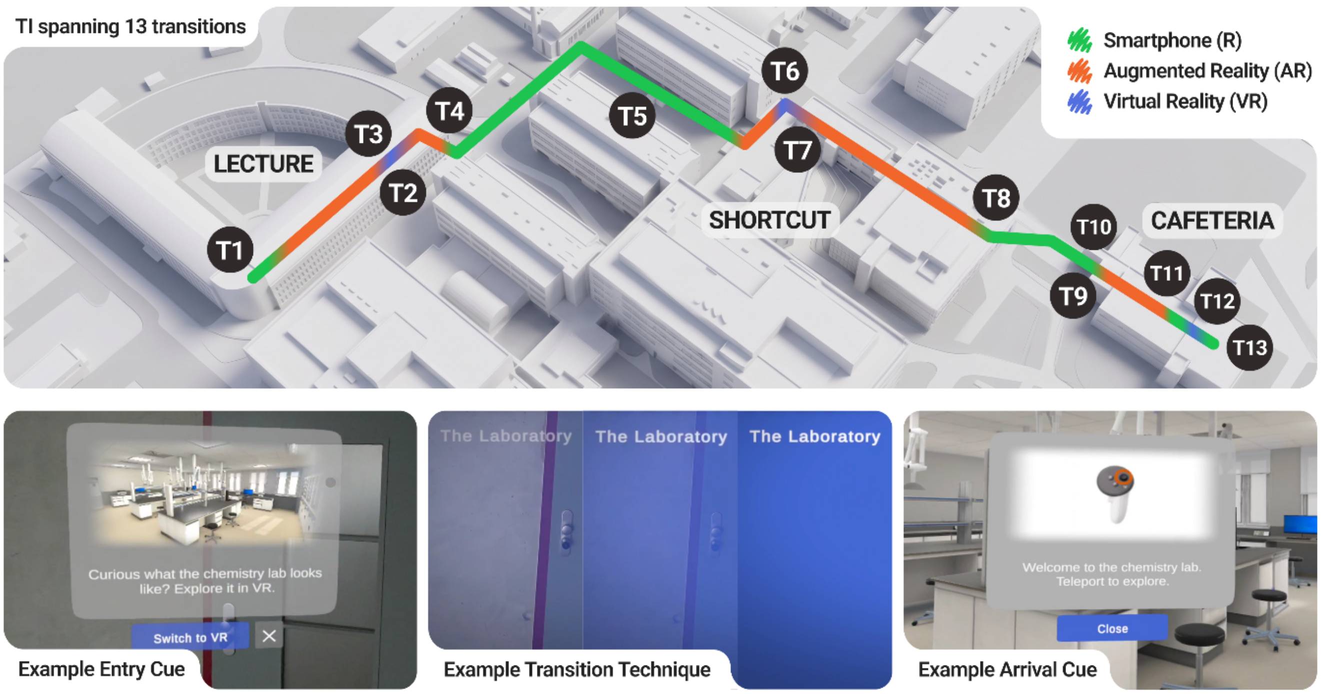

Figure 1: Overview of the study prototype and its campus route spanning 13 transitions across smartphone, AR, and VR, with examples of three design interventions: entry cue, transition technique, and arrival cue.

Abstract

Transitions among physical, augmented, and virtual reality are a critical design problem in cross-reality systems. Prior research has identified transition-related challenges, but predominantly in spatially constrained lab environments, leaving open how such challenges unfold across the diverse transitions and contexts of real-world use. We conducted a qualitative study in which 18 participants completed differing tasks along a public campus route, encountering 13 transitions, each implemented in two variants. Five categories of challenges emerged, mapping onto distinct phases before, during, and after the transition: fear of the unknown, spatial disorientation, social discomfort, and physical strain, consistent with prior research, and functional uncertainty, a previously undocumented category arising from interaction paradigm carry-over between contexts. We then analyzed the design approaches implemented within each phase and discussed how they can be operationalized to address the identified challenges.

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CCS Concepts

• **Human-centered computing** → **Mixed / augmented reality**; **Virtual reality**; **User studies**.

Keywords

Cross-Reality, Transitional Interfaces, Transition Techniques, User Challenges, Qualitative User Study

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1 Introduction

Transitional Interfaces (TIs) [5] define interactive systems situated within mixed or cross reality (MR/CR) [21] that facilitate users in shifting between various "realities" along the Reality–Virtuality Continuum (RVC) [27]. They encompass personal computers or mobile devices and Augmented/Virtual Reality (AR/VR) experiences delivered through head-mounted displays (HMDs), enabling users to fluidly transition to displays and input and output modalities that optimally align with their current tasks [21]. For instance, a user navigating a university campus might start on their smartphone, switch to AR for navigation, jump into VR to explore an unfamiliar area, and then come back to physical reality, all as part of one seamless experience. Previous work conceptualizes this behavior as *transitions* between different *contexts* [14, 15]. A context is defined by its position on the RVC (e.g., AR, VR, reality) [27] and attributes such as scale (e.g., macro, micro, nano), representation type (e.g., photorealistic, non-photorealistic, symbolic), and user parameters like navigation method (e.g., natural walking, teleportation). A transition is thus a movement between two viewpoints belonging to different contexts [15].

Yet, moving from one context to another is not without friction. Research has indicated that transitions introduce spatial disorientation, social discomfort, physical effort, and fear of the unknown [23, 41]. These challenges intensify when users arrive in an unfamiliar context without sufficient preparation [23, 41]. Prior work on the design of transitions has addressed this primarily at the level of the transition techniques, comparing visual metaphors such as fades, portals, and gradual scene constructions between contexts [8, 20, 22, 31–33]. Less attention has been given to what happens before the transition starts, specifically how users decide whether and when to transition when they have limited information about the target context, and to what happens immediately after, when users must re-establish spatial orientation, recall their task, and adjust to a new interaction paradigm [26, 29]. Nearly all existing work has been conducted in stationary, controlled laboratory settings [26, 29], and how these challenges arise, compound, and interact during transitions in a mobile, real-world public setting remains unknown.

We address this gap with a qualitative study of a TI in a real-world setting: a cross-reality system that distributes interactions across unmediated physical reality (R), AR, and VR in a mobile, route-based setting. We designed a prototype around a university campus in which 18 participants moved through three buildings while completing navigation, exploration, and social tasks. The prototype included 13 transitions, each implemented in two variants: a richer *variant A* combining design interventions before, during, and after a transition and a reduced *variant B* providing only minimal scaffolding before a transition. A counterbalanced within-subjects design ensured each participant experienced both variants. We collected think-aloud feedback, post-session interviews, and per-transition ratings and treated the qualitative data as the principal evidentiary basis for the analysis.

Our findings show that transition challenges are not uniform across context pairs or task types. Their occurrence and magnitude are contingent upon the specific contexts they bridge, the characteristics of the associated task, the surrounding social environment, and the user's degree of familiarity with the specific transition and target context. More sophisticated transition designs showed their strongest benefits in cases where the target and origin contexts differed considerably across cognitive, functional, and perceptual dimensions, resulting in a higher number and severity of challenges [7]. Richer designs provided minimal additional benefit in scenarios in which the transition was already highly predictable and the context gap was limited.

This paper makes four contributions.

- **Contribution 1:** Empirical evidence from a qualitative study (n=18) of a real-world TI comprising 13 transitions across R, AR, and VR, characterizing how transition challenges manifest under mobile, everyday conditions outside controlled laboratory settings.
- **Contribution 2:** Empirical evidence that transition challenge occurrence and severity are not uniform but contingent on transition-level factors: the origin-target context pair, task structure, social setting, and user familiarity, mapped across the entry, limbo, and arrival phases.
- **Contribution 3:** Identification of functional uncertainty as a previously undocumented TI challenge category, arising from interaction paradigm carry-over between contexts rather than simple unfamiliarity with available interactions.
- **Contribution 4:** A challenge-profile calibration approach to transition design, grounded in a direct A/B comparison across all 13 transitions, showing which design interventions address which challenge categories and when elaborated design is warranted.

In the following, we first review related work on challenges and design solutions in TI research, with the aim of identifying existing gaps. We subsequently provide a detailed description of our user study design and the implemented prototype. This is followed by the analysis of the collected qualitative data, as well as a systematic discussion of the overarching characteristics and outcomes of the identified challenges and the corresponding design solutions. We conclude by discussing limitations and future work.

2 Related Work

Our discussion of previous and related work focuses on three categories of work: (1.) Core TI research that is foundational for TIs, establishes key terminology, and highlights open problems in TI research (2.) Work on TI, MR, or XR research that discusses user challenges occurring before, during, or after transitions (3.) Work on design principles, templates, and other guidance intended to support the systematic design and implementation of transition processes.

2.1 Transitional Interfaces: Background and Terminology

The concept of TIs traces back to the MagicBook by Billinghurst et al. [5], a system that used animated transitions between AR and VR to facilitate exploration along the RVC [27]. Across these early systems, *interaction continuity* across perceptual, functional, and cognitive dimensions emerges as a central design principle [7]. The original definition of transitions by Grasset et al. [14] further evolved into multi-step models, with most arriving at a three-phase structure spanning the time before, during, and after transitions [18, 29, 34]. In this paper, we refer to these three phases as *entry*, *limbo*, and *arrival*, capturing respectively the anticipatory moment before a user commits to a transition, the temporary in-between state during crossing, and the re-orientation moment upon reaching the target context. Further work developed systematic evaluation frameworks, specific questionnaires, or data visualization lenses for TIs [1, 36, 37].

The growing number of surveys and systematic reviews covering a literature corpus of 306 relevant publications in the recent past show a growing field with considerable scope and depth [2, 26, 29]. The advent of standalone HMDs that support smooth, high-quality transitions between AR and VR, exemplified by devices like the Meta Quest 3 and Apple Vision Pro, has created new and broader application scenarios for TI research. These range from dedicated professional settings such as immersive data analytics [25, 38] and museum experiences [34] to everyday consumer scenarios including public transport, shopping, and outdoor environments [4, 35, 39].

