

# Chapter 3

## Multimodal Context– Awareness in AI– Driven Virtual Reality

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### ABSTRACT

*This chapter examines how context-aware artificial intelligence (AI) enhances virtual reality (VR) by increasing immersion, user engagement, and adaptive interactivity. Drawing on foundational theories of presence and immersion (e.g., Slater, 2009; Csikszentmihalyi, 1990), this investigation examines how AI systems interpret environmental, behavioural, and verbal cues to personalise and enrich immersive experiences. Reviewing recent innovations in generative AI, reinforcement learning, and intelligent agent design, the chapter analyses the capacity of these technologies to support dynamic content generation, adaptive gameplay, and naturalistic interaction. Complementing the literature review, a user-centred survey captures VR user perceptions and priorities regarding intelligent, adaptive systems. The chapter*

DOI: 10.4018/979-8-3373-3690-9.ch003

*concludes with a discussion of ethical considerations, user modelling challenges, and future research directions, offering a timely contribution to ongoing debates in AI-driven entertainment design.*

## **INTRODUCTION**

With the rapid development of digital technology, many aspects of everyday life have been changed, resulting in major global interests in computer systems that can sense and respond to context (Augusto, 2022). These transformations are particularly noticeable in the field of integration between Artificial Intelligence (AI) and Virtual Reality (VR), where technology has shifted away from traditional pre-programmed static experiences towards more dynamic interactive experiences. Modern VR platforms are no longer limited to simply using visual immersion alone, but now they routinely capture rich streams of contextual information, including environmental cues, body movement, and speech. AI systems continuously interpret this multimodal information to allow VR environments to respond in real-time. By combining AI and VR together, we can produce more immersive, personalised and adaptive user experiences (Ojha et al., 2024; Shirazi et al., 2024; Yu et al., 2024).

Recent studies have highlighted a clear move from fixed simulations to environments that evolve in response to use behaviour. AI-driven dialogue systems, for instance, can allow users to naturally interact with virtual non-player characters (NPCs), which strengthens immersion and realism. Rong (2024) notes that these systems can support more realistic and believable communication. Beyond conversations, AI can also adjust environmental parameters such as lighting, difficulty or even narrative pacing in line with the emotional or physical states of the user. These adaptations form a continuous feedback loop, where a user's behaviour actively shapes the VR experience (Song et al., 2024; Ojha et al., 2024).

### **Motivation**

The motivations behind this chapter were to investigate how multimodal context-aware AI can enhance user engagement in VR experiences by continuously analysing environmental signals, user actions, and the user's voice input in real time. The study draws on recent research, technologies, and practical applications across the domains of entertainment and education (Augusto, 2022; Cao et al., 2023; Dyulicheva & Glazieva, 2022; Song et al., 2024). Context-awareness in this case reflects the AI's ability to interpret situations and respond based on those interpretations, and by

integrating this awareness with technical systems, it allows the system to adapt to individual needs (Augusto, 2022).

Context refers to information that describes what is going on within a situation, while context-awareness refers to the ability to utilise that information to modify the system (Augusto, 2022; Carrera-Rivera et al., 2022). Since VR environments in themselves contain many different forms of multimodality, such as speech, hand gestures, head and eye tracking, etc, these inputs allow systems to utilise various forms of context to understand the user's intent and generate coordinated responses (Cao et al., 2023). However, to achieve this, all context must be properly interpreted into meaningful information in real-time. This process is particularly difficult to achieve since VR environments are dynamic, and context can change quickly, and the system must react accurately to maintain user immersion.

In the context of gaming, AI systems monitor player behaviour to personalise experiences through adapting NPC behaviour, procedural generation, or dynamic difficulty adjustments (Ojha et al., 2024; Song et al., 2024). As interaction data is produced, these systems gradually learn to align responses with the emotional and cognitive states of the player (Dyulichева & Glazieva, 2022; Mansouri et al., 2021). An example of this is the potential of AI-driven CGI influencers that utilise expressive virtual characters to sustain engagement. By modelling facial expressions and emotional cues, these avatars enhance communication and maintain attention in entertainment and marketing contexts (Yu et al., 2024).

In the context of development, AI agents increasingly support automated play-testing through the use of AI methods such as Deep Reinforcement Learning (DRL) and Monte Carlo Tree Search (MCTS). These methods allow large-scale simulations to take place, which reveal gameplay patterns and potential issues that may arise (Roohi et al., 2021). Overall, this chapter will consider both technical advances and user responses to context-aware AI within VR.

## **Objectives**

This chapter has two objectives: firstly (O1) to review recent developments in context-aware AI for VR environments, mainly focusing on multimodal context, including environmental, behavioural, and speech data, as well as enabling AI techniques such as reinforcement learning, generative models, and intelligent agents. Secondly (O2), to present the findings from a user survey conducted to examine the expectations and preferences of users regarding context-aware features in VR. Together, these two objectives combine theoretical insights with empirical evidence to show how context-aware AI can influence the user experience and system behaviour.

Additionally, this chapter also examines how context-aware AI supports immersive, adaptive and emotionally responsive VR experiences by analysing user behaviour,

emotions and preferences. Through these, AI systems can personalise both learning and entertainment content, resulting in increased engagement and perceived realism (Shirazi et al., 2024). Despite these benefits, context-aware AI also raises design and ethical challenges. To address these concerns, the chapter incorporates findings from a user survey exploring attitudes towards adaptive features in VR environments.

The analysis considers demographic factors, measures of presence and satisfaction, and qualitative feedback on usability and narrative structure. It also responds to gaps identified by Augusto (2022), particularly the need for clearer definitions of context-awareness in system activation and interaction. Through its focus on multimodality and context-awareness, this chapter offers guidance for developing AI systems that are effective, responsible, and centred on user needs.

## **Chapter Structure**

Section 2 introduces the background research, outlining concepts related to context-awareness and user engagement in VR, with a focus on gaming and entertainment. Section 3 reviews recent literature, examines adaptive behaviour, interactive systems, and relevant case studies, and identifies research gaps. Section 4 details the research methodology, including study design, data collection, participant recruitment, and analysis. Sections 5 and 6 present and discuss the findings, highlighting key trends, user perspectives, and challenges such as privacy, adaptation, and scalability. Section 7 outlines future research directions and practical implications, and lastly, Section 8 serves as the conclusion for this chapter.

## **BACKGROUND AND THEORETICAL FOUNDATIONS**

### **Understanding Context and Engagement in VR**

Immersion is a core part of VR and is often described as deep involvement that draws users' attention away from the real world (Berkman & Akan, 2019). It is supported by visual quality, spatial audio, and multisensory feedback such as haptics (Slater, 2009). These features allow users to perceive changes through movement, known as sensorimotor contingencies. However, immersion is defined differently across fields and is often confused with presence or engagement. Nilsson et al. (2016) address this by distinguishing among system immersion (technical quality), narrative immersion (story involvement), and challenge-based immersion, offering a clearer structure for understanding VR experiences.

Presence, on the other hand, refers to the feeling of "being there" in a virtual space (Berkman & Akan, 2019). Slater (2009) separates this into Place Illusion,

created through consistent sensory feedback, and Plausibility Illusion, where virtual events seem believable. When both are present, users may react as if events are real, known as Response-As-If-Real behaviour. Presence is shaped not only by technology but also by personal and contextual factors such as experience and expectations (Triberti et al., 2025).

Engagement describes the psychological depth of user involvement and enjoyment. Rutrecht et al. (2021) link VR engagement to flow, showing that greater immersion increases both flow and presence. AI-supported VR can help sustain this state by adapting the difficulty, pacing, and content to a user's performance and preferences (Shirazi et al., 2024). This aligns with the previously defined challenge-based immersion, where a balanced level of difficulty helps maintain attention (Nilsson et al., 2016).

