Designing Usable Information Display in Immersive Virtual Environments

A Comparative Analysis of Diegetic and Non-Diegetic Designs to Identify Design Factors

Shan Jiang†
School of Computing
Dublin City University
Dublin, Ireland
shan.jiang3@mail.dcu.ie

Brendan Rooney
School of Computing
University College Dublin
Dublin, Ireland
brendan.rooney@ucd.ie

Hyowon Lee
School of Computing
Dublin City University
Dublin, Ireland
hyowon.lee@dcu.ie

ABSTRACT

One of the characteristics offered in the Virtual Reality (VR) interaction is the way the information is displayed in the VR environment: labels, icons, text and instructions are usually associated with or attached to objects in VR (diegetic approach) but a unique affordance of the medium allows such information to be shown at any fixed location, independent of the user's viewpoint (non-diegetic approach). There are number of design decisions that need to be made in these two approaches, yet very little literature exists to support such decisions. In this study, we develop simple VR prototype systems that feature both diegetic and non-diegetic approaches in information display, and conduct usability testing with 15 participants. From this study, we identify a few potentially significant factors that future interaction designers will need to consider in designing usable information display in VR: the user's preference changing from non-diegetic to diegetic approaches as their level of familiarity/proficiency improves corresponding to their wishes from simpler, clearer and more consistent displays to more realistic and immersive ways of display; the strategies needed for making the sizes of labels/text attached to distant objects more legible or readable for diegetic displays; and the trade-offs between access to information and visual obstruction for non-diegetic displays. Unique affordances of VR interaction mean that the extensive body of knowledge in the form of design principles, guidelines and heuristics available today is not sufficient to support the design of truly usable VR experiences. We expect that the findings in this study will help the VR interaction designers more easily create usable VR experiences in the future.

CCS CONCEPTS

• Human-centered computing → Virtual reality

KEYWORDS

Virtual reality, Immersive systems, User experience, Interaction Design.

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1 Introductions

While Virtual Reality (VR) technology is driving a wave of new applications in a variety of domain areas such as education, training and gaming, many interaction challenges that impact usability and experience are still unresolved and often tackled through costly trial-and-error processes in the market today. This is partly due to the unique characteristics of VR interactivity where new, additional design decisions are required that the design of conventional 2D interactivity – with all its established body of design knowledge that had accumulated and available today – did not need to consider.

One of more obvious design issues arising is the way information is displayed to the user in VR. While it is generally expected that the way any piece of information (textual or otherwise) is shown in a VR environment should be the same or similar to how it is shown in real world, an additional affordance of VR interactivity means that such information could be presented as fixed to the user's viewpoint, regardless of where the user is facing. In the former approach, generally termed as diegetic UI, the information to be displayed is embedded (or nearly embedded) within the virtual environment, presented as part of the scene and thus seen as "belonging" to the world. Examples include text labels attached to (or floating near) the surface of objects, instructions and dashboards embedded on the wall or desk in the VR world. This spatial integration may enhance realism and immersion since the way information is displayed resembles our experiences in the real world.

The latter approach termed as non-diegetic UI, by contrast, places the information as overlay, fixed to the user's view, independent of the virtual world's geometry (i.e. maintaining its position relative to the user's gaze). Sometimes referred to as "head-locked HUD (Heads-Up Display)", they ensure persistent visibility and thus may support more efficient task completion. Yet they may disrupt the sense of "being there," appearing intrusive or disconnected from the environment. Currently there is no good understanding of when to use these approaches (i.e. diegetic and non-diegetic UIs) other than reasonable assumptions as mentioned above, and in particular, what the design issues and decisions are that need to be considered when designing usable VR interaction for each approach.

This study attempts at answering a research question: what are the key factors and issues in designing effective in-VR information display in regards to diegetic and non-diegetic approaches that can leverage the characteristics of VR interactivity? We developed simple VR prototypes that support both approaches, and conducted usability testing with 15 participants to qualitatively capture the level of usability and most importantly, derive a series of design insights that could be the first step towards establishing a new body of design knowledge on the alternatives, options and considerations that the designers should take into account for usable VR interaction.