Some research on transition has concentrated on particular pairings of origin and target context. A substantial body of work examines transitions within HMDs from augmented to virtual environments, systematically comparing transition techniques such as fades, portals, teleportation beams, and replica-based transitions [8, 20, 22, 31–33, 40]. A parallel line of work addresses disengagement from immersive environments back to unmediated reality [18, 23, 30, 32]. Other work focuses on maintaining task and spatial continuity through anchoring structures and spatial mental models [11, 41]. A separate line of research has examined transitions in shared and social settings. Studies of collaborative TIs document how users in different XR contexts face challenges around joint attention and context asymmetry [37], and how co-present bystanders who are not wearing a headset perceive and react to a transition [19, 24, 28].

Notably, the user challenges that arise across this breadth of work have not been systematically analyzed or described through a shared lens. Individual studies have documented specific difficulties, but these observations have not been consolidated into a coherent challenge taxonomy that spans all three transition phases. The same fragmentation characterizes prior design work. A substantial body of research has produced concrete design considerations, patterns, solutions, and other prescriptive guidance for TI. However, most contributions focus on specific, localized aspects of the broader design problem: a particular technique, a specific context pairing, or a single phase of the transition sequence.

2.2 User Challenges in Cross-Reality Transitions

Research has documented a spectrum of experiential challenges that arise when users move between realities [23, 41]. These challenges cut across all three transition phases and persist across different contexts and TI systems, suggesting they reflect fundamental properties of transitions rather than artifacts of particular implementations. In the following characterization, we organize findings by the nature of the challenge, grouping them thematically even where the descriptive terms used in prior work do not fully align.

Fear of the unknown. A persistent source of friction in the entry phase is the user's inability to anticipate what the target context will look, feel, or behave like before committing to a transition [41]. This consideration intersects with the difficulty users face when assessing whether the anticipated effort associated with a transition is warranted by, and therefore offset by, the anticipated benefits. With limited information, users are more hesitant to engage, as they cannot make a cost-benefit assessment of the transition [26, 35]. An early TI user evaluation showed that participants explicitly requested a preview showing where they would end up after transitioning, providing initial evidence that uncertainty is a primary barrier [13]. An exploration of world-switching interfaces confirms that the quality of pre-transition information strongly determines willingness and confidence to cross [12].

Spatial disorientation. During the arrival phase, users are required to establish a spatial mental model of the unfamiliar environment while simultaneously reorienting their body within it, often without adequate support, creating a potential for spatial disorientation [41]. The chance and magnitude of this risk are jointly determined by the perceived discrepancy in perceptual characteristics [7] between the origin and target contexts, together with the structural properties and design of the transitional process [12, 18, 31, 32]. A design space identifies physical integrity and self-orientation as the two most immediate demands [11], and research of the VR exit moment lists navigating physical space and reorienting in time as distinct experiential challenges [23, 29, 30, 43]. For transitions between previously visited contexts, *forgetting* and *inconsistency* occur when the remembered layout of a previously visited environment no longer aligns with its present configuration [41]. In naturalistic settings, the problem is further compounded: an in-the-wild study of VR headset use on real train journeys found that significant real-world changes slipped unnoticed because the spatial attention required to navigate the virtual context left no capacity to monitor the physical one [4].

Social challenges. Transitions create asymmetries between the transitioning user and those around them that neither party is well-equipped to manage [4, 19, 23, 24, 28, 37]. A foundational study of the VR exit moment identifies re-entering social situations as one of five distinct experiential challenges at crossing [23], and users have been shown to weigh social environment against desired immersion rather than optimizing for system usability, meaning that the social cost of transitioning is actively factored into decisions about whether and when to cross [28]. Switching between desktop, tablet AR, and VR HMD contexts generates coordination challenges around joint attention and context asymmetry when users work collaboratively [37]. Taken as a whole, this research shows that social friction is a multifaceted problem space that depends on the particular environment, the way multiple users' contexts are arranged and combined, and the character of the relationships among those users, whether they are actively collaborating or merely sharing a space with limited interaction.

Physical effort and strain. Cross-reality transitions impose physiological effort that accumulates with repeated use into strain. The physical act of donning and doffing the headset itself has been observed in several studies but has received surprisingly little systematic attention despite constituting a distinct challenge in the limbo phase [23, 34, 36, 37, 41]. Users reported cumbersome fitting procedures and general discomfort from extended HMD wear [34, 41], users with glasses and long hair encountered particular difficulty during each donning and doffing episode [18, 41], and post-session accounts describe headset removal itself as an uncomfortable experience [36]. Further works showed that the perceived cost of putting the headset back on led users to delay taking it off for as long as possible, a strategy that itself generates strain and confirms that the physical effort of switching devices, combined with the cognitive cost of adapting to different interfaces, produces a cumulative load [35, 37, 43]. In mobile and in-the-wild settings, this cumulative physical cost of managing a headset over an extended session adds a layer of fatigue [4].

Most of the evidence reviewed above was gathered in controlled laboratory environments, relying on structured onboarding, experimenter explanations, and training trials before participants undertook study tasks, a limitation confirmed as a gap in the field [29]. The few in-the-wild studies available suggest that challenges are not merely reproduced but amplified when transitions occur in real-world mobile contexts [4, 19, 39]. To date, no empirical study has systematically examined the described challenge categories together across the three transition phases. Such an investigation is needed to clarify when and how each emerges, which structural properties give rise to each, and whether real-world use surfaces challenges not yet documented.

2.3 Design Interventions: Entry Cues, Transition Techniques, and Arrival Cues

The four challenge categories identified above call for design responses across all three transition phases. For the limbo phase, transition techniques constitute a well-established design category with a substantial body of comparative work [8, 20, 31–33]. The entry and arrival phases have also attracted design contributions, though these are scattered across the literature under terminology specific to particular contexts or systems. In this paper, we collect these contributions under two organizing terms: entry cues for any design element operating before a user commits to a transition and arrival cues for any design element supporting users upon reaching the target context. This allows us to map existing and new findings by their temporal position in the transition rather than by the specific system or context they were developed for.

Entry cues. Entry cues operate in the origin context and facilitate anticipatory processing, comprehension, and informed decision-making before a user commits to a transition, functioning as invitations that preserve user agency [2, 30]. Their primary function is to make both transition availability and the costs and benefits of initiating it legible. Previous work shows that missing or inadequate designs in the entry phase can impair spatial mental model formation and cascade into arrival-phase disorientation [26, 35, 41]. Visual previews are among the most consistently positively evaluated entry design elements, with implementations ranging from high-fidelity portals and worlds-in-miniature to sliced visual fragments and simple location labels, all rated favorably across independent studies [12, 15, 42]. By providing a glimpse of the target context before commitment, they support expectation-building and enable users to begin forming a spatial mental model of the destination, reducing both hesitation to cross and disorientation upon arrival. Where multiple modalities are available, redundant cues increase robustness under divided attention [34, 42]. In collaborative and mobile settings, entry cues can carry additional social information about collaboration partners and bystanders that could encourage a transition [34, 35].

Transition techniques. Transition techniques operate during the limbo phase and shape the perceptual and interactive experience of the crossing itself. No single technique is universally optimal: expressive techniques such as portals and orbs maximize presence and hedonic quality for narrative or exploratory transitions, while minimal techniques such as fades and cuts better serve frequent, task-oriented crossings where efficiency dominates [8, 20, 26, 31–33]. The central challenge is maintaining coherence as contexts change; gradual approaches, retaining real-world information during crossing, morphing physical replicas into the target environment, or blending the real world into VR at the boundary zone, improve body ownership illusion, spatial orientation, and transition smoothness relative to instant switches [16, 22, 31–33, 40]. Preserving stable spatial references during the crossing reduces cognitive reset and supports spatial mental model continuity across contexts [32, 44].

Arrival cues. Arrival cues have the goal to support users in restoring spatial orientation and re-engaging with the social situation in the target context. Disorientation and uncertainty immediately after transitioning are among the most consistently reported friction categories in qualitative transition studies [23, 41]. Despite this well-characterized demand structure, post-arrival design remains the least-developed phase in the transition design literature. Among the few works addressing the destination-side experience, George et al. propose a placement logic that returns users to a fixed entrance point rather than their prior position in the context, separating spatial orientation demands from scene-change adaptation upon arrival [11]. Wang et al. identify MR-based narrative transitional spaces as designs capable of easing arousal, mitigating perceptual carry-over, and sustaining social connection after prolonged VR immersion [43]. In collaborative and public contexts, arrival additionally requires explicit co-presence signaling and bystander reintegration [11, 23]. Post-arrival design has thus been studied primarily as a problem space, documenting what users must recover from upon arriving, rather than as a systematically evaluated design space.

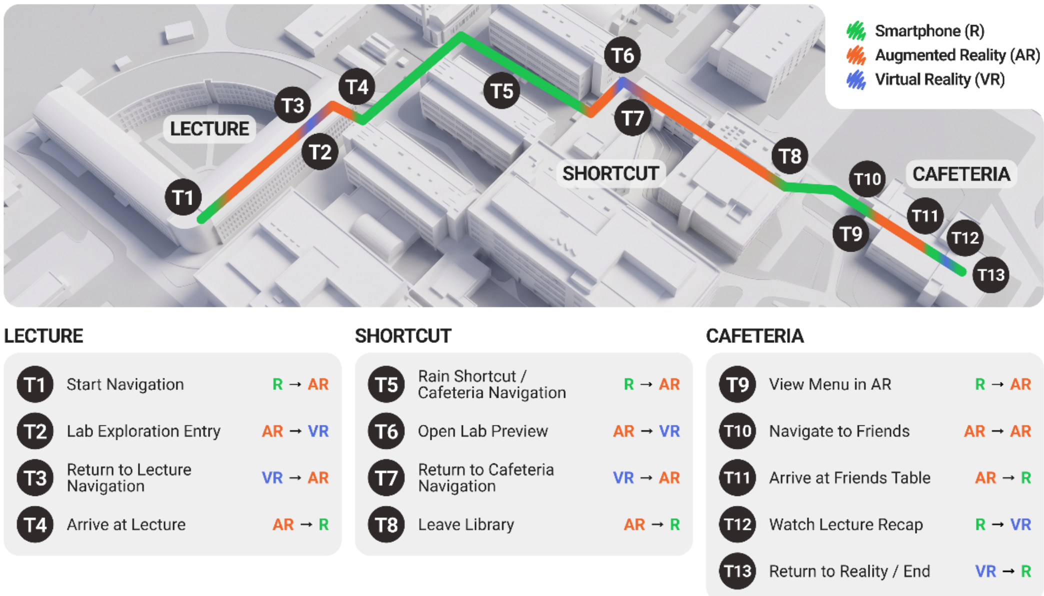

Figure 2: The campus route followed by participants, with all 13 transitions marked and color-coded by context: green for smartphone (R), orange for augmented reality (AR), and blue for virtual reality (VR). Transitions are grouped by the three campus locations visited during the session.