Interactivity refers to meaningful user actions that elicit system responses. This includes physical actions, voice, or influencing NPC behaviour (Wang et al., 2021). High interactivity increases user agency and depends on both hardware and AI-driven software. When responses are smooth and timely, realism and immersion are strengthened (Ojha et al., 2024; Cao et al., 2023).

Context-awareness connects these elements by including environmental, movement, physiological, and speech information (Augusto, 2022; Carrera-Rivera et al., 2022). Context-aware VR uses AI to interpret this data and adapt experiences in real time through multimodal fusion of gestures, gaze, and voice (Cao et al., 2023). These systems can also predict preferences by learning from behaviour, allowing experiences to adjust over time (Shirazi et al., 2024).

## **Theoretical Foundation**

The theoretical foundation of context-aware AI in VR draws from cognitive psychology, Human Computer Interaction (HCI), immersive media, and intelligent systems. Context-awareness is viewed as an interaction between human perception and adaptive technology rather than a purely technical feature. Flow Theory (Csikszentmihalyi, 1990) and Slater's model of presence (2009) explain how engagement depends on a balance between challenge and a strong sense of "being there". Self-Determination Theory further shows how personalisation supports motivation by addressing autonomy and competence (Ryan & Deci, 2000).

Context in VR can be grouped into environmental, behavioural, and verbal domains. Environmental context includes factors such as lighting and sound that support immersion (Slater, 2009; Moon et al., 2022). Behavioural context encompasses signals that guide adaptive responses, such as changes in pacing or difficulty (Dyulichева & Glazieva, 2022; Ojha et al., 2024). Verbal context involves speech and dialogue and is interpreted through natural language processing to support social

interaction (Song et al., 2024; Reiners et al., 2021). Together, these inputs allow AI systems to detect, interpret, and adapt to user states in real time.

From a systems perspective, context-aware VR follows a sequence of context definition, use, and development (Augusto, 2022; Carrera-Rivera et al., 2022). AI models support multimodal data processing, real-time adaptation, and intelligent virtual agents capable of personalised interaction (Reiners et al., 2021). User acceptance of these systems is influenced by perceived usefulness and ease of use, as described by the Technology Acceptance Model (Fussell & Truong, 2022).

## **Relevance for Gaming and Entertainment**

AI and VR together are reshaping gaming and entertainment through real-time adaptation to user behaviour. By combining environmental, behavioural, and verbal data, systems can adjust visuals, sound, pacing, difficulty, and dialogue to suit individual users. Engagement and presence emerge from the combined effects of immersion, interactivity, and context-awareness, supported by Flow Theory and presence models (Csikszentmihalyi, 1990; Slater, 2009). In games, AI analyses player behaviour and emotions to personalise narratives, challenges, and NPC interactions (Ojha et al., 2024; Song et al., 2024; Shirazi et al., 2024). Additionally, generative AI enables more natural dialogue and dynamic environments, increasing player agency and emotional involvement (Song et al., 2024).

Advanced methods such as DRL and MCTS further improve opponent behaviour and game balance, helping maintain long-term engagement and replayability (Roohi et al., 2021). Context-aware AI also strengthens Plausibility Illusion by ensuring that virtual events respond credibly to user actions, supporting RAIR behaviour (Slater, 2009). By interpreting signals such as gestures and speech, AI helps create virtual worlds that feel responsive and alive (Augusto, 2022).

## **LITERATURE REVIEW: INNOVATIONS IN CONTEXT-AWARE AI**

### **The Role of AI in Contextual Understanding**

Context plays a key role in how humans understand situations and make decisions, and it is increasingly used in computer science to design intelligent, context-aware systems (Augusto, 2022). In Intelligent Environments, context-awareness connects areas such as computing, the Internet of Things, and Ambient Intelligence (Augusto, 2022). In VR, AI enables systems to interpret contextual cues and adapt behaviour to support immersion and engagement.

## Environmental Context Understanding

AI has significantly improved how VR systems understand and respond to environmental context, helping maintain immersion through real-time adaptation. One example is dynamic visual adjustment, which reduces discomfort caused by changing lighting. Abbasi et al. (2024) propose a U-Net-based model that adapts colour and contrast during scene transitions, improving visual consistency and user focus. This shows how AI-driven visual calibration can enhance immersion.

AI-assisted rendering also supports real-time responses to user actions, such as updating lighting and shadows when a virtual light is switched on. These effects strengthen Plausibility Illusion by making virtual responses feel coherent and realistic (Slater, 2009). Spatial mapping further extends environmental awareness, as modern headsets use depth sensors to align virtual content with physical space. Systems such as ManySense VR integrate real-world data, including weather, into VR scenes to synchronise virtual ambience with external conditions (Moon et al., 2022). This approach reflects the concept of the Observable World, where sensor data is transformed into meaningful context that guides system responses (Augusto, 2022). Environmental context is further enhanced through adaptive audio and haptics, such as spatial sound and tactile feedback, which deepen presence and embodiment.

## Behavioural Interaction and Adaptation

Behavioural context-awareness allows VR systems to interpret user actions and respond in real time. Advances in gesture recognition and computer vision have reduced reliance on controllers, enabling natural interaction through body movement (Wang et al., 2021). Actions such as pointing or waving can trigger NPC responses, supporting sensorimotor contingencies and increasing realism (Slater, 2009). Multimodal systems combine gestures, voice, and gaze to infer user intent more accurately such as for instance, in LearningVerseVR, are used to direct attention and control interactions, creating natural experiences (Cao et al., 2023). Behaviour modelling is also used in training simulations, where AI adapts scenarios based on detected actions, ensuring events occur at meaningful moments (Wang et al., 2021).

Adaptive gameplay systems use reinforcement learning to adjust difficulty based on performance, helping maintain flow by balancing challenge and skill (Dyulicheva & Glazieva, 2022; Mansouri et al., 2021). Emotional adaptation adds further depth, particularly in horror games, where AI monitors stress indicators and alters pacing or intensity in real time (Ojha et al., 2024). Similar methods support personalised learning by adapting feedback and content to learner progress (Song et al., 2024). Additionally, emerging bioadaptive systems integrate real-world signals such as heart rate to influence visuals or pacing, allowing VR experiences to respond to

emotional and physical states. These approaches move VR towards fully responsive environments that integrate behaviour, emotion, and embodiment.

## Voice and Language Processing

Voice and language form another important modality in context-aware VR. Advances in speech recognition and natural language processing, particularly through large language models, have shifted interaction from simple commands to natural conversation. Systems using models such as GPT-4 can interpret speech and generate context-aware responses, enabling fluid dialogue with virtual characters (Rong, 2024).

In education, voice-based interaction supports adaptive learning by analysing spoken responses to assess understanding and tailor guidance (Shirazi et al., 2024; Dyulichева & Glazieva, 2022). LLM-powered NPCs can engage in unscripted dialogue, adapting tone, content, and behaviour in real time. Platforms such as LearningverseVR combine dialogue generation with gestures and expressions, improving emotional realism (Song et al., 2024).

Voice input also supports personalisation by capturing user preferences and intentions through natural speech. Over time, systems can recall this information to refine content and interaction styles. As a result, VR environments are evolving into conversational systems where characters can listen, respond, and adapt meaningfully. This growing role of voice interaction is reflected in the user study presented later in this chapter.

## Enabling Technologies: Learning, Generation, and Agents

Reinforcement learning, generative AI, and intelligent agents drive progress in context-aware VR. Reinforcement learning enables systems to adapt environments dynamically by learning which actions maximise engagement, such as adjusting lighting, pacing, or difficulty (Roohi et al., 2021). These feedback loops help sustain flow and improve user experience.