2 Literature Review

2.1 Approaches in Information Display in Virtual Reality

Both diegetic and non-diegetic information displays in VR have been used in a number of applications and products. Examples of diegetic UI include wrist displays in Lone Echo[1] and computer terminals in Job Simulator[2], both providing feedback directly within the world. Some studies found that these interfaces can strengthen realism and immersion [1][2], but may also reduce usability if placed poorly [3].

An example of non-diegetic UIs is Half-Life: Alyx[3] in which head-locked HUDs show health, time, and inventory, always visible no matter where the user looks. Although they may break the sense of realism, they improve usability by reducing search time and keeping key information always accessible [4].

In No Man's Sky VR[4], both diegetic and non-diegetic UIs are mixed (see Figure 1): the mission terminal is diegetic, placed as an object in the world, while mission details and stats appear as non-diegetic HUD overlays. This design illustrates an emerging design rationale for the choice of the approach: contextual, interaction-based data may be best delivered diegetically, while persistent, player-centric information may benefit from non-diegetic presentation [5].

[1] Lone Echo - A VR adventure game developed by Ready At Dawn (2017), Oculus Studio. https://www.echo.games/

[2] Job Simulator: The 2050 Archives – VR simulation game developed by Owichemy Labs (2019). https://store.steampowered.com/app/448280/Job_Simulator/

[3] Half-Life: Alyx – A VR first-person shooter game developed by Valve (2020). https://www.half-life.com/en/alyx

[4] No Man's Sky Beyond (VR) – An action-adventure survival game developed by Hello Games (2018). https://www.nomanssky.com/

Figure 1: Example of mixing diegetic and non-diegetic interfaces in No Man's Sky VR. The mission terminal (in-world monitor display on the right side) is a diegetic object in the game world, while player statistics like currency and progress (the text display at the centre) are shown in non-diegetic HUD overlays.

2.2 Comparative Studies and Their Findings

Empirical studies on diegetic and non-diegetic UIs have shown mixed results. Some suggest diegetic interfaces enhance immersion - Saling et al. found most participants preferred them in a VR fighting game [6], and Rosyid et al. reported increased immersion when non-diegetic HUDs were removed [7]. However, diegetic designs may reduce usability. Dickinson et al. found that users reported higher cognitive load and more effort to locate information in a VR training task [3], especially under time pressure. Marre et al. also showed that while diegetic interfaces helped novice users, experienced users performed equally well with non-diegetic ones [8].

As can be expected, the type of information and task context also matter. Real-time data such as remaining time, health status or other scores benefits from constant visibility and thus may be better suited to non-diegetic displays. In a VR shopping task, Sun et al. found that diegetic UIs improved decision-making and satisfaction [9]. Köhle et al. showed that players preferred diegetic feedback during solo narrative play, while they preferred non-diegetic HUDs in competitive, fast-paced scenarios [5].

These studies suggest that diegetic and non-diegetic UIs need not be treated as opposing choices a designer has to make. In many cases, they could work together, depending on the task goals, the type of information, the context of the VR environment and other potential design factors that our study has attempted to discover in this paper. The question is not so much on whether one is better than the other and in what situations, but for each approach, what are the kinds of design options and alternatives that need to be considered (e.g. optimal information placement, visual contrast, timing, interaction mechanisms, etc.) in order for them to effectively offer usable interactivity in VR: this is the gap in the literature in the field today, without readily-available know-how or clear guidelines, and in this paper we attempt to fill this by identifying the key design factors that VR interaction designers need to consider.

3 Design Rationale

This section explains the thinking behind the design of the simple diegetic and non-diegetic UIs developed in the study. Each interface was created to balance experimental control with realism, based on common VR design principles, cognitive fit theory, and perceptual ergonomics [5][10][11].

3.1 Diegetic User-Interface Design

The diegetic UI was designed to follow immersive interface conventions by placing information to be displayed directly in the virtual environment. These elements are tied to (or near) virtual objects or locations, only appear when relevant, and require users to shift attention or position - helping to support spatial presence [1][2]. Figure 2 shows the global information panel used in the diegetic condition, placed on a wall beside the user.