Together, entry cues, transition techniques, and arrival cues form the three-part design vocabulary around which the following study is organized. Prior work has developed each category largely in isolation, in stationary settings, and with a narrow range of transition types, without empirically testing which design responses effectively address which challenge categories under mobile conditions. The following study examines these intervention categories to reduce or even alleviate the four challenge categories identified above.

3 User Study

Real-world TI use exposes users to conditions that controlled laboratory settings cannot easily replicate: unscripted movement through public spaces, variable social environments, and transitions whose timing and situational context are not pre-arranged by the experimenter. Motivated by the challenge landscape identified in the related work and by the persistent gap between laboratory findings and naturalistic use [26, 29], this study pursued two goals. The first was to observe how transition challenges arise naturally across a diverse set of transitions in a mobile, real-world setting, examining which challenges emerge, in which phases, and under what conditions. The second was to evaluate whether and how design interventions across the entry, limbo, and arrival phases can address those challenges.

To support the first goal, the prototype was designed to include a wide variety of transitions differing in origin and target context, task structure, and situational conditions. This breadth was necessary to examine when and why challenges arise and whether their occurrence and severity depend on properties of the specific transition, rather than merely to confirm that challenges exist. For the second goal, each transition was implemented in two variants: a richer *variant A* that combined elaborated design elements across all three phases and a reduced *variant B* providing only the minimal scaffolding needed to announce the transition. The comparison was not intended to establish whether A globally outperforms B but to probe under which conditions design elaboration matters, for which challenge profiles it is most consequential, and which challenges persist even with elaborated design available.

Additional variants, isolating individual phases or combining them selectively, would have allowed more precise attribution of effects to specific design elements but would have resulted in merely partially designed transitions with limited ecological validity. We therefore prioritized two complete, end-to-end designs over a larger set of experimentally decomposed ones.

3.1 Prototype

The prototype was implemented as an iOS smartphone application combined with a Unity application for the Meta Quest 3. Participants interacted with the system across three contexts: R (smartphone), AR, and VR. A university campus was chosen as the setting for several reasons. It provided a naturalistic, mobile environment in which transitions between these contexts could arise as part of a plausible everyday task sequence rather than as isolated experimental stimuli. Including all three contexts in a single continuous session also allowed the prototype to encompass context pairs with meaningfully different perceptual, functional, and cognitive dimension profiles [7].

The scenario cast participants as prospective students spending a day on campus. At the beginning, the participant was directed via smartphone to an unknown lecture hall. On the way, a message from a friend character named Peter asked them to find out how many workplaces were available in the chemistry lab. After exploring a VR version of the lab, the participant continued to the lecture hall. The next task was a lunch with Peter in the cafeteria. During the walk, the system warned of approaching "rain" and redirected the participant through the library via a shortcut. In the library, a message from Peter prompted the participant to check out posters for an open lab day, with a VR preview of the event available from that location. Upon reaching the cafeteria, participants could view an AR preview of the day's menu before selecting a meal. They were then directed to Peter's table. The final task involved catching up on a missed lecture, available in VR. Completion of the lecture concluded the session.

3.1.1 Transitions. The prototype contained 13 transitions shown in Figure 2. A complete run-through of the route, including all 13 transitions in both variants, is provided in the supplementary video accompanying this paper.

The 13 transitions span seven distinct origin-target context combinations, each implemented in both variant A and variant B. Several design choices were applied consistently across all rich-variant transitions: cues were color-coded by target context (orange for AR, blue for VR, and green for R), and all AR and VR arrival cues rotated to face the participant. The reduced variant of each combination contained only a basic entry cue and minimal transition technique; the rich variant additionally included elaborated entry cues, arrival cues, and more graduated transition techniques. The following describes the design rationale and implementation for each context combination.

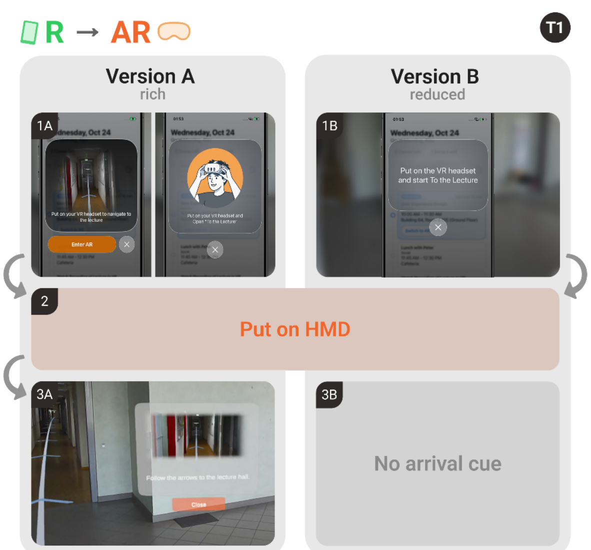

Figure 3: R→AR transition example. A sequence of T1 in which the user starts a navigation to the lecture hall.

R→AR transitions (T1, T5, T9) represent a mobile-first entry point characteristic of everyday consumer TI scenarios [26, 39]. In our prototype, R denotes the unmediated physical environment with the smartphone as the interaction device. When a transition into AR was initiated, one of the researchers handed the participant the VST HMD with the study application already running and the camera-based passthrough view active. Donning the headset therefore placed participants directly into the AR context.

Prior work documents that arriving in a new context without prior information intensifies disorientation and hesitation [41], motivating the visual destination preview and instructional video in the rich variant. In the reduced variant, participants were prompted to put on the HMD and start the application (Figure 3.1B). The rich variant showed a visual preview of the destination, either an image of the target area (T1, T9) or a route to a building (T5), alongside a looped instructional video demonstrating HMD donning (Figure 3.1A). Upon entering AR, the rich variant presented an arrival cue directing participants to follow the route or begin the relevant task (Figure 3.3A).

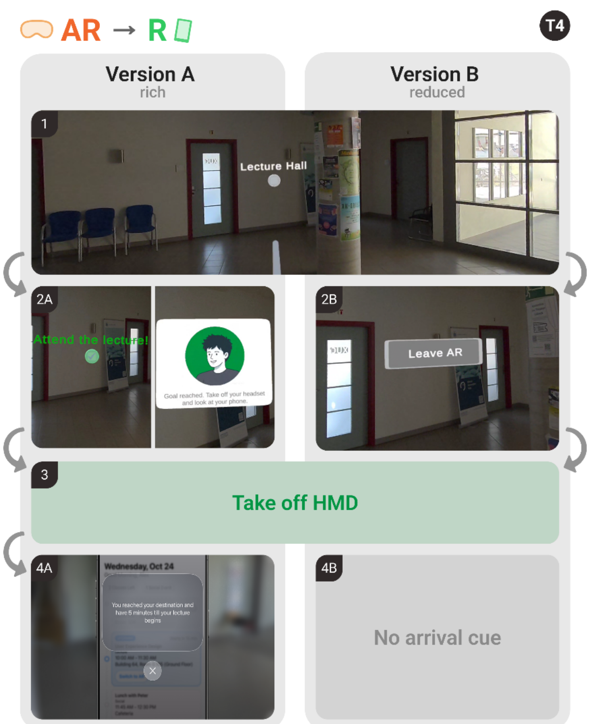

Figure 4: AR→R transition example. A sequence of T4 in which the user arrives at their lecture.

AR→R transitions (T4, T8, T11) communicate to the users that their current task is complete before removing the headset, a moment prior work identifies as a primary source of hesitation and task-completion ambiguity [23, 41]. The animated completion feedback and context-specific arrival message in the rich variant were designed to close this gap, drawing on design proposals for explicit task-boundary signaling upon arrival [11]. In the reduced variant, the destination was represented by a circle with a title label (Figure 4.1); as participants approached, the circle disappeared and a prompt asked them to leave AR (Figure 4.2B). The rich variant triggered an animation on arrival at the circle and displayed a cue confirming arrival and instructing the participant to remove the HMD, accompanied by a looped instructional video (Figure 4.2A). On the smartphone, participants received a context-specific arrival message, for example confirmation of arriving at the lecture hall or notification that a friend was already waiting (Figure 4.4A). The rich variant also used continuous proximity audio and cue rotation to face the participant.