Generative AI enables rapid content creation across environments, dialogue, and interactive objects. Tools such as NVIDIA Edify can generate 3D scenes from text prompts (Delgado, 2024), while platforms like LearningverseVR use generative models to create adaptive narratives, dialogue, and rewards (Song et al., 2024). These methods support personalised and evolving experiences rather than fixed scenarios.

Intelligent agents combine learning, perception, and language to act proactively within VR. They interpret multimodal inputs and adapt behaviour to guide users, personalise interaction, or control pacing. Examples include horror game directors that adjust fear levels based on physiological data (Ojha et al., 2024) and educational NPCs that respond emotionally and verbally to learners (Song et al., 2024). Agents

are also used for automated playtesting, simulating user behaviour to optimise design and reduce development costs (Roohi et al., 2021).

## **Case Studies and Existing Applications**

Context-aware AI has expanded rapidly across real-world applications, with a strong impact in gaming and entertainment, as well as in education, training, healthcare, and autonomous systems. When combined with VR and XR, these systems improve engagement, decision-making, and responsiveness through real-time adaptation and feedback.

### **Gaming and Entertainment**

The integration of AI with immersive technologies has reshaped gaming and entertainment, enabling experiences that are more adaptive, personalised, and emotionally engaging. AI supports not only in-game interaction but also broader digital ecosystems that influence user behaviour. In online entertainment and e-commerce, AI systems analyse browsing patterns and reviews to deliver targeted content and personalised promotions, increasing conversion rates and supporting customer segmentation and sales forecasting (Bag et al., 2021).

Within games, AI agents have reached high levels of performance in complex titles such as Starcraft II, Dota 2, Go, and Atari games, largely through Deep Reinforcement Learning (Reiners et al., 2021). These techniques are also used in automated playtesting for commercial games like Angry Birds Dream Blast, where AI predicts difficulty and engagement to reduce player churn and support level design (Roohi et al., 2021).

Serious games further demonstrate the value of adaptive AI. The Tactical Language Training System game supports Arabic language learning through culturally grounded NPC interactions, using adaptive hypertext to personalise support based on learner progress (Mansouri et al., 2021). Similarly, Rome Reborn employs intelligent NPCs driven by the ATOM dialogue system and Instinct AI engine to simulate historically grounded interactions, offering both educational depth and contextual realism (Mansouri et al., 2021).

### **Broader Applications**

Outside entertainment, context-aware AI in VR plays a growing role in education and professional training. Immersive simulations provide safe, repeatable, and cost-effective environments that support experiential learning and decision-making (Fussell & Truong, 2022). In aviation and military training, VR improves proce-

dural learning and readiness, while in medicine and engineering, it enables virtual laboratories where learners can practise complex tasks with real-time feedback (Shirazi et al., 2024).

In healthcare, AI-enhanced VR and AR are especially valuable for practising high-risk procedures without real-world consequences. Virtual patients, powered by NLP and behaviour modelling, allow trainees to rehearse diagnostic interviews and clinical communication in controlled settings, improving skill transfer and confidence (Reiners et al., 2021).

Context-aware AI is also used in autonomous systems and scientific visualisation. AI-XR environments support the training of robots and autonomous vehicles by simulating rare or dangerous scenarios that are difficult to recreate physically (Reiners et al., 2021). In medical visualisation, AI-assisted XR enables detailed 3D exploration of anatomy, supporting surgical planning by automatically highlighting relevant structures and reducing preparation time (Reiners et al., 2021).

## **Gaps in Current Research**

Despite progress, several limitations remain in current research on context-aware AI in VR. A major gap identified under Objective O1 is the lack of standardised design and evaluation methods for multimodal context-aware systems. Many solutions are domain-specific and difficult to replicate or scale, limiting interoperability and the effective use of reinforcement learning, generative models, and intelligent agents (Augusto, 2022).

A second gap concerns the limited use of human-centred theory in system design, where users are often treated as passive data sources rather than active contextual agents, and existing frameworks provide little guidance for aligning system behaviour with user experience (Augusto, 2022). Access to high-quality multimodal data also remains restricted in early VR systems (Carrera-Rivera et al., 2022), while the nature of black-box models raises concerns about trust and transparency. These challenges are examined in this chapter's user survey (Devagiri et al., 2022) and connect to Objective O2, since many studies continue to emphasise short-term engagement rather than long-term cognitive or behavioural effects, with participant samples that are often demographically narrow (Shirazi et al., 2024). This chapter responds to these gaps through a mixed-methods survey that captures diverse user perspectives on adaptivity, feedback, and trust.

Future research should move toward systematic evaluation of multimodal fusion strategies and better temporal alignment across inputs. Developing shared measurement tools that combine presence, cognitive load, and biosignal data would improve comparability and rigour across studies.

## **METHODOLOGY**

### **Research Design**

This chapter uses a mixed-methods research design that combines a literature review with a user-centred survey. The literature review analyses current frameworks, systems, and case studies to classify multimodal context-aware approaches in immersive environments. Alongside this, the survey captures user perceptions, expectations, and ethical concerns related to AI-enhanced VR. Together, these methods support a balanced view of both system capability and user experience. To ensure alignment between aims and methods, each research objective is linked to a specific component of the study:

- Objective O1: To review recent innovations in context-aware AI applied to VR, addressed through a systematic literature review that examines multimodal inputs and enabling technologies.
- Objective O2: To assess user perceptions and expectations of context-aware features in immersive VR environments, examined through a mixed-methods survey combining quantitative ratings and qualitative feedback.

### **Data Sources and Selection Criteria**

The literature and case studies were selected through a structured screening process that prioritised relevance, quality, and recency. Peer-reviewed articles and industry reports published between 2021 and 2025 were included, with emphasis on studies presenting practical systems or clear theoretical models of context-aware AI in VR. The main selection criteria were:

- Direct focus on multimodal context inputs (environmental, behavioural, verbal).
- Use of AI technologies such as RL, generative models, or intelligent agents.
- Applications in gaming, entertainment or training.
- Inclusion of user-adaptation or affective-computing.
- Evidence of empirical evaluation or real-time implementation.

### **Survey Design and Participants**

The survey was designed to assess attitudes towards AI-enhanced VR systems, with a focus on context-aware adaptivity. It included 23 questions using mixed formats, such as multiple-choice items, Likert-scale ratings, checkboxes, and open-ended

responses. Topics covered demographics, experience with VR and AI, preferred adaptive features, ethical concerns, and overall satisfaction. A full overview of the survey questions and their purpose is provided in Appendix A.

A total of 31 participants were recruited through a university mailing list, word-of-mouth, and student organisations, including the ICT Student Association. This strategy ensured participation from individuals across different academic backgrounds, while still mainly focusing on obtaining data from ICT students who are most likely to be familiar with AI and VR. Demographic data included age, gender, faculty affiliation, and level of study. Most participants were aged between 16 and 24. Gender distribution was 68% male, 19% female, and 13% undisclosed. ICT students formed the largest group, followed by Arts, with the remaining participants drawn from a range of other faculties (see Appendix B for further information).

Most respondents were enrolled in bachelor's programmes, followed by master's students and a smaller group of graduates. Some participants reported other educational levels, including doctoral and post-secondary study. VR usage was generally limited: 45% reported rare use, and 38% had never used VR. Familiarity with AI in VR was mostly moderate, with many describing themselves as somewhat familiar. Participants also reported the types of VR applications they had experienced. Participants with little or no VR experience were included and asked specifically about ethical concerns related to AI in immersive environments.

Survey data was analysed using descriptive statistics and cross-tabulation for quantitative items, alongside thematic analysis of open-ended responses. Likert-scale questions allowed clear comparison across participants, while qualitative responses provide deeper insight into user expectations and concerns.