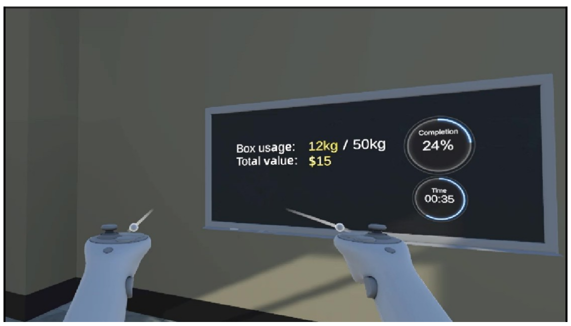

Figure 2: Diegetic UI panel anchored on a virtual wall, showing global metrics such as box usage, total value, task completion, and time remaining.

The panel's wall-embedded placement was chosen to simulate real-world dashboards, such as those in warehouses or factories. Users need to turn their head or body to check the data, which encourages engagement with the environment and follows ideas from embodied interaction [12].

The information is divided into two zones: text-based metrics (e.g. "Box usage", "Total value") are on the left, and circular visuals for task progress and time are on the right. This layout follows the Gestalt principle of proximity, making it easier for users to quickly scan and understand the display [11].

Bold sans-serif fonts with shadow effects improve readability under changing lighting. Dynamically changing values (e.g. "12kg" or "$15") are highlighted in yellow.

Figure 3 shows the object-specific label that appears when a user picks a cube object. This small panel floats above the object and shows real-time weight and value. A semi-transparent gray background improves contrast while still blending into the virtual environment, following suggestions from VR readability studies [10][13], although the optimal levels of colour and transparency will depend on the degree of "busy"ness around the environment.

Figure 3: Diegetic object label showing weight and value, which appears above the object when (and only when) it is selected by the user.

This label disappears when the user stops interacting with the object (by dropping it on the shelf or anywhere in the environment). The font size is adjusted for clear reading from about 0.5 meters, which is a typical viewing distance when holding objects in VR [14].

3.2 Non-Diegetic User-Interface Design

The non-diegetic UI was designed as a head-locked overlay that always stays in view, fixed at slightly upper-left and upper-right sides from the user's viewpoint (not very far from the centre of the user's view, since text reading at a peripheral location not by turning the head but by rolling the eyes is challenging). This allows users to access both global and object-specific information at any time, reducing effort - especially helpful for beginners or when tasks are time-sensitive [9][15]. Figure 4 shows the screen shot of the non-diegetic UI design.

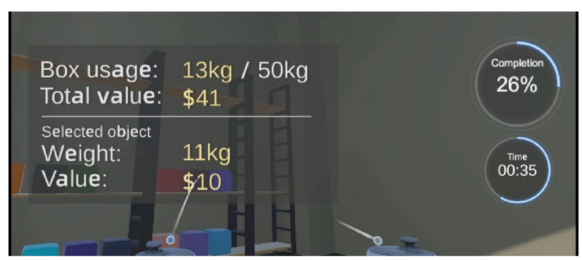

Figure 4: Non-diegetic UI with head-locked overlays showing task metrics and object info. The layout stays in the same relative position as the user moves.

In this design, global information ("Box usage", "Total value") as well as specific information of an object ("Weight", "Value") when it was picked by the user are displayed on the top-left corner on a dark, semi-transparent panel; on the top-right, circular indicators display time and task progress, again with semi-transparent circle background (but no additional rectangular panel behind). This layout follows best practices from heads-up displays in games and simulations [16].

The font and colours are the same as in the diegetic version to keep consistency. The dark, semi-transparent panel ensures readability on different backgrounds, following AR/VR interface studies [17]. The fixed panel and circular displays are placed at 0.5 meters away from the user, and the font size was adjusted through several rounds of informal testing to make sure that it is easy to read without being too small (difficult to read) or too large (bothering the view of the environment). Because the interface stays in a fixed screen-space position, users can quickly glance at key information without searching for it.