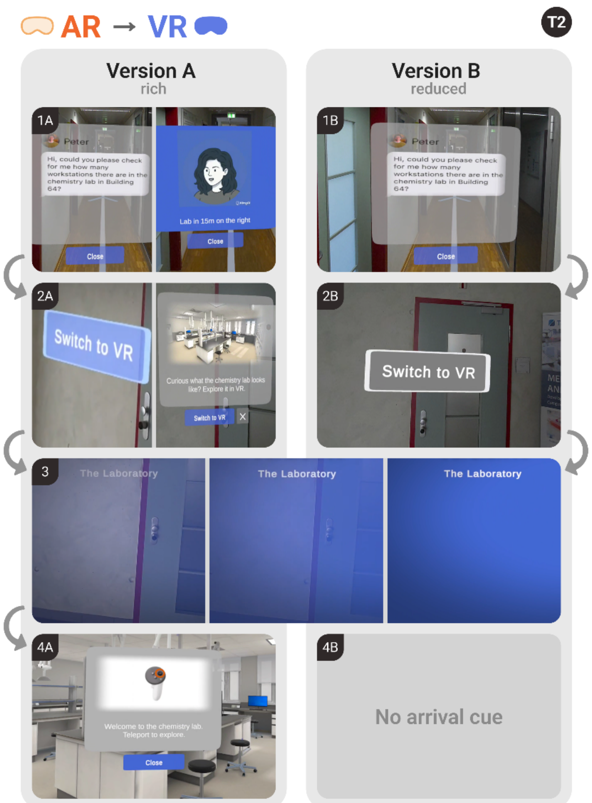

Figure 5: AR→VR transition example. A sequence of T2 in which the user explores a virtual laboratory.

AR→VR transitions (T2, T6) constitute the most extensively studied context combination in the TI literature, with multiple comparative studies evaluating visual techniques for this crossing [8, 20, 22, 31, 32]. Both transitions were motivated by messages from Peter asking participants to complete a task in VR, in the example checking the number of available workspaces in the chemistry lab (Figure 5.1B). In the reduced variant, the entry cue indicated only that a VR transition was available (Figure 5.2B). The rich variant included an additional audio system message identifying the VR entry point (Figure 5.1A); on approach, the entry cue expanded to show a preview of the VR environment, explain the transition rationale, and offer an explicit option to decline (Figure 5.2A), building on evidence that context previews and preserved user agency reduce fear of the unknown before committing [12, 41]. In both variants, the transition to VR occurs as a fade to a blue screen with a title for the VR context, followed by a hard cut to the target environment (Figure 5.3). The rich variant added an arrival cue reminding participants that teleportation was available via the controller (Figure 5.4A), addressing the locomotion paradigm shift.

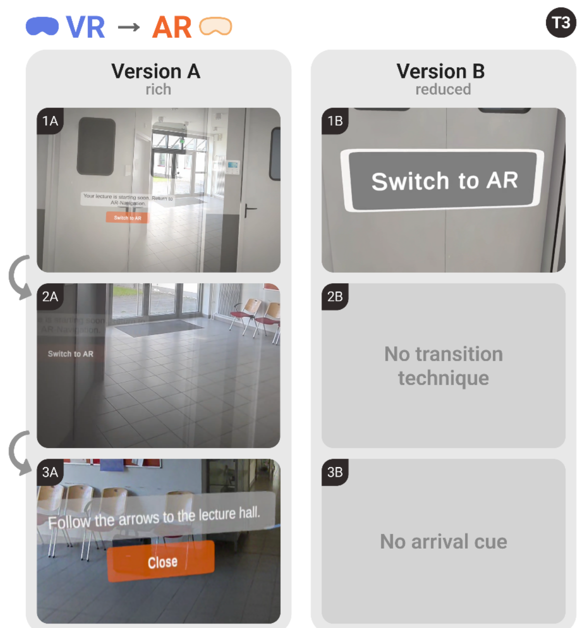

Figure 6: VR→AR transition example. A sequence of T3 in which the user continues their navigation to the lecture hall after visiting a virtual laboratory.

VR→AR transitions (T3, T7) require users to reconstruct a spatial mental model of the physical environment after leaving immersion, a crossing documented as particularly disorienting [18, 23, 30]. The virtual door frame used in the rich variant (Figure 6.1A) was informed by design proposals for spatially coherent exit affordances that co-locate the exit point with a live preview of the destination context [11, 32]. In the reduced variant, the transition occurred via a hard cut to AR as the baseline technique. Instant cuts are one of the canonical scene-transition techniques [20], correspond to the default behavior of deployed HMD systems, and add no temporal cost, which matters for frequent task-driven crossings where even brief animated transitions can be perceived as too slow and distracting from the task [31]. The rich variant gradually faded out the VR environment (Figure 6.2A), building on evidence that preserving real-world visual information during the crossing supports spatial reorientation relative to abrupt switches [22, 32], and displayed an arrival cue prompting participants to follow the route to their next destination (Figure 6.3A).

The *AR→AR* transition (T10) represents a context switch within a single point on the RVC, where the display technology remains constant but the task frame, navigation goal, and social context all

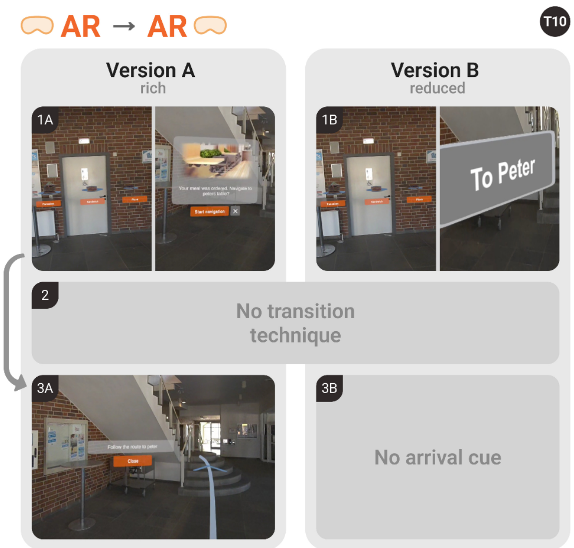

Figure 7: AR→AR transition example. A sequence of T10 in which the user is guided to their friends' table after selecting a dish.

shift. An entry cue appeared after participants selected their meal, offering navigation to Peter's table (Figure 7.1B). In the rich variant, approaching the cue expanded it to show a preview of Peter's table, confirm that the meal had been ordered, and prompt participants to begin navigation (Figure 7.1A). An arrival cue then directed them to follow the route (Figure 7.3A).

R→VR transition (T12) represents one of the largest perceptual and functional jumps in the set, moving from a handheld 2D interface to a fully immersive environment with a different locomotion paradigm. Evidence that abrupt context switches increase spatial disorientation at VR entry motivated the graduated environment reveal in the rich variant [23, 32]. The entry cue followed the same structure as the smartphone-to-AR combination (Figure 8.1A and 8.1B). The reduced variant hard-cut to VR and began the lecture after a three-second delay. The rich variant first revealed the lecture hall furniture, then gradually faded the full environment into view (Figure 8.3A), and displayed an arrival cue allowing participants to initiate the lecture by interacting with it (Figure 8.4A).

VR→R transition (T13) shares many of the challenges of the VR→AR combination: spatial disorientation, social re-entry, and loss of task frame upon leaving immersion are among the most consistently documented difficulties at the VR exit moment [23, 30]. In the reduced variant, Peter simply asked participants to remove the HMD and leave. In the rich variant, the lecture video paused, part of the virtual environment became semi-transparent, and a system message informed participants that Peter wanted to leave and prompted them to remove the HMD (Figure 9.1A). This partial transparency was intended to ease the perceptual gap before full disengagement [44]. The rich variant also presented a smartphone arrival cue notifying participants that their next bus would arrive in five minutes (Figure 9.3A).

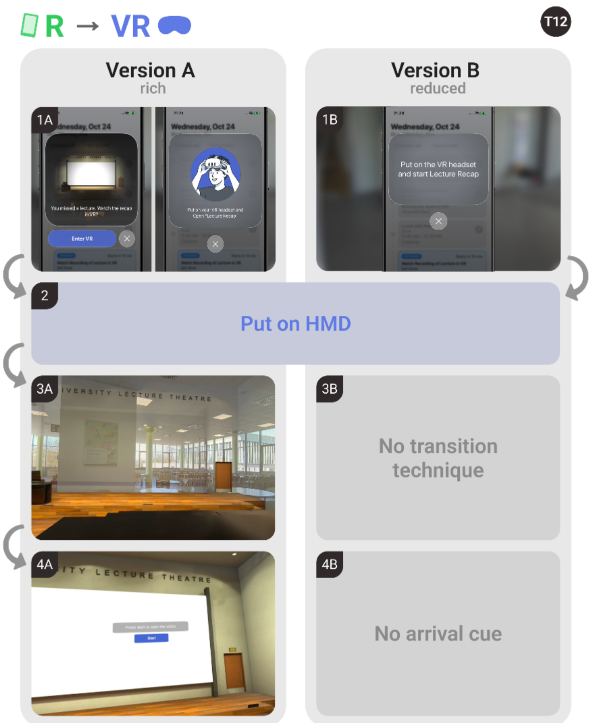

Figure 8: R→VR transition example. A sequence of T12 in which the user watches a virtual recap of a lecture they missed.

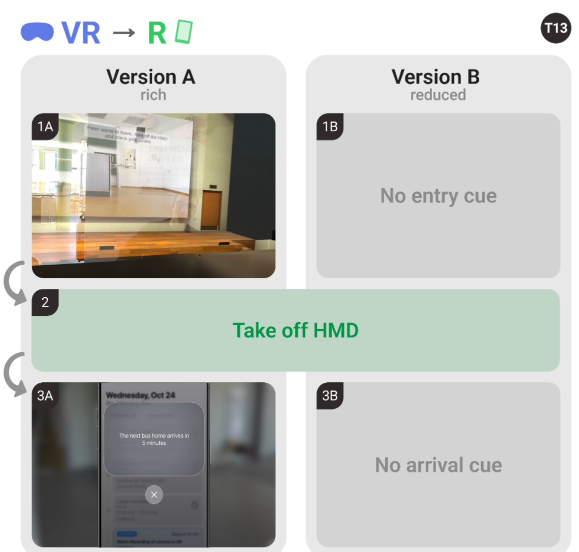

Figure 9: VR→R transition example. A sequence of T13 in which the user ends their session in a virtual lecture and continues where they left off in the real world.