## **Ethical Considerations**

It is important to note that all the participants of the survey were clearly informed about the purpose of this study and how their data would be used, all participation was voluntary, and consent was implied through the survey's completion. All questions within the survey gave the user the option to skip questions if they didn't want to answer, or didn't feel comfortable answering. No personally identifiable information was collected, and only broad demographic categories such as age, gender, and faculty affiliation were used. All data was also anonymised and analysed in a compiled form

Apart from this, context-aware AI in VR also raises wider ethical concerns. Adaptive systems often rely on continuous data collection, which can blur the boundary between personalisation and surveillance. This highlights the need for clear and transparent design with strong user control, so users can decide if they want to be utilise adaptive features and adjust or disable them when they wish.

When legal requirements are combined with human-centred design, context-aware VR systems can protect privacy and autonomy while still offering engaging and adaptive experiences. Transparency and user control help ensure that adaptivity supports immersion without compromising ethical responsibility.

## **FINDINGS AND ANALYSIS**

### **Technological Trends in AI for VR**

Recent advances in AI-VR integration have driven a shift from static, scripted experiences toward adaptive and personalised virtual environments. This change is largely enabled by the use of multimodal context inputs, including environmental, behavioural, and verbal data, which allow systems to respond intelligently to user actions and conditions in real time.

A key trend is multimodal context-awareness, where VR systems combine data from sensors (such as lighting and spatial layout), behavioural tracking (including movement, gestures, gaze, and physiological signals), and verbal interaction (speech and natural language). By fusing these inputs, VR applications can infer user intent and adjust feedback, interaction, and content to maintain immersion. Technologies such as gesture recognition, head-gaze tracking, and natural language processing support seamless and responsive interaction. These developments are driven by several core AI technologies:

- Reinforcement Learning (RL) agents adapt virtual environments and characters based on user behaviour. In games, RL dynamically adjusts difficulty and pacing to sustain engagement, while in development, it supports automated playtesting by simulating diverse player behaviours (Roohi et al., 2021).
- Generative models, including GANs, diffusion models, and large language models, enable real-time content generation such as unscripted NPC dialogue, dynamic narratives, and on-demand 3D assets. These models increase realism and variation in VR experiences (Song et al., 2024).
- Virtual agents combine perception, RL, and generative capabilities to act as responsive participants in VR. They support roles such as NPCs, tutors, or virtual patients, responding to multimodal user input across entertainment, education, and healthcare contexts.

This technological foundation supports a growing range of applications:

- Adaptive AI in gaming personalises experiences by modelling player behaviour and emotional state. In genres such as horror, systems adjust tension and difficulty using physiological and behavioural signals to create tailored emotional responses (Ojha et al., 2024).
- AI-supported learning environments adapt content, pacing, and feedback to learner performance and engagement. Platforms such as LearningverseVR use free-form dialogue and scriptless NPCs to support active and personalised learning (Shirazi et al., 2024).
- Training and simulation systems, including virtual patients, use AI agents to model complex scenarios and provide real-time feedback, enabling safe and repeatable skill development in medical and professional training (Reiners et al., 2021).

Another strong trend is the use of affective computing to support user adaptation. Systems increasingly analyse emotional cues, facial expressions, voice tone, and physiological data to adjust interaction styles and content in real time. For example, VR horror games respond to detected fear levels, while educational simulations vary feedback intensity based on engagement.

Many of these approaches are supported by empirical studies and live deployments. Research shows that adaptive visual models can improve immersion by responding to environmental changes, and conversational NPCs powered by language models increase perceived realism. Applications such as VRChat and LearningverseVR demonstrate the practical impact of multimodal, context-aware AI on user experience.

Overall, AI for VR is moving toward systems that integrate multimodal context-awareness, learning and generative models, intelligent agents, and emotional adaptation. These technologies enable VR environments that not only react to users but also anticipate needs and co-create experiences, supporting more adaptive and human-centred virtual worlds.

## Survey Outcomes

This subsection presents findings from the participant survey, highlighting user priorities, expectations, and ethical concerns regarding AI-driven, context-aware VR systems. Although based on a small sample, the survey offers insight into emerging preferences for interactivity, adaptivity, and ethical design. For full results, see Appendix B or Table 1.

*Table 1. Summary of key survey results on AI-enhanced VR preferences and perceptions*

Survey Item	Result (Rounded to percentage)
Top-Valued Features	
Real-time environment adjustment	68%
Adaptive difficulty levels	63%
Emotionally responsive avatars	37%
Natural language interactions	36%
Personalised content recommendations	21%
Experience & Exposure	
The user has never used AI in VR	58%
The user is unsure if they used AI in VR	16%
Preferred Adaptations	
Behavioural adaptivity rated “important” or higher	61%
Prefer adaptive difficulty and narrative changes	88%
Support speech-tone-based interaction adaptation	64%
Support emotion-based environment changes	29%
Control Preference	
Prefer hybrid (automatic + user-controlled) adaptation	74%
Ethics	
Support for AI ethics regulation	94%
Concern about data misuse or surveillance	90%
User Discomfort/Issues	
Reported no discomfort using AI in VR	80%
Experienced technical issues	70%
Feedback	
Interest in more conversational AI NPCs	High (qualitative responses)
Likelihood to recommend AI-enhanced VR	Neutral to hesitant overall

Preliminary expectations suggested that users would favour real-time adaptive features and natural interactions in VR, which the survey largely confirmed. When asked to select the most valuable AI-driven features (up to three), most participants prioritised real-time environment adjustments (68%) and adaptive difficulty levels (63%) (Figure 8 in Appendix B). Emotionally responsive avatars (37%) and natural language processing (36%) were also valued, while only 21% selected personalised content recommendations, indicating users prefer immediate interactivity over passive personalisation.

User sentiment largely affirmed AI’s role in enhancing immersion. Most agreed that “AI enhances the realism of VR experiences,” supporting the view that well-

implemented AI adaptivity strengthens plausibility and presence. However, 58% had never interacted with an AI-driven VR system, and 16% were unsure (Figure 10 in Appendix B), showing limited exposure to context-aware features. Physical behavioural adaptivity was rated “important” or “extremely important” by eleven participants (Figure 11 in Appendix B), highlighting the value of sensor-driven interactivity for realism and embodiment.

Preferred context-aware adaptations included adjusting difficulty based on performance and changing narrative paths (88%), with 64% supporting adaptive interactions based on speech tone, but only 29% endorsing environment-wide emotional adjustments (Figure 12 in Appendix B). This suggests emotional responsiveness is appreciated in agents but may feel intrusive when applied globally. Respondents largely favoured a hybrid model combining automatic and user-controlled adaptations (74%) (Figure 13 in Appendix B), reflecting HCI best practices for maintaining user autonomy.

Participants were generally neutral in rating satisfaction with AI-driven VR features and interaction intuitiveness (Figure 14 and B15 in Appendix B), indicating these systems are acceptable but not yet seamless, likely due to limited exposure. Ethical considerations were prominent: 32% were unaware of AI ethics in VR, though those with technical backgrounds or frequent VR use showed higher awareness. The main concerns were data misuse or surveillance (90%), manipulation (65%), bias (61%), and lack of transparency (55%) (Figure 17 in Appendix B). Most users were uncomfortable with AI collecting behavioural data to enhance experience (Figure 20 in Appendix B), and 94% supported regulatory oversight (Figure 21 in Appendix B).

Among those who had interacted with AI in VR, 80% reported no discomfort (Figure 18 in Appendix B), though 20% did, and 70% experienced technical issues (Figure 19 in Appendix B). Many participants expressed interest in conversational AI NPCs capable of real-time dialogue, reflecting trends in LLM integration and demand for more human-like interaction.