4 Methodology

4.1 Experimental Design, Prototype and Task

We conducted usability testing sessions with diegetic and non-diegetic UIs in a task-based VR setting. Each participant completed the same value-maximisation task in both conditions (i.e. within-subject), with order counterbalanced to reduce learning effects. Interaction mechanics, including selection and placement of cubes via hand controllers, were identical in all sessions, so that the information display approach (i.e. diegetic and non-diegetic) was the only changing factor. The VR prototype was implemented in Unity 3D using Microsoft Visual Studio, and Meta Quest 2 as the headset for the participants.

The task required each participant in VR to pack cube objects of different weights and values into a container with a 50 kg limit. In the diegetic UI condition, global metrics such as total weight, value, and task progress were displayed on a wall-mounted panel within the virtual environment, while information specific to the cube object appeared as floating labels anchored to the cube.

In the non-diegetic UI condition, all information was presented through head-locked overlays fixed in screen space. Interaction mechanics, including selection and placement of cubes via hand controllers, were identical in both conditions. A quiet computer lab was booked and used for the sessions, sufficiently large enough to walk around with the headset on.

4.2 Participants

Fifteen participants (ages 18 – 50) took part: eight novice users (little or no VR experience) and seven experienced users (frequent VR use). They came from backgrounds including computing, design, and education. All completed both UI conditions in a single session while the researcher observed all interactivity, and provided questionnaire responses plus open-ended feedback.

4.3 Measures

We recorded both objective metrics (total packed value, weight, and completion time) and subjective ratings and opinions. After each condition, participants rated usability, clarity, immersion, frustration, and enjoyment on 5-point Likert scales. At the end, they indicated their preferred UI approach for global and object-specific information and shared qualitative feedback on strengths, issues, and possible improvements.

5 Findings and Analysis

5.1 Overall Preference for Non-Diegetic Interfaces

Out of 15 participants, 13 preferred the non-diegetic UI. They highlighted its clear presentation, ease of access (seeing the information), and lower interaction effort. Performance data aligned with these opinions: in most cases, participants achieved higher total packed value and faster completion times with the non-diegetic UI. For example, Participant 2 (P2) achieved 48 kg / 463 value in the non-diegetic condition, compared to 38 kg / 249 in the diegetic condition, noting that "the information is more immediately accessible."

Likert-scale results reinforced this pattern. Non-diegetic UIs received consistently higher ratings for usability and information clarity, particularly from novice users. Many rated non-diegetic usability as 4 or 5 out of 5, while diegetic usability often fell between 2 and 3. Several participants described the diegetic interface as "hard to read at a distance" or "requiring too much movement to check the panel." In contrast, the non-diegetic display was frequently described as "straightforward," "convenient," and "always there when I need it."

These findings indicate that for task-focused VR interactions especially those requiring quick decisions, non-diegetic UIs can offer a clear functional advantage by reducing visual search time and keeping information readily available, overall in support of other prior studies cited in Section 2.

5.2 Diegetic UI Feels More Real

While non-diegetic UIs were generally favoured for clarity and speed, several experienced participants valued the immersive qualities of the diegetic UI. For example, Participant 3 (P3) rated both approaches equally for usability and comprehension but gave the diegetic UI higher scores for immersion and enjoyment, saying it "felt more like a game than a task," whereas the non-diegetic UI felt "too much like software."

Similar views came from Participants P10, P12 and P14, who described the diegetic UI as "realistic" and "natural." P10 likened it to using a real-world dashboard (requiring head or body movement to check information) which reinforced their sense of being in the virtual space.

These responses point to a clear trade-off: diegetic UI may be less efficient but can enhance spatial presence and embodied interaction - qualities some users value as much as, or more than, task performance.

5.3 Different Levels of Experience

VR experience played a key role in shaping preferences. All eight novice users in our study preferred the non-diegetic UI for both global and object-specific information display. They consistently cited ease of understanding, reduced effort, and greater confidence in completing the task. As a participant (P11) explained, "As a beginner, I just want information to be in front of me without having to look for it."

Experienced users (n=7) were more split. While most still preferred non-diegetic UI for global metrics, several (n=3) favoured diegetic UIs for object-specific data, appreciating their natural spatial integration. P12 noted, "The diegetic labels on the boxes feel more believable - they fit into the world," even though they admitted the non-diegetic version was faster.