Transitions 1 through 8 were deliberately designed to be structurally comparable to support systematic analysis across context combinations and encounter order. Transitions 10, 12, and 13 were too context-specific to implement more than once. Outdoor segments between buildings were navigated without the HMD due to environmental conditions.

3.2 Study Design

The study used a within-subjects design, with each participant experiencing both the richer *variant A* and the reduced *variant B* across the 13 transitions. This design was chosen for two reasons. First, it controls for individual differences in XR experience, spatial ability, and technology affinity that would otherwise confound comparisons between design conditions in a smaller sample size. Second, and particularly relevant for the qualitative component, it enabled participants to draw direct comparisons between the two design levels during the post-study interview, producing more grounded and specific reflections than a between-subjects design would have afforded.

To mitigate ordering effects, two counterbalanced prototype sequences were used. A pure block design, in which all rich transitions preceded all reduced ones or vice versa, was rejected on two grounds. Participants who encountered rich cues first might draw upon the information carried by those cues when rating the reduced variant later, artificially inflating reduced-variant scores, while a reversed block would have made the two-condition structure immediately obvious to participants. The base assignment therefore followed an alternating pattern across the session. The only deliberate exception concerned the two VR excursions in the prototype, T2, T3, T6, and T7 (AR into VR and back). Each excursion was kept at a single consistent variant rather than alternated, because switching design richness mid-excursion would have fragmented what participants experienced as a single coherent episode in VR. Table 1 shows the resulting variants for each transition in the two prototype sequences.

Transition	Contexts	Version 1	Version 2
T1	(R→AR)	A	B
T2	(AR→VR)	B	A
T3	(VR→AR)	B	A
T4	(AR→R)	A	B
T5	(R→AR)	B	A
T6	(AR→VR)	A	B
T7	(VR→AR)	A	B
T8	(AR→R)	B	A
T9	(R→AR)	A	B
T10	(AR→AR)	B	A
T11	(AR→R)	A	B
T12	(R→VR)	B	A
T13	(VR→R)	A	B

Table 1: Transitions and their respective variants in prototype version 1 and 2

3.3 Study Procedure

The duration of the conducted studies ranged from 60 to 90 minutes, including both the pre-study briefing and the post-study interview. Each session began with a briefing in which participants were informed of the study's purpose, procedure, and their rights as participants. Each participant signed a consent form covering voluntary participation, the audio recording of the session, the transcription and subsequent analysis of the recording, and the use of anonymized excerpts in academic publications. Data collection and processing followed applicable local regulations on research data and the protection of personal data. Participants could withdraw at any point without giving a reason and could request that specific passages be excluded from analysis. Audio recordings and session notes were stored on access-restricted institutional infrastructure; transcripts were pseudonymized at the point of transcription.

Following the briefing, participants completed the pre-study questionnaires, which included the Affinity for Technology Interaction (ATI) scale [10], basic demographic information, and questions about prior XR experience covering frequency of use, typical use cases, and any experienced side effects. A short tutorial then familiarized participants with the basic interaction and locomotion affordances available in AR and VR, without introducing any of the transitions or tasks included in the study itself.

Each session was conducted by two researchers: one guiding the participant through the route and one carrying the HMD between buildings. The researcher carrying the HMD also prepared it before every transition that required donning it, ensuring the study application was running and the target context was already active at handover. Both took structured per-transition notes throughout the session, and audio was recorded continuously.

Participants were asked to think aloud as consistently as possible during the study, verbalizing thoughts, reactions, and difficulties as they arose. After each transition was completed, the guiding researcher conducted a brief structured probe. If a participant had not commented unprompted on the transition, the researcher asked them to reflect on any challenges encountered and on the design elements just experienced. In either case, the researcher then asked for an explicit rating of the participant's overall personal experience of the transition just completed, on a five-point scale from −2 (very negative) to +2 (very positive). The rating deliberately targeted the holistic experience of the crossing rather than a specific construct such as usability or physical comfort, as its purpose was to contextualize the qualitative feedback given immediately before.

Both the post-transition probing and the rating were deliberate methodological choices. Collecting transition-level feedback immediately after each crossing, rather than at the end of the session, was essential for accuracy: pilot observations confirmed that details regarding individual transitions, in particular the role of specific design elements and the phase in which a challenge arose, were consistently lost when participants were asked to reflect retrospectively across the full route after 13 transitions in varied settings. Although probing after each transition introduces brief interruptions to the study flow, this cost was accepted as necessary to obtain reliable and specific qualitative data. The per-transition rating served primarily to contextualize the qualitative responses rather than as an independent outcome measure.

At the end of the session, participants took part in a semi-structured interview covering their overall transition experience, impressions of entry and arrival cues, favorite and least favorite transitions and the reasons for these preferences, and any additional observations or design suggestions.

The resulting dataset treats the qualitative material as the primary source of evidence. Think-aloud protocols and post-transition probes form the principal data, supplemented by post-session interview transcripts and structured researcher notes. Per-transition ratings and explicit preference choices support and contextualize the qualitative findings rather than functioning as independent outcome measures. ATI scores and XR background data from the pre-session questionnaire complete the dataset.

3.4 Participants

We recruited 18 participants (5 women, 13 men; age range: 21 to 73 years, median: 26.5, mean: 28.3 years, SD: 11.14). All participants had normal or corrected-to-normal vision. Participants represented a broad range of prior XR experience: 6 reported using XR less than once per year, 8 a few times per year, and 4 reported weekly use. Technology affinity, measured with the ATI scale [10], ranged from 2.4 to 5.3 (mean: 4.3, SD: 0.9). The sample skewed male and toward the lower end of the age range, which should be considered when interpreting the findings.

Exploratory inspection of the data did not surface systematic patterns linking ATI scores, prior XR experience, or demographic variables to either the per-transition ratings or the qualitative themes. Given the sample size and the qualitative orientation of the study, we treat this as a descriptive observation rather than evidence of independence; the findings reported below should be read as accounts of challenges and design responses that arose across a heterogeneous participant group, not as claims of generalizability across user profiles.

3.5 Data Analysis Method

The qualitative data were analyzed using a hybrid thematic analysis approach [6], combining a deductive starting framework derived from the related work with inductive emergence of new themes from the data [9]. Two researchers conducted the analysis.

Data sources for each participant included structured per-transition notes taken by both researchers during the walkthrough, organized into tables covering each of the 13 transitions across the three phases (entry, limbo, arrival), parallel notes from the post-study interview following the same organizational schema, and a continuous audio recording of the full session. Following each session, both researchers reviewed their notes jointly, reconciled discrepancies, and produced a combined participant summary documenting the principal observations per transition and per phase. Where interpretations diverged, disagreements were resolved through structured discussion until consensus was reached.

The initial thematic structure was organized around two frameworks derived from the related work: the challenge categories identified in prior literature and the three design categories (entry cues, transition techniques, arrival cues). These provided an organizing scaffold from which analysis could depart. The analysis proceeded iteratively across sessions rather than as a single retrospective pass: at the end of each day of data collection, we used affinity diagramming [17] to cluster that session's observations, grouping related notes into emerging themes and subthemes and identifying patterns that cut across participants. Early sessions generated the most new theme additions; later sessions primarily confirmed, refined, or subdivided existing themes.

Once all sessions were complete, the audio recordings were transcribed and read through in full. This served two purposes: to surface observations not captured in the structured notes, and to identify participant quotations substantiating the more abstract claims built up across the thematic summaries. Both researchers reviewed the transcripts against the accumulated thematic structure, merging, splitting, or reorganizing themes where the fuller record warranted it.

4 Analysis and Results

This analysis treats the qualitative material as the primary source of evidence and uses collected ratings and preference data from the closing questions only where they reinforce the qualitative observations.

The primary themes structuring the following subsections were deductively derived from the challenges and design interventions referenced in the related work section. The more fine-grained subthemes were then inductively derived from the qualitative participant feedback.

4.1 User Challenges

The following sub-themes were derived deductively from the literature discussed in the related work section, enabling a systematic comparison between how they appeared in existing literature and our empirical work. Functional uncertainty was added as an additional sub-theme, as participants consistently reported functional-related issues when entering contexts, a pattern that did not map onto any challenge profile described in prior literature [23, 41]. Throughout this section, observations that were specific to one variant are labeled with the corresponding transition and variant (e.g., T2B); observations reported without such labels occurred across both variants.

Fear of the unknown. Eight participants described anticipatory problems before the transition during the entry phase, not knowing what would happen if they accepted a transition. These reports concerned almost exclusively the reduced variant B, in which no preview of the target context was available. Six participants stated that, especially before VR transitions (T2B, T6B, T12B), they wanted to know their destination and what awaited them there.

Spatial disorientation. Ten participants experienced spatial disorientation, predominantly during transitions in which VR served as either the origin or target context, with the main source being the abruptness of VR entry. Eight participants who experienced T2B, T6B, or T12B without visual preparation through an entry cue described being suddenly placed in an unfamiliar virtual environment with no sense of how they arrived there. Two participants reported feeling spatially disoriented when switching from VR back to AR in T3B and T7B, noting that they were unexpectedly confused about their physical position and orientation in the real world. Another specific spatial challenge was cue placement outside the direct field of view. Five participants encountered cues anchored to the side of the scene or at the periphery rather than directly ahead, causing them to miss the cue on first glance and subsequently search for it.

Social discomfort. A smaller but still important cluster of comments concerns social discomfort. Six participants raised challenges related to the social setting of transitions, manifesting in two distinct sub-patterns. The first concerned social unawareness during VR immersion. Three participants reported discomfort specifically when transitioning into VR within a shared public space, caused by the inability to monitor the people and environment around them. The second sub-pattern was spatial self-awareness when using AR cues in shared spaces. Five participants felt uneasy occupying space while engaged with a cue, especially when cues were placed where they had to stand or walk in the flow of pedestrian traffic.