Subgroup analyses revealed no meaningful trends due to the small sample size. Overall, participants most valued real-time environment adjustments (68%) and adaptive difficulty scaling (63%), moderately prioritised emotional and verbal adaptivity (37% and 36%), and emphasised ethical transparency and regulatory oversight. These findings suggest future VR systems should combine technical adaptivity with ethical intelligibility, balancing automation with user agency. Context-aware AI should be framed not merely as a tool for efficiency but as an experiential mediator, enhancing trust, flow, and presence through personalised yet explainable feedback. These insights provide guidance for developers, educators, and researchers aiming to design adaptive VR systems that are both cognitively engaging and socially responsible.

## Comparative Analysis

This subsection examines how empirical user insights align with technological developments, highlighting convergences and gaps between capabilities and experience. Comparing survey responses with literature reveals where AI-driven context-awareness in VR meets user expectations and where implementation lags.

A clear area of alignment is user preference for real-time environmental and behavioural adaptivity. Participants rated real-time environment adjustments (68%) and adaptive difficulty levels (63%) as most valuable, reflecting innovations like reinforcement learning agents that scale difficulty or adjust lighting and pacing based on context (Roohi et al., 2021; Abbasi et al., 2024). Interest in emotionally responsive avatars and natural language processing also aligns with advances in affective computing and conversational AI, including emotionally reactive NPCs in games (Ojha et al., 2024) and scriptless dialogue in educational VR (Song et al., 2024).

Users strongly favoured context-aware systems that adapt difficulty and narrative paths (88% each), supporting theoretical models of engagement and flow (Csikszentmihalyi, 1990) and confirming that AI-enhanced adaptivity sustains immersion. Preference for hybrid automatic/user-controlled adaptations (74%) echoes human-centric design principles prioritising agency and transparency (Augusto, 2022; Carrera-Rivera et al., 2022). Ethical concerns, data misuse, manipulation, bias, and lack of transparency were prominent, with 94% advocating regulatory oversight, reflecting scholarly calls for responsible AI (Paneva et al., 2025; Devagiri et al., 2022).

However, discrepancies are evident between technological promise and user experience. Despite the literature describing real-time adaptive systems, emotionally intelligent NPCs, and biofeedback-driven gameplay, 58% of respondents had never encountered AI-driven VR, and 16% were unsure, suggesting limited mainstream deployment. Users were generally neutral on intuitiveness and satisfaction, contrasting literature claims of high engagement, indicating implementation quality and onboarding may be inadequate.

Low interest in personalised content recommendations (21%) also contrasts with AI use in streaming and e-commerce (Bag et al., 2021), implying that VR users value immediate interactivity over passive curation. Likewise, only 29% supported environment changes based on emotional states, highlighting possible unease or preference for more direct adaptivity. Finally, despite literature advocating explainable and transparent systems, users reported ethical discomfort and a strong desire for control and regulation, suggesting governance tools such as Explainable AI (XAI) dashboards and consent mechanisms are not yet standard in deployed systems.

## Cross-Domain Comparison of Context-Aware VR Applications

*Table 2. Cross-domain comparison of context-aware VR applications*

<b>Feature / Category</b>	<b>Gaming &amp; Entertainment</b>	<b>Education &amp; Training</b>	<b>Healthcare &amp; Therapy</b>	<b>Industrial &amp; Professional Training</b>
Primary Goals	Enhance immersion, emotional engagement, and challenge balancing	Support learning, skill acquisition, and cognitive engagement	Rehabilitation, emotional regulation, and exposure therapy	Safety, situational awareness, performance optimisation
Contextual Inputs (Sensors / Data)	Behavioural cues (movement, reaction time), physiological signals (heart rate, gaze), and vocal tone	Task performance metrics, gaze tracking, speech, and gesture	Biometric data (EEG, heart rate, skin conductance), behavioural tracking	Motion capture, eye tracking, and task completion data
Adaptive Outputs / Features	Dynamic difficulty adjustment, emotion-adaptive NPCs, procedural storytelling	Adaptive tutoring, multimodal feedback, and cognitive load regulation	Stress-level adjustment, emotion-guided feedback, adaptive pacing	Real-time task guidance, fatigue monitoring, adaptive simulation
Key Constraints	Latency, over-adaptation risk, and data privacy in consumer devices	Measurement validity, learner diversity, and institutional data policy	Medical data compliance (HIPAA/ GDPR), sensor accuracy, patient safety	Reliability, network latency, integration with enterprise systems
Design Priorities	Real-time responsiveness, user agency, transparent adaptation	Instructional alignment, adaptability, and ethical data handling	Clinical validity, empathy in design, and strict privacy control	Operational realism, data integrity, minimal cognitive load

Table 2 illustrates how context-aware AI functions differently across application domains. While the core mechanism, multimodal sensing and adaptive feedback, remains consistent, the ethical, technical, and experiential priorities vary. In gaming, adaptivity serves engagement and flow; in education, it enhances personalisation and retention; in healthcare, it safeguards well-being through calibrated intervention; and in industrial training, it optimises performance within operational limits. Recognising these domain-specific constraints and goals enables the development of more targeted frameworks for context-aware VR, balancing technological sophistication with user trust and ethical transparency.

## Case Studies

### Gaming: Emotionally Adaptive Horror Experiences

Emotionally adaptive VR horror games show a compelling use of context-aware AI, exemplified by Ojha et al.'s (2024) "Horror Director" system. The system uses behavioural context-awareness via a machine learning model that infers player fear from gameplay traces, without relying on biometric sensors. Fear levels are labelled using self-reported Likert-scale ratings collected during play. Horror Director uses a Finite State Machine with three pacing states, Relax, Build Peak, and Sustain Peak, to introduce horror elements at psychologically optimal moments. These stimuli are triggered by player-specific fear profiles rather than scripted events, creating personalised fear trajectories. Technical requirements included bounding-zone tagging, light and audio mapping, and a fast prediction loop under 4ms for seamless VR integration.

Empirical results show increased immersion, fear, and enjoyment with adaptive stimuli like whispers, flickering lights, and creaking floors. These outcomes align with Slater's (2009) plausibility illusion and Csikszentmihalyi's (1990) flow model. Challenges remain in generalising fear models trained on narrow, self-reported data, but the work highlights how real-time behavioural modelling can transform horror game design from static scripting to responsive, emotionally tuned interactivity.

### Education: LearningverseVR and Scriptless NPCs

In education, Song et al.'s (2024) LearningverseVR demonstrates how generative AI and multimodal context-awareness can enhance learning. The platform integrates a Unity-based VR client with a backend using Flask, MySQL, GPT-3.5, and a local ChatGLM instance. NPCs are powered by LLMs, allowing free-form conversations that interpret verbal input and behavioural signals. They can also show emotion and perform body movements via tone and action indicators. Context cues are parsed in real time to guide responses, animations, and instructional strategies. The system also includes World, Organic, and Inorganic agents that adapt to environmental features such as weather, flora, and social interactions.

LearningverseVR enables adaptive learning paths, gamification, and emotionally aware NPC interaction. Users report higher motivation, engagement, and knowledge retention due to personalised pacing and challenge levels (Shirazi et al., 2024; Song et al., 2024). NPCs maintain conversational memory, allowing personalised exchanges that enhance plausibility illusion and flow. Scriptless design reduces development workload, supporting scalable, narrative-rich learning experiences. Coordinating multiple agent types and ensuring coherent world behaviour remains challenging,

highlighting the need for scalable architectures and long-term context management. Learningverse VR shows how context-sensitive AI can align interactivity with learner autonomy and engagement.