These findings are overall in line with those from other previous studies, and suggest a shift in priorities as users gain VR experience: novice users tend to prioritise cognitive simplicity and constant feedback, while experienced users increasingly value realism, and embodied interaction - mirroring trends seen in other interactive media where expectations evolve with expertise.

6 Discussions

This section shares insights and ideas directly and indirectly derived and extrapolated from the findings above, and represents the main contribution of the paper for future VR interaction designers to consider when designing diegetic and non-diegetic information display for VR environment.

6.1 Evolving User Needs: From Clarity to Immersion

Our study found a clear difference in UI preferences between novice and experienced users. Novices strongly preferred non-diegetic UI, valuing their clarity, quick access to information, and low cognitive demand. Experienced users, while recognising these practical benefits, expressed a stronger preference for diegetic approach, appreciating their spatial integration to the environment and thus immersive feel.

This shift in preference is similar to patterns seen in other digital media, where interfaces often move from simple and functional designs to richer, more integrated experiences, and eventually to a refined balance between the two [18]. In early use, the priority is getting things done – novice users in our study rated non-diegetic overlays highest for usability and information clarity. Over time, as users become more comfortable, they tend to start to value narrative consistency and environmental coherence, even if that means sacrificing some efficiency.

As one experienced participant (P11) explained, non-diegetic UI felt "too clear - like doing a task in software, not exploring a virtual world." This reflects findings by Lu et al., who showed that expert VR users preferred adaptive, context-aware UIs that maintain immersion while still providing essential feedback [19].

In other words, our results potentially suggest a progression in user needs, a kind of learning curve in VR UI preferences. We can conjecture that at first, users want persistent, easy-to-read overlays that help them understand and complete tasks. With experience, they tend to prefer interfaces that blend more naturally into the virtual world, using contextual cues, subtle animations, and environmental feedback. Designing future VR UIs with this progression in mind may mean adopting a layered approach - starting with straightforward, non-diegetic support for newcomers, and evolving toward richer, more integrated diegetic information display as users become more skilled. Understanding this will be important in helping the designers strategise in supporting specific (or diverse) type of users for their products.

6.2 Visual Reach vs. Interaction Distance

One key usability issue in the study was the difficulty of reading text labels in diegetic UI when interacting with distant objects. In VR, users can select and manipulate far-away objects via raycasting, but diegetic labels are usually on or near the object's position and scale with the distance from the user. As a result, text often appears too small to read unless the object is brought closer to the user (or the user moves close to the object). This is where the VR world and real world diverge: in real world, text and labels on far-away objects are not readable (since they are too small) and the only way to read them is to go near it; in VR, as long as there is a way to pick/select objects far away from the user (e.g. raycasting), it should be possible to use them. This means that there is a need to show the labels, instruction or other text associated with the objects in a way that is readable from any distance.

This is more than a small annoyance: it can break interaction flow in tasks that require quick and frequent access to information. Prior studies have reported similar problems, noting higher cognitive load for spatially dependent interfaces, especially under time pressure or when switching contexts frequently [3]. Our participants described this as disruptive, with several commenting they had to "pull objects close just to read the label." (P8)

Based on these observations, a few design alternatives can be considered:

Distance-aware scaling – Labels, text and icons could scale dynamically based on their projected distance from the user's viewpoint, keeping them readable without moving the object closer. Similar methods have been tested in dynamic HUD systems, especially in VR exergaming [18]. An obvious issue will be the reduced sense of reality and visual clutter when there are many objects with labels at a distance, bound to crowd the area with overlapping cloud of text.

Gaze-aware dynamic adjustment – Text or icons located far away could enlarge, reorient, or increase contrast based on the user's real-time eye movement (using the technique broadly termed gaze-contingent UI as proposed and experimented [20] [27]). This method may be beneficial in VR context when used together with other more definite and intentional gestures such as pointing with the controller.

Hybrid approach - For frequent distant interactions, a temporary non-diegetic overlay (e.g., a small popup panel on the side of the user's view) could appear while the object is selected, then fade away when the interaction with that object is over. Studies in mixed reality show that such a method can maintain immersion while improving readability [21], but more studies are needed on how to dynamically switch between the two in a way that is least disruptive.