Physical effort and strain. Five participants reported physical strain from the HMD, manifesting as bodily discomfort, including mild dizziness, and as accumulated effort from repeated donning and doffing, though the behavioral consequence was visible across a wider group. N3 described the repeated adjustment as *quite an effort each time* and N10 noted the overhead *adds up* across transitions. This cumulative cost shaped transition behavior directly: eleven participants hesitated to remove the headset at AR→R transitions without clear confirmation that the task was finished, anticipating the risk of having to don it again immediately if it had not been. This pattern was most apparent in T4B, T8B, and T11B, where no task completion feedback preceded the prompt to remove the headset.

Functional uncertainty. Functional uncertainty mainly involved confusion regarding the locomotion paradigm, specifically a loss of awareness of which movement modality was currently active. This arose specifically around entering or leaving VR, where teleportation via controller replaces physical walking. Four participants who received no arrival cue in T2B or T6B momentarily defaulted to physical movement on entering the virtual environment. N17 noted that without the reminder to use the controller, they would have probably walked straight into a bench. N12 similarly described not daring to move, fearing a physical collision with a column, before recalling the joystick interaction to teleport. The inverse occurred on VR exit in T3B and T7B. Two participants reported a lingering effect of the VR teleportation, noting that after switching back to AR, they still attempted to use the teleportation-based locomotion technique there. N3 described his experience through a metaphor: "*It's similar to the moment you get off a trampoline. You jump, and when you land back on solid ground, it just feels different for a moment.*"

4.2 Overall Design Observations

Beyond the phase-specific findings, four themes emerged consistently across entry cues, transition techniques, and arrival cues. These observations are not tied to a single transition phase and are reported here as cross-cutting patterns before the phase-specific analyses.

Learning effects. Eleven participants described recurring transition types as becoming easier with repetition. Participants noted that cues that felt necessary during a first encounter were perceived as redundant when the same transition type appeared again later in the route. This effect was most pronounced for cues providing general contextual information, like the arrival cues in T1, T5, T9, and T10. Once the interaction pattern was known, participants wanted the system to reduce scaffolding rather than repeat it at the same level of detail. Four participants expressed a desire to adjust cue verbosity themselves over time, describing a preference for an experience that becomes leaner as transitions become familiar.

Cue modality. Participants showed varied preferences across cue modalities. Animations, used only in *variant A*, were the most valued style, mentioned positively by eleven participants. Eight participants found the animations in T4A, T8A, and T11A helpful for conveying successful task completion.

Static images were mentioned positively by six participants. Three participants expressed dissatisfaction that *variant B* lacked images in places where the corresponding *variant A* had included comparable images during similar transitions. The most valued functional aspect of the images was their role as visual previews in entry cues before entering VR environments.

Five participants saw images mainly as supplementary context, relying on text to determine required actions. Preferences for text density were mixed: six favored detailed, explicit instructions to avoid ambiguity, while three preferred brief, concise text.

Audio cues prompted the most divided reactions. Seven participants found brief, one-time sounds useful for drawing attention to cues outside their direct view. Voice audio was more polarizing: six participants considered it helpful and natural, while seven found it tiring, too fast, or socially inappropriate in public. Three participants reported that simultaneous audio and visual information in T2A and T6A caused sensory overload.

Cue placement. Cue placement produced two recurring problems. Eight participants reported confusion when world-anchored cues were slightly displaced from their real-world reference, treating spatial misalignment as a semantic error rather than a minor visual imprecision; three added that this precision requirement applies specifically to cues whose meaning derives from their location. Four participants described cues without environmental anchoring, such as device-switch instructions or arrival confirmations, as better suited to following the user than occupying a fixed point in space. Four participants reported missing peripherally placed cues during active navigation, and five noted a further tension in shared spaces: cues anchored centrally in a room forced a choice between positioning themselves where the cue was visible and positioning themselves where they would not obstruct others.

Attention guidance. Seven participants described situations in which a cue was present in the environment but outside their current field of attention, resulting in delayed detection or a missed cue on first pass. Several participants proposed a brief directional sound or a spatial indicator as a way to draw attention toward the cue without requiring them to already know where to look. N9 specifically noted that an arrow or spatial pointer indicating the direction of a cue would reduce friction.

4.3 Entry Cues

Participants identified entry cues as the primary design feature distinguishing variant A from variant B, especially during transitions. Across the qualitative data, entry cues served two primary functions: informing participants about the possibility of a transition and reducing uncertainty about the target context before participants committed to a transition. The findings reported below are organized around these functions and the specific design characteristics that shaped how participants responded to entry cues.

Context previews. The most consistently valued entry cue element was a preview of the target context presented before the participant committed to the transition. Two preview modalities appeared in the A-condition prototypes: a static image (T1A, T2A, T5A, T6A, T9A, T12A) and a live AR window showing a partial view of the real world through the virtual door frame (T3A, T7A).

Seven participants reported that entry cue previews reduced problems related to spatial disorientation, and six participants mentioned that they helped them with fear of the unknown, specifically by communicating what the target context would look like before the transition occurred.

The preview images were explicitly mentioned positively by three participants. The live portal window visible in T3A and T7A as a see-through opening into AR was appreciated by five participants. Three participants further noted that the AR window helped with issues related to social disorientation by allowing them to see whether other people in the physical space were directing attention toward them. Four participants expressed criticisms towards the portals, but in each case their criticism was directed at the specific implementation rather than the concept. They criticized the window size and the partial occlusion of the virtual scene.

Two-stage design. The most consistently supported result regarding entry cue design was a preference for arranging entry cues in two successive stages when they needed to indicate not only that a transition was possible but also that the current-context task had been completed. This meant first acknowledging task completion and only then introducing the upcoming transition. Fourteen participants described that they valued the two-stage design of the *variant A* or preferred it to the reduced *variant B*.

Seven participants expanded this preference in interviews into a broader principle: entry cues should present information in steps, not all at once. Instead of one screen combining task completion, transition rationale, target context preview, and action instructions, they preferred receiving these elements sequentially and progressing at their own pace.

Agency to decline and precision of wording. Five participants indicated that the availability of an option to decline a transition made the entry cue less forceful. The presence of a decline action was described as signaling that the transition constituted a choice rather than a system-imposed interruption, reducing the perceived abruptness of the impending context switch.

Additionally, five participants reported that the wording of entry cues needed to be precise, particularly when participants encountered a given transition type for the first time. Participants emphasized that entry cues must convey both the characteristics of the upcoming context and the specific user action required to engage with the transition.

Door metaphor for VR→AR transitions. The *variant A* entry cue for transitions from VR→AR (T3A, T7A) took the form of a virtual door frame placed within the VR scene. The real world was seen through it, serving simultaneously as a preview of the target context and as the designated exit point. Seven participants appreciated this entry cue design for its spatial coherence and intuitive affordance for leaving the virtual context. Three participants valued having the exit and entry points co-located, noting that consistent spatial position made it easier to find the transition trigger on return. Four participants appreciated the entry cue's design because the door served as a familiar metaphor for exiting a room.

Four participants disagreed with the door metaphor, finding it added unnecessary navigation. They preferred a body-anchored or persistent UI element to exit VR directly, without teleporting to the door. This preference was especially strong among those already familiar with the environments, who felt the distance to the door no longer justified its spatial narrative.

Social context as a substitute for entry cues. Five participants reported that they did not need a formal entry cue to initiate a transition when a social signal already conveyed sufficient information about the upcoming context. In the study, this occurred in T11 when participants could see the friend character Peter in the physical environment, making a notification about the next task redundant. Participants reported that visible social intent and physical proximity alone motivated the transition, without extra system guidance.

At T13B, a contradictory pattern appeared in VR→R transitions. Five participants explicitly rejected using social interactions as the sole cue to exit VR. Without system support, they found these interactions unexpected because, while immersed, they could not perceive Peter's intention to start a conversation.

4.4 Transition Techniques

Participants consistently reported that gradual context revelation, rather than abrupt replacement, reduced spatial disorientation and made reorientation easier. This was most evident for fades and the VR slow build and most clearly violated by the colored hard-cut screen.

Colored hard-cut screens. At AR→VR transitions, the prototype used a colored monochrome screen as a hard cut. Five participants reacted negatively, and three of them reported spatial disorientation and general dislike. Two recurring issues were the overly intense color and the lack of information about the upcoming context.

Fade length requires calibration. Five participants reported positively about fades. N6 noted that fades reduced spatial disorientation by visually bridging contexts, giving participants time to release their current spatial model before engaging with the new one. Two participants found the fades too long, noting that the extended intermediate state created a disruptive pause in continuity.

Particle effects. Six participants responded positively to the particle emission effects at the moment of context switching, describing them as visually pleasing. Two participants questioned the purpose of the effects, finding them noticeable but unclear in communicative intent.

VR slow buildup. The most complex transition technique in the study was the gradual scene construction deployed at T12A, in which the lecture hall VR environment built up progressively as participants entered rather than appearing in a single frame. Four participants reported liking both the concept and its implementation, describing the staged reveal as helping them reorient spatially within the new context before it demanded action. Participants explicitly linked the gradual build to avoiding spatial disorientation on VR entry.

Speed perceptions varied across participants. Two participants felt the build progressed too quickly, finishing before they registered the environment, while four found it too slow, describing the intermediate state as an awkward pause.

4.5 Arrival Cues

Arrival cues were positively evaluated across the study, with participants most consistently valuing them after transitions into VR. Across the qualitative data, three distinct categories of information emerged that participants expected or missed upon arrival: confirmation of the current task objective, clarification of the available interaction paradigm, and basic spatial grounding in the new context.

Arrival cues address three distinct information needs. Participants described three categories of information that arrival cues provided or were missing without them.

Seven participants reported on the value of explicit locomotion paradigm reminders upon VR arrival. Some mentioned that getting one instantly clarified how to interact and reduced hesitation. Others pointed out that its absence in *variant B* created a gap that left them briefly unsure whether they should move physically or rely on the controller. N15 noted that a clear locomotion reminder on first VR entry would have prevented a brief hesitation while acknowledging that the need disappeared on subsequent visits.