## Healthcare: Virtual Patients and Adaptive Training

In medical training, context-aware AI in VR allows realistic virtual patients (Reiners et al., 2021). These AI avatars adapt to trainees' verbal and nonverbal cues, adjusting their responses to guide clinical reasoning. The systems track spoken questions, hesitation, and confusion, adapting interactions to promote best practices. Studies show improved knowledge retention, confidence, and accurate assessment of clinical skills through real-time analysis.

## Real-Time Environmental Adaptation: ManySense VR

A notable example of environmental context-awareness is the ManySense VR framework, which integrates real-time weather and environmental data from external APIs into the VR scene (Moon et al., 2022). If it is raining in the user's city, the virtual world synchronises with overcast skies and appropriate soundscapes. This context fusion enhances presence and realism, making the virtual environment feel more aligned with the user's actual situation and promoting a deeper sense of immersion.

## Automated Playtesting and Game Design Optimisation

AI-driven agents employing reinforcement learning and Monte Carlo Tree Search have advanced the process of game design and testing (Roohi et al., 2021). In commercial titles like Angry Birds Dream Blast, a combination of DRL and MCTS agents simulates thousands of play sessions to predict level difficulty, identify player retention bottlenecks, and refine content to maximise engagement.

In summary, these case studies collectively underscore how dynamic interaction and multimodal context-awareness, enabled by advanced AI technologies, can significantly elevate user engagement, satisfaction, and learning outcomes in VR. The empirical evidence and real-time implementations across gaming, education, training, and healthcare reinforce the value of adaptive, human-centred AI in shaping the next generation of immersive experiences.

## DISCUSSION

### Synthesis of Findings

The convergence of AI and VR, particularly through context-aware systems, has been shown to improve user immersion, engagement, and personalisation across entertainment and education. Both the reviewed innovations and survey insights indicate that AI integration in VR is transformative, but effective implementation requires interdisciplinary collaboration and user-centred design.

A key advantage of context-aware AI in VR is its ability to create dynamic, responsive environments. Unlike static experiences, AI enables real-time adaptivity, which strengthens the sense of presence because the VR system can anticipate user actions and update sensory feedback in line with expectations (Triberti et al., 2025). Multimodal interactions, combining gestures, voice, and head gaze, support natural and efficient communication, with each modality compensating for others' limitations (Cao et al., 2023). Integrating speech and affective models with contextual sensing, such as dynamic lighting, enhances clarity, immersion, and intuitive control (Abbasi et al., 2024). Contextually adaptive environments, coupled with narrative and clear goals, align with user expectations, deepening the sense of "being there" (Triberti et al., 2025).

From a design perspective, context-aware AI must balance immersion with usability. Developers need to integrate models ranging from RL to natural language processing without overwhelming users. Cognitive load and attention must be considered, for example, by avoiding adaptive transitions during peak focus. This highlights the need for collaboration among HCI specialists and AI researchers to create experiences that are both contextually rich and psychologically coherent.

Personalisation is another major benefit. In games and educational platforms, AI can model behaviour, emotion, preferences, and performance to tailor content (Ojha et al., 2024; Song et al., 2024; Dyulicheva & Glazieva, 2022). VR horror games can detect fear responses and adjust pacing or narrative elements in real time, increasing emotional impact (Ojha et al., 2024). In educational VR, AI adapts difficulty and content to support learning trajectories and retention (Shirazi et al., 2024; Dyulicheva & Glazieva, 2022). These feedback loops improve both engagement and effectiveness.

Beyond VR, context-aware AI supports Smart-Product Service Systems (S-PSS), dynamically adjusting to user situations and environmental inputs (Carrera-Rivera et al., 2022). These systems enhance operational performance, predictive analytics, and targeted marketing, demonstrating applications beyond immersive experiences (Bag et al., 2021; Munir et al., 2022).

In training and professional development, AI-driven VR agents enable scenario-based learning that adapts to users' skills in real time (Reiners et al., 2021). In aviation and medical education, VR allows repeatable, risk-free practice of high-stakes procedures, improving memory, reducing costs, and fostering critical thinking (Fussell & Truong, 2022; Shirazi et al., 2024). AI agents capable of decision-making and emotional expression provide human-like interactions that enhance learning and engagement.

AI-generated virtual influencers extend affective computing and digital communication by expressing nuanced emotions, enriching interaction, and supporting emotionally resonant strategies in entertainment and marketing (Yu et al., 2024). Overall, these applications show the transformative potential of context-aware AI, though success depends on human-centric design, ethics, and adaptive practices. Emphasising cognitive ergonomics and inclusive design is essential to realise the benefits of AI-augmented VR.

## **Challenges and Concerns**

Despite its promise, context-aware AI in VR faces complex challenges across technical, ethical, methodological, and human-centred domains.

### **Complexity in Contextual Understanding**

Interpreting multifaceted, real-time contextual cues remains a large challenge. Systems draw on diverse data sources, including behaviour, biometric signals, and sensor data, which vary in reliability and format (Carrera-Rivera et al., 2022; Bag et al., 2021). Processing real-time streams requires high-speed, accurate analytics to maintain responsiveness. Inputs like gestures or voice commands, are often ambiguous. Multimodal fusion algorithms are needed to resolve conflicts and provide clear interaction (Cao et al., 2023). For example, simultaneous inputs from different modalities require prioritisation schemes to decide which action to execute.

Dynamic contexts, such as real-time gaming or manufacturing, introduce uncertainties in predicting user behaviour, particularly when historical data is limited or unreliable (Devagiri et al., 2022; Dyulicheva & Glazieva, 2022). AI-generated humanoid figures may also trigger the “uncanny valley” effect, where near-human appearances create discomfort or distrust (Yu et al., 2024). Designing emotionally resonant agents that avoid adverse reactions remains an ongoing challenge.

## Real-Time Processing and Computational Cost

Maintaining low-latency responsiveness in AI-driven VR is a key challenge. Multimodal systems must process high-dimensional sensor data and render feedback instantly to preserve immersion (Cao et al., 2023; Reiners et al., 2021). Even small delays, such as lag in head tracking, can break presence and reduce usability (Slater, 2009). While some models, like fear detection systems, can predict reactions in milliseconds, running them consistently in real time requires significant computational resources (Ojha et al., 2024).

Training these models is even more demanding. DRL, for instance, can require weeks on high-performance computing infrastructure to reach optimal performance (Yin et al., 2023). Such requirements limit participation by smaller teams and slow research progress. Hardware constraints also play a role as VR systems need efficient, powerful chips to handle intensive computation cost-effectively and reliably, especially for real-world deployment (Devagiri et al., 2022).

## Data and Ethical Considerations

Privacy is another concern in context-aware VR, since these systems collect sensitive behavioural and physical data. Users may not realise the extent of information captured, including eye movements, speech, posture, or physiological signals, which can reveal mood, identity, or health (Paneva et al., 2025). Transparent consent and in-system privacy controls, such as virtual “privacy monitors,” are essential to protect users.

Ethical design also requires user control over AI adaptivity. Systems should avoid user profiling and offer override options, allowing individuals to adjust or reject intrusive changes. Bias in AI models presents another risk since demographic skew in training data can lead to poor performance for underrepresented groups (Ojha et al., 2024). Similarly, voice or gesture recognition may fail in noisy environments, reducing accessibility and usability (Cao et al., 2023).

The increasing realism of AI characters raises psychological and ethical concerns. The “uncanny valley” effect can create discomfort (Yu et al., 2024), and virtual influencers, for instance, may manipulate emotions if not properly regulated. Black-box AI systems are often opaque, risking user distrust, and over-reliance on AI in educational settings may undermine critical thinking or alter traditional mentorship roles (Shirazi et al., 2024). Legal and ethical frameworks remain limited, highlighting the need for robust governance (Devagiri et al., 2022).