6.3 Balancing Readability and Visual Obstruction

In our study, most novice participants preferred non-diegetic UI where the information panel was positioned at slightly upper-left and upper-right sides in the user's field of view. This aligns with a common trend in commercial VR applications, where essential UI elements are placed not very far from the centre of the user's vision.

However, experienced participants raised concerns about central HUDs blocking their view, breaking immersion, and feeling disconnected from the environment (e.g., P7: "It blocks my eyes too much"; P14: "It obstructs my view"). This echoes a previous study that found that central HUDs improve efficiency but reduce immersion when static and fully opaque [23].

Peripheral Offset as a Compromise - P3 said "It should be slightly off-center, not blocking directly in front", while P7 noted that placing it "too far to the sides would feel uncomfortable." Placing the non-diegetic information display at a suitable location in the user's view point seems tricky: not directly at the centre of the user's view (since it will obstruct what s/he is trying to see in front), but not too far from it, either, say 10 – 15 degrees vertically or horizontally still within the binocular fusion zone[5]. There are established practices in flight simulation and automotive AR, where fully-central and extremely-peripheral placements are avoided due to readability and occlusion trade-offs [24][25]. The ideal offset from the centre of vision in the context of VR interaction seems elusive, and perhaps the type of task the VR system supports should be the factor in the decision.

Typography and Layering for Legibility - Font size, weight, contrast, and background opacity all affect the balance between legibility, readability and unobtrusiveness. Our design used bold sans-serif fonts with drop shadows and semi-transparent gray panels for non-diegetic information display, an approach supported by previous work [13][26], showing that shadows and transparency improve readability in dynamic scenes without fully blocking 3D content. Participant feedback supported this, too: P5 wanted "clearer presentation of information," and P9 suggested a "semi-transparent background" to reduce the sense of occlusion. These practices are now standard in major platforms such as Oculus Quest, SteamVR, and Apple Vision Pro, all of which use translucent backgrounds, moderate contrast, and layered text to maintain visibility while preserving environmental awareness. The issues raised here are the more fine-grained design decisions such as the exact font size/weight/contrast level ideal for a specific distance and the colour and transparency level of the non-diegetic panels.

Toward Adaptive Layouts - Our results suggest that adaptive or dynamic designs for these (panel/information position relative to the user's viewpoint, panel colour and transparency level, etc.) flexibly determined depending on task, user expertise or gaze may be a good overall solution for non-diegetic information display. For example, the non-diegetic panel could move slightly away from the centre during object manipulation to avoid blocking the views or hands, then return to a central position during passive monitoring.

[5] Binocular fusion zone is the area in a person's vision where the brain combines slightly different images received from each eye to create a single, unified, three-dimensional image.

7 Conclusion

Design of VR interactivity today suffers from the lack of design knowledge of at all levels of details, making the design act very much a "blackbox" approach where different companies experimentally try out potentially useful interactive techniques then see the consequences. While some of the 2D design knowledge could be applied to the design of VR interaction design, the challenge is the aspects of UI *unique to VR interactivity*, such as the diegetic and non-diegetic dichotomy where there is no direct way to apply any of the 2D design knowledge.

While the scale of the usability testing conducted in this study was not sufficient to generalise the findings in themselves, the designerly exploration conducted by designing simple prototypes, conducting usability testing and the observations and findings for extrapolation resulted in identifying three major design factors that the designers should consider: (1) opportunity to support the evolving user preferences from non-diegetic to diegetic as their expertise develops, (2) how to handle the labels/text far away from the user, and (3) considerations on striking a balance between showing the information and blocking the user's view. Further studies are planned involving a larger pool of participants to allow more quantitative observations for a more statistically meaningful analysis. More sophisticated set of tasks might further help generalise the results.

There must be many other unknown design factors that are still to be identified and explored further. Our study in this paper is a step towards building a comprehensive inventory of such design factors that will help future VR designers build the interactivity with the level of usability which the general public enjoy today with the conventional websites and mobile apps.

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