Ten participants described that an arrival cue should confirm why they had transitioned and what they were now supposed to do. This was particularly salient in transitions that followed sub-tasks: N14 reported that the arrival cue in T3A was especially helpful because the original goal of reaching a lecture had receded from working memory during the intermediate task of counting chairs in VR, and the cue served as a re-anchoring to the primary objective.

Three participants reported that arrival cues helped them reorient spatially in the new context, even when the cue was not specifically designed for that purpose. Simply naming the space or showing a contextual image on arrival provided a reference point that reduced the disorientation of finding oneself in an unfamiliar environment.

VR transitions need stronger arrival cue support. Five participants reported that arrival cues were more useful after VR transitions than after transitions into AR or R. N9 explicitly attributed this to the greater density of new perceptual input in VR: *in AR, you still see the real world, and there are only a few new elements; in VR, there are far more impressions all at once, and it can overwhelm you more quickly, which is precisely why more guidance there is especially important to me.* N17 drew the same contrast directly: *for AR and the phone, I wouldn't have needed those cues at all, because I can see where I am. For VR, it really matters to feel picked up.*

Learning effects. As with entry cues, participants observed that arrival cues became less necessary as transition types became familiar. Two participants specifically noted that when the relevant information is already known, including an arrival cue becomes unnecessary and can even detract from the overall user experience.

4.6 Transition-Specific Findings

While the challenge categories and cross-cutting design observations described above apply broadly across the prototype, their magnitude and the degree to which richer designs mitigated them varied considerably depending on the origin and target context. The transition ratings, shown in Figure 10, corroborate these differences: variant A outperformed variant B across all context combinations, with the size of the gap tracking closely with the perceptual and functional distance of each crossing.

AR→VR. Entering VR from AR was consistently described as the transition class requiring the most preparation and guidance. Ten participants identified T2 and T6 as the most demanding transitions they encountered, and the qualitative reasons are consistent across participants. They described not knowing what the virtual space would look like before entering it, feeling disoriented upon arrival in a completely unfamiliar environment, and not knowing how to navigate once inside, abruptly required to teleport instead of walk. The A-over-B rating difference is the largest in the dataset ($A = 1.44$, $B = -0.11$, $\Delta = 1.55$).

VR→AR. Returning from VR to AR was generally described as less demanding than the reverse direction. Six participants offered a similar qualitative account: exiting VR is easier when the target context is already known and therefore predictable, because the physical world provides an immediately available orienting reference once re-entered. The moderate A/B rating gap ($A = 1.28$, $B = 0.72$, $\Delta = 0.56$) reflects that richer support still improved the experience, but the baseline difficulty was lower than for entering VR.

AR→R. Leaving AR to return to reality was the primary context in which goal-completion feedback mattered most in our prototype. Nine participants described these transitions as unsatisfying without explicit confirmation that the current task had been completed, and nine linked uncertainty in these transitions to the absence of clear device-switch communication. The pattern is visible in the transition-specific data: across T4, T8, and T11, *variant A* outperformed *variant B* substantially ($A = 1.63$, $B = 0.30$, $\Delta = 1.33$).

R→AR. Transitions from physical reality into AR showed the smallest A/B difference in the dataset ($A = 1.30$, $B = 1.22$, $\Delta = 0.08$). Qualitatively, participants described these transitions as becoming transparent quickly. Once the pattern of putting on the headset and following navigation arrows was established, little additional scaffolding was needed. This aligns with the broader learning effect already reported.

R↔VR. A recurring theme in participant commentary was discomfort with direct transitions between R and VR, in either direction. Five participants described these transitions as more disorienting than those passing through AR, attributing this to the absence of any intermediate perceptual anchor between the two maximally distant contexts. Three participants explicitly preferred or suggested a staged transition that preserved some connection to the prior context before fully replacing it, echoing the preference for gradual context revelation observed in the transition technique findings.

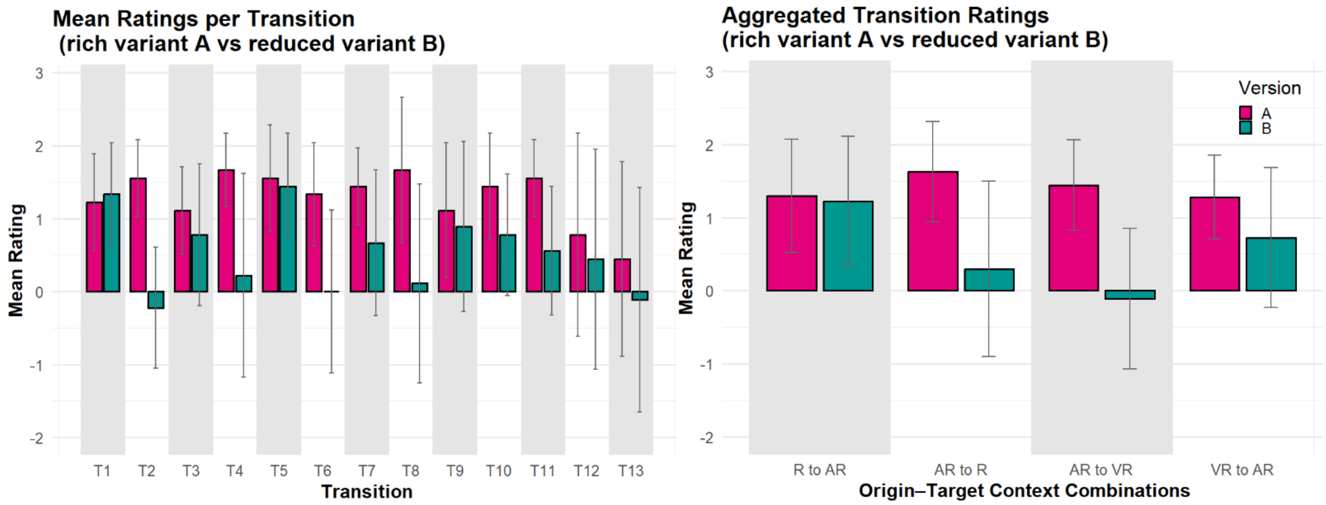

Figure 10: Mean transition ratings for *variant A* (richer design) and *variant B* (reduced design), with standard deviations shown as error bars. Left: individual ratings across all 13 transitions. Right: ratings aggregated across the four recurring origin-target context combinations. *Variant A* received higher mean ratings in all but one case (T1, where *variant B* was marginally higher: $A = 1.22$, $B = 1.33$, $\Delta = 0.11$**). Among the aggregated combinations, AR→VR showed the largest gap (**$A = 1.44$, $B = -0.11$, $\Delta = 1.55$**), followed by AR→R (**$A = 1.63$, $B = 0.30$, $\Delta = 1.33$**), VR→AR (**$A = 1.28$, $B = 0.72$, $\Delta = 0.56$**), and R→AR, which showed the smallest difference (**$A = 1.30$, $B = 1.22$, $\Delta = 0.08$**).**

5 Discussion of Challenges and Design

We begin the discussion by examining the five categories of challenges that emerged from the data, discussing how their occurrence and intensity were shaped by the specific characteristics of the respective transitions. Subsequently, we discuss the ways in which the design interventions implemented across the entry, limbo, and arrival phases addressed these challenges and consider the implications of these findings for the design of transitions.

5.1 The Challenge Landscape: What Appeared and Why

The four challenge categories from prior literature were all observed; a fifth, functional uncertainty, emerged from the data. While the categories remained consistent with what has been described in stationary cross-reality and TI research [23, 26, 41], the specific forms in which they appeared were shaped by the characteristics of our prototype.

Importantly, the challenges did not appear uniformly across all 13 transitions. Their presence and severity varied considerably depending on the combination of origin and target context and on the nature of the task associated with each transition.

Prior work identifies pre-transition uncertainty as a primary barrier to engagement [13, 41], with the quality of available pre-transition information shown to directly determine users' willingness and confidence to cross [12]. Our findings reinforce and extend this picture. Six participants who reported hesitation in the entry phase were the same ones who experienced functional uncertainty and spatial disorientation on arrival, suggesting that fear of the unknown works not merely as an isolated entry-phase friction but as a precursor that, when unaddressed, can cascade into arrival-phase challenges [26, 35].

Spatial disorientation was greatest during transitions into VR, where the perceptual gap [7] between the origin context and its real-world spatial mental model and the target context's application spatial mental model was largest [41]. It also occurred on VR exit, but less severely. We interpret this asymmetry as a familiarity effect, as previously described in literature [41]. Participants returning to AR re-entered a familiar context, reducing spatial reorientation costs even without explicit cues.

The social discomfort in this study extended beyond the transition itself, manifesting as a constant awareness of bystander attention during VR use and AR interaction in shared spaces. This aligns with prior findings that users actively factor the social cost of transitioning into their decision about whether and when to cross [28] and that re-entering social situations constitutes a distinct experiential challenge at the transition point [23]. What our present findings add is a public-space dimension: participants sought to minimize their social footprint by repositioning toward room edges and expressed discomfort when world-anchored cues required them to occupy pedestrian traffic flow.

Physical strain was primarily reported as the cumulative effort of repeated headset donning and doffing across the route, consistent with prior work [23, 34, 36, 37, 41]. Beyond discomfort, this perceived cost directly shaped transition behavior: at AR→R transitions, participants were reluctant to remove the headset without explicit task completion confirmation, wary of having to don it again if the preceding task turned out to be unfinished. This reflects a broader pattern of cost-benefit evaluation at the transition decision point, in which the anticipated physical cost of an unnecessary device switch raised the threshold for committing to the transition [26, 35].

The root cause of this strain is largely hardware-bound: headset weight, fitting mechanisms, and compatibility with glasses are beyond the reach of cue design. What transition design can do is reduce the number of unnecessary don and doff cycles, by consolidating consecutive tasks within the same context where the scenario permits, and by providing unambiguous task-completion feedback so that no headset removal is ever performed under uncertainty about whether it will need to be reversed.