## Methodologies and Evaluation

Evaluating AI-driven VR systems presents methodological challenges. Current frameworks often assess isolated aspects, like situational awareness, rather than providing holistic insight (Munir et al., 2022). Many studies rely on subjective feedback from questionnaires or interviews, which can be influenced by personality or temporary states (Carrera-Rivera et al., 2022).

Physiological measures, such as eye-tracking, EEG, or ECG, provide objective data on cognitive and emotional states but can be intrusive and logistically complex (Carrera-Rivera et al., 2022). Generalising findings is difficult because most studies are conducted in narrow settings with limited demographics (Roohi et al., 2021). Long-term effects of adaptive VR, such as on memory, learning retention, motivation, or digital well-being, remain underexplored (Shirazi et al., 2024).

## Interdisciplinary Perspectives and Future Challenges

Inclusive design is essential to build HCI systems that support users with diverse needs. In storytelling, context-aware adaptivity must balance narrative flexibility with cognitive limits to avoid disrupting flow. Media psychology shows that anthropomorphic agents can increase user confidence if consistent and trustworthy, but misuse risks ethical violations. From a technical perspective, integrating LLMs into real-time VR introduces latency and coherence challenges in generated responses (Rong, 2024). Researchers must evaluate how users perceive AI understanding and determine limits for adaptive interaction.

Addressing these challenges requires interdisciplinary collaboration, clear governance, and emphasis on user agency. To fully realise the potential of context-aware VR, development must advance not only in technology but also in ethical, equitable, and human-centred design.

## FUTURE DIRECTIONS

### Emerging Technologies and Innovations

The evolution of AI and VR is driving innovations that may reshape how users interact with digital environments. Integrating advanced AI with immersive VR offers opportunities for more adaptive, responsive, and emotionally attuned experiences. These intelligent systems can dynamically learn from users and context, creating new research avenues across education, entertainment, healthcare, and beyond.

## Bio-Adaptive Systems and Emotion-Aware Interfaces

Future applications can utilise Bio-adaptive VR systems to track heart rate, EEG, or skin conductance to detect emotional states in real time. For example, an educational VR simulation could adjust lesson pacing or provide hints based on detected stress or fatigue. Developing reliable closed-loop systems requires advances in affective computing and collaboration with neuroscience and psychology. Emotion-aware systems promise more empathetic, engaging, and effective experiences (Dyulicheva & Glazieva, 2022; Yu et al., 2024).

## Cross-Platform Contextual Intelligence

Context-aware AI will extend beyond standalone VR to AR, mobile, and traditional screens. Mixed-reality systems may use geolocation, calendar events, or social interactions to tailor experiences. For instance, a theme park could integrate AR location data to inform VR narratives, adapting rides or storytelling to the user's prior experiences. Cross-platform awareness will require robust AI capable of aggregating and interpreting diverse data streams (Carrera-Rivera et al., 2022; Bag et al., 2021).

## Advanced AI Models for Perception and Interaction

Deep learning (DL) and reinforcement learning (RL) remain central. DL extracts hierarchical patterns from complex data, supporting object detection, sentiment analysis, and scene understanding. RL trains agents through trial-and-error in dynamic environments, relevant for autonomous vehicles, robotics, and games (Reiners et al., 2021; Roohi et al., 2021). Generative AI and LLMs enable scriptless NPC interactions, producing real-time dialogue, emotion, and behaviour based on context. Future systems may also generate 3D models, environments, animations, and full-scene video to personalise content in real time (Song et al., 2024).

## Large-Scale Behavioural Analytics and Federated Learning

With the increasing adoption of context-aware VR, the potential to conduct large-scale behavioural analytics is becoming more feasible. Aggregated, anonymised data from millions of interactions, such as voice commands, gaze patterns, and movement trajectories, can help improve AI models for better immersion and responsiveness. However, privacy remains important to ensure data protection while enabling context-awareness. Research in this area must focus on developing tech-

niques that maintain privacy while allowing AI systems to generalise from diverse user interactions (Ojha et al., 2024; Carrera-Rivera et al., 2022).

## **Immersive Simulation and Virtual Laboratories**

In education and professional training, VR is poised to enable increasingly complex and realistic simulations. AI-powered virtual laboratories will allow learners to conduct repeatable, hands-on experiments in immersive environments, particularly valuable in domains like medicine, engineering, and the physical sciences (Shirazi et al., 2024). These environments will adapt in real time to learner performance, providing customised feedback and dynamically adjusting task difficulty to optimise skill development.

## **Human-Centric AI and VR Design and Impact**

AI in VR must treat users as active participants. Systems should integrate characteristics like learning style, motivation, and emotional state into adaptive logic (Augusto, 2022). Broad, diverse participant representation is critical to avoid bias and enhance generalisability. XAI and human-in-the-loop mechanisms will help maintain trust and user control, particularly in sensitive domains like education and healthcare (Devagiri et al., 2022). Research should also address health risks, such as eye strain, motion sickness, and disorientation, ensuring safe and engaging VR experiences.

## **Recommendations for Practitioners and Researchers**

### **Practical Guidance for Developers, Educators, and Industry Stakeholders**

Technological development must remain human-centred. Systems should focus on user benefit rather than technical sophistication. Developers must explicitly integrate human preferences, behaviours, and characteristics into context-aware models throughout all stages of development (Augusto, 2022).

Practitioners should offer multimodal input options, including gestures and voice, to allow users to choose the most comfortable or efficient method. Gestures can provide immediate control, while voice-gaze combinations support manipulation of distant or abstract objects (Cao et al., 2023). In professional training settings, demonstrating measurable benefits in engagement, efficiency, or outcomes can encourage adoption (Fussell & Truong, 2022).

Personalisation should be strategically applied in fields like marketing. AI can track consumer behaviour to create emotionally responsive campaigns (Bag et al., 2021), while virtual influencers or avatars should display appropriate emotions aligned with communication goals (Yu et al., 2024). In education, adaptive systems should adjust difficulty and pacing in real time, with VR simulations enhancing learning. Gamification elements such as badges, points, and leaderboards can sustain motivation and provide feedback (Song et al., 2024; Shirazi et al., 2024).

Developers must comply with regulations such as GDPR and the EU-AI Act, and communicate clearly about what data is collected, why, and how it is used (Carrera-Rivera et al., 2022; Shirazi et al., 2024). Consent mechanisms should be built into all systems to ensure ethical compliance and trust. Institutions should provide hardware, software, and user support to ensure successful integration into workflows and learning environments (Shirazi et al., 2024). Operational efficiency can be enhanced through AI in industrial settings, and predictive maintenance, safety optimisation, and large-scale analytics are key applications, and collaborative intelligence, where AI augments rather than replaces humans, will be critical for long-term value (Devagiri et al., 2022; Munir et al., 2022; Bag et al., 2021).

## Research Priorities for Advancing Context-Aware AI in VR

Researchers should develop rigorous, human-centred frameworks for context awareness that account for interactions between system behaviour and user activity (Augusto, 2022). Modular and scalable architectures are also needed to support real-time data flows and multi-user environments while remaining robust (Carrera-Rivera et al., 2022).

Real-time processing is still a challenge for multimodality, so further work on efficient, low-latency AI and ML algorithms is essential for managing context in fast-changing environments (Carrera-Rivera et al., 2022). Domain adaptation strategies should be explored to ensure that skills learned in XR transfer effectively to real-world tasks (Reiners et al., 2021). Simulation design also requires attention, as VR worlds with multiple intelligent agents and real-world unpredictability can provide richer learning scenarios and more rigorous training conditions (Reiners et al., 2021).