Functional uncertainty was the only challenge category not previously documented in the transitional interface literature, and its concentration at AR→VR and VR→AR transitions points to the larger perceptual and functional gap [7] between these context pairs as its primary driver. Beyond simple unfamiliarity with available interactions, the data revealed a more specific phenomenon, namely a carry-over of the prior context's interaction paradigm into the new one. Participants entering VR defaulted to physical walking before recalling that teleportation was intended, while participants returning to AR reported a residual impulse to teleport rather than walk. N3 captured the experience precisely: "*It's just like jumping on a trampoline. You jump, and when you land back on solid ground, it just feels different for a moment*". This shows that functional uncertainty in cross-reality transitions is not simply a matter of forgetting available interactions but reflects an active interference between competing interaction paradigms that persists briefly even when the correct paradigm is known. That this pattern appeared in both crossing directions underscores its bidirectionality and points to paradigm-switching rather than paradigm-learning. Its relative absence from previous laboratory-based research is likely an artifact of the structured onboarding and explicit task instructions that most controlled studies provide before participants begin, effectively eliminating the challenge before it can arise.

Taken together, the five challenge categories did not operate independently. Fear of the unknown in the entry phase frequently preceded spatial disorientation and functional uncertainty on arrival in the same participants, pointing to a cascade structure in which unresolved pre-transition uncertainty compounds into post-transition difficulties. Physical strain, meanwhile, intersected with task structure and functional uncertainty, raising the threshold for committing to a transition. The challenges that arose most severely were those where origin and target contexts differed most across functional, perceptual, and cognitive dimensions [7], and where the *B variant* provided insufficient scaffolding to bridge that gap. What the data suggest overall is that the challenge profile of a transition is not a fixed property but a function of the context pair, the task, the social setting, and the user's accumulated familiarity.

5.2 Design Responses to the Identified Challenges

The challenge profile described in the previous section has direct implications for how transitions should be designed. Because challenges depend on the context pair, task, and social setting rather than appearing uniformly, the design response must vary accordingly. Thus, the challenge profile is the natural starting point for design. Identifying which challenges a transition is likely to create is essential for selecting relevant design elements and setting the right level of complexity. The following discussion examines how entry cues, transition techniques, and arrival cues addressed each of the five challenge categories.

Since fear of the unknown is located exclusively within the initial entry phase, it cannot be addressed through transition techniques or arrival cues. Context previews were the most consistently valued mechanism for reducing it, consistent with prior work showing that preview quality directly determines users' willingness and confidence to cross [12, 13, 42]. The door metaphor used for VR→AR transitions served the same function spatially, making the target state visible and the exit affordance intuitive before commitment [41]. Offering users the option to decline a transition communicates that crossing carries real cost rather than being a system-imposed obligation [30]. Physical effort also plays a role in this challenge. Although no design intervention can eliminate the effort associated with switching devices, appropriately constructed entry cues can render this effort more acceptable by explicitly articulating the rationale for the transition. Participants who were informed about what to expect demonstrated a greater willingness to incur this cost, whereas participants who lacked such information had no basis on which to evaluate its acceptability.

Spatial disorientation is most effectively addressed through a combination of all three phases. An entry cue including a preview allows users to begin forming a spatial mental model before crossing, which von Willich et al. identify as the primary mechanism for mitigating spatial friction [41]. The portal window was the strongest implementation of this, offering a three-dimensional, spatially accurate preview rather than a flat image. The cases in which participants missed cues placed outside their field of view were a consequence of world-anchored placement, whose position is fixed by its real-world referent, rather than an intentional design choice. Corrective strategies are readily available and were proposed by participants themselves: brief directional audio, spatial pointers or arrows toward off-screen cues, and body- or view-anchored placement for cues whose meaning does not derive from a specific location. Regarding transition techniques, hard cuts were the most disorienting element in the study, providing no continuity or orienting signal [32], while fades and gradual scene builds gave participants time to release their prior spatial model before the new environment demanded engagement, validating previous research on transition techniques [33]. Arrival cues contributed through spatial grounding and task reanchoring, though they played a supporting rather than primary role for this challenge.

Social discomfort is the challenge that cue design can address least directly, consistent with prior findings that social cost is a structural feature of public XR use rather than a design artifact [28]. What design can do is minimize the social footprint by placing cues in positions that do not require users to stand in high-traffic areas, preferring body-anchored or field-of-view-anchored cues over centrally placed world-anchored ones if they don't have a spatial semantic meaning.

Functional uncertainty places the greatest demand on arrival cues. Because it manifests after crossing, entry cues can prepare but cannot resolve it. Participants needed a restatement of their task, clarification of the available interaction paradigm, and at AR→R transitions, explicit confirmation that the preceding task was complete before they would commit to removing the headset. Transition techniques contribute less directly, since the challenge is informational rather than perceptual, though gradual techniques reduce the cognitive cost of crossing and leave more capacity for processing arrival information.

A cross-cutting finding across all three phases is the learning effect. Challenges rooted in unfamiliarity, namely fear of the unknown, spatial disorientation on VR entry, and functional uncertainty, diminished substantially after initial exposure as participants internalized the relevant paradigms. This progression indicates that cues should facilitate a gradual reduction in support, providing comprehensive scaffolding during initial exposure and subsequently decreasing cue density as user familiarity and competence increase. Part of this reduction likely reflects novelty wearing off rather than skill acquisition alone: with each transition type encountered at most three times, we cannot separate genuine paradigm learning from the fading of first-exposure effects, which further supports adaptive rather than fixed scaffolding.

The overarching principle emerging from these observations is challenge-profile calibration. Our data does not support a fixed recommendation for transition design; what it demonstrates is that appropriate design is determined by the specific challenge profile of a given transition, dictated by its origin and target contexts divergences across functional, perceptual, and cognitive dimensions [7], task structure, frequency, and social conditions. High-challenge transitions warrant deliberate design across all three phases; lower-challenge transitions require little beyond a basic trigger.

6 Limitations and Future Research

This study prioritized ecological validity and exploratory breadth over experimental control, and several design decisions carry trade-offs that limit the directness with which the findings can translate into specific validated design principles. The prototype did not incorporate collaborative use, complex work-oriented activities, or high-frequency repetition of specific transition types, though it encompassed considerably more individually designed transitions, tasks, and situational configurations than most previously reported studies on transitional interfaces. The qualitative focus produced a rich account of how and why challenges arise but does not support statistically grounded claims or rigid design guidelines. *Variants A* and *B* bundled multiple design elements across all three phases rather than varying a single element at a time, making it difficult to attribute observed effects unambiguously to individual components. Each of these decisions was deliberate, made in service of studying transitions as they actually unfold in real-world conditions.

The prototype was also strongly task- and event-driven: every transition was motivated by an explicit goal within the scenario. In exploratory or open-ended scenarios without externally defined tasks, entry cues that justify a transition through its task rationale may carry less weight, while context previews, arrival support, and paradigm reminders are likely to remain relevant. How challenge profiles and the effectiveness of the three intervention categories shift in such settings remains an open question.

The following section presents several noteworthy observations that, while not yielding definitive guidelines or conclusive results, delineate promising directions for future research.

The learning effect warrants dedicated longitudinal investigation. Because participants encountered each transition at most three times, the observed reduction in scaffolding need reflects early familiarity rather than the preferences of experienced users. A longitudinal research design would provide a more rigorous and comprehensive account of how transition-related support needs to change over time, which components can be reduced or eliminated, and which challenges diminish or potentially disappear.

Portal-based entry cue previews, the most consistently valued design element in the study, represent a further area warranting dedicated investigation. Parameters including window size, spatial overlap between contexts, and scene fidelity were raised by participants but could not be systematically evaluated within the present design. A comparative study of different portal configurations would allow more precise recommendations, extending existing work on portal-based transition techniques [32, 33] into their specific role as entry cue mechanisms.

The mobile and public-space character of TIs raises social research questions that go beyond what cue design alone can address. Social discomfort was a persistent challenge that the present study was not equipped to investigate systematically. How the experience changes with different bystander densities, more or less conspicuous hardware, or evolving social norms around XR use in public remains an open question that prior work on wearable technology acceptability [3] only partially addresses.

Finally, functional uncertainty was not derived from prior TI literature but emerged directly from the data as a challenge of particular prominence in real-world use. Future work should investigate functional uncertainty in isolation, examining how it arises across different transition types, how it interacts with entry and arrival cue design, and how it can be reliably measured, with the goal of establishing it as a validated challenge construct within the TI literature.

7 Conclusion

In this paper, we reported a qualitative study of a real-world TI deployed across a real-world university campus route, in which 18 participants encountered 13 transitions spanning R, AR, and VR. Four challenge categories previously reported in laboratory-based research, namely spatial disorientation, fear of the unknown, social discomfort, and physical strain, were validated under real-world mobile conditions. Functional uncertainty, not previously observed in TI research, was identified as a fifth category that proved particularly prominent in real-world use. The occurrence of the five challenges was shaped by the mobile, multi-transition, public-space setting of the prototype, and their distribution across transitions and transition phases was not uniform. The specific form and severity of each challenge depended on the combination of origin and target context, the structure of the associated task, the social environment, and the user's degree of familiarity with the transition type. Using a direct comparison of richer and reduced design variants across all 13 transitions, we demonstrated how entry cues, transition techniques, and arrival cues were able to mitigate or even resolve differing challenge profiles. We proposed challenge-profile calibration as the overarching design principle: identifying which challenges a given transition is likely to produce and using that understanding to determine which design elements across the three phases are warranted and at what level of elaboration.

8 AI Disclosure

ChatGPT, Claude, and Gemini were utilized to support the generation of images, for building the prototype, and for spell-checking or rewording selected parts of the manuscript. An on-premise version of Whisper was used to transcribe the audio recordings of each study session. All AI-generated suggestions were carefully reviewed and edited by the authors to ensure scientific accuracy and compliance with academic standards.

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