Further research is needed to understand cognitive, behavioural, and educational effects, including skill retention, motivation, and higher-order thinking (Shirazi et al., 2024). XAI remains important for improving interpretability and trust, particularly in education, healthcare, and safety contexts (Devagiri et al., 2022). Researchers should also develop stronger metrics for situational awareness that better reflect complex, multitasking environments (Munir et al., 2022).

## CONCLUSION

This chapter has explored how AI and VR come together through multimodal context awareness, drawing on literature and survey evidence. The findings show that AI can read environmental, behavioural, and verbal cues to shape responsive and personalised virtual experiences. Inputs such as voice, gaze, gesture, and physiological signals enable VR systems to adjust in real time, while techniques such as RL, generative models, and intelligent agents support scriptless interaction, bio-adaptive pacing, and dynamic content creation across various fields.

Survey responses reinforce these insights, with participants showing support for real-time adaptation, emotionally aware characters, and shared control between users and AI. Users reported greater immersion when systems adjusted difficulty, narrative flow, or social interaction. At the same time, concerns about data privacy, transparency, and user autonomy remain important, pointing to the need for responsible and user-centred design in future systems.

## REFERENCES

- Abbasi, M., Váz, P., Silva, J., & Martins, P. (2024). Enhancing Visual Perception in Immersive VR and AR Environments: AI-Driven Color and Clarity Adjustments Under Dynamic Lighting Conditions. *Technologies*, 12(11), 11. Advance online publication. DOI: 10.3390/technologies12110216
- Augusto, J. C. (2022). Contexts and Context-awareness Revisited from an Intelligent Environments Perspective. *Applied Artificial Intelligence*, 36(1), 2008644. DOI: 10.1080/08839514.2021.2008644
- Bag, S., Srivastava, G., Bashir, M. M. A., Kumari, S., Giannakis, M., & Chowdhury, A. H. (2021). Journey of customers in this digital era: Understanding the role of artificial intelligence technologies in user engagement and conversion. *Benchmarking*, 29(7), 2074–2098. DOI: 10.1108/BIJ-07-2021-0415
- Berkman, M. I., & Akan, E. (2019). Presence and Immersion in Virtual Reality. In Lee, N. (Ed.), *Encyclopedia of Computer Graphics and Games* (pp. 1–10). Springer International Publishing., DOI: 10.1007/978-3-319-08234-9\_162-1
- Cao, L., Zhang, H., Peng, C., & Hansberger, J. T. (2023). Real-time multimodal interaction in virtual reality, A case study with a large virtual interface. *Multimedia Tools and Applications*, 82(16), 25427–25448. DOI: 10.1007/s11042-023-14381-6
- Carrera-Rivera, A., Larrinaga, F., & Lasa, G. (2022). Context-awareness for the design of Smart-product service systems: Literature review. *Computers in Industry*, 142, 103730. DOI: 10.1016/j.compind.2022.103730
- Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience*.
- Delgado, G. (2024, July 31). NVIDIA Researchers Harness Real-Time Gen AI to Build Immersive Desert World. NVIDIA Blog. <https://blogs.nvidia.com/blog/real-time-3d-generative-ai-research-siggraph-2024/>
- Devagiri, J. S., Paheding, S., Niyaz, Q., Yang, X., & Smith, S. (2022). Augmented Reality and Artificial Intelligence in industry: Trends, tools, and future challenges. *Expert Systems with Applications*, 207, 118002. DOI: 10.1016/j.eswa.2022.118002
- Dyulicheva, Y. Y., & Glazieva, A. O. (2022). Game based learning with artificial intelligence and immersive technologies: An overview.
- Fussell, S. G., & Truong, D. (2022). Using virtual reality for dynamic learning: An extended technology acceptance model. *Virtual Reality (Waltham Cross)*, 26(1), 249–267. DOI: 10.1007/s10055-021-00554-x PMID: 34276237

- Mansouri, B., Roozkhosh, A., & Farbeh, H. (2021). A Survey on Implementations of Adaptive AI in Serious Games for Enhancing Player Engagement. *2021 International Serious Games Symposium (ISGS)*, 48–53. DOI: 10.1109/ISGS54702.2021.9684760
- Moon, J., Jeong, M., Oh, S., Laine, T. H., & Seo, J. (2022). Data Collection Framework for Context-Aware Virtual Reality Application Development in Unity: Case of Avatar Embodiment. *Sensors (Basel)*, 22(12), 12. Advance online publication. DOI: 10.3390/s22124623 PMID: 35746405
- Munir, A., Aved, A., & Blasch, E. (2022). Situational Awareness: Techniques, Challenges, and Prospects. *AI*, 3(1), 1. Advance online publication. DOI: 10.3390/ai3010005
- Nilsson, N., Nordahl, R., & Serafin, S. (2016). Immersion Revisited: A Review of Existing Definitions of Immersion and Their Relation to Different Theories of Presence. *Human Technology*, 12(2), 108–134. DOI: 10.17011/ht/urn.201611174652
- Ojha, A., Narain, S., Raj, A., Agrawal, T., Wadhwa, B., & Joshi, M. (2024). Dynamic virtual reality horror sports enhanced by artificial intelligence and player modeling. *Multimedia Tools and Applications*, 83(32), 77415–77432. DOI: 10.1007/s11042-024-18414-6
- Paneva, V., Winterhalter, V., Malladi, N. S. S. V., Strauss, M., Schneegass, S., & Alt, F. (2025). Usable Privacy in Virtual Worlds: Design Implications for Data Collection Awareness and Control Interfaces in Virtual Reality (No. arXiv:2503.10915). arXiv. <https://doi.org//arXiv.2503.10915> DOI: 10.48550
- Reiners, D., Davahli, M. R., Karwowski, W., & Cruz-Neira, C. (2021). The Combination of Artificial Intelligence and Extended Reality: A Systematic Review. *Frontiers in Virtual Reality*, 2, 721933. Advance online publication. DOI: 10.3389/frvir.2021.721933
- Rong, Z. (2024). Application of Natural Language Processing in Virtual Experience AI Interaction Design. *Journal of Intelligent Learning Systems and Applications*, 16(4), 4. Advance online publication. DOI: 10.4236/jilsa.2024.164020
- Roohi, S., Guckelsberger, C., Relas, A., Heiskanen, H., Takatalo, J., & Hämäläinen, P. (2021). Predicting Game Difficulty and Engagement Using AI Players. *Proc. ACM Hum.-Comput. Interact.*, 5(CHIPLAY), 231:1-231:17. DOI: 10.1145/3474658
- Rutrecht, H., Wittmann, M., Khoshnoud, S., & Igarzábal, F. A. (2021). Time Speeds Up During Flow States: A Study in Virtual Reality with the Video Game Thumper. DOI: 10.1163/22134468-bja10033

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist*, 55(1), 68–78. DOI: 10.1037/0003-066X.55.1.68 PMID: 11392867

Shirazi, B. N., Safavi, A. A., Aftabi, E., & Salimi, G. (2024). The Integration of Virtual Reality and Artificial Intelligence in Educational Paradigms. 2024 11th International and the 17th National Conference on E-Learning and E-Teaching (ICeLeT), 1–6. DOI: 10.1109/ICeLeT62507.2024.10493089

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 364(1535), 3549–3557. DOI: 10.1098/rstb.2009.0138 PMID: 19884149

Song, Y., Wu, K., & Ding, J. (2024). Developing an immersive game-based learning platform with generative artificial intelligence and virtual reality technologies – “LearningverseVR”. *Computers & Education: X Reality*, 4, 100069. DOI: 10.1016/j.cexr.2024.100069

Triberti, S., Sapone, C., & Riva, G. (2025). Being there but where? Sense of presence theory for virtual reality applications. *Humanities & Social Sciences Communications*, 12(1), 79. Advance online publication. DOI: 10.1057/s41599-025-04380-3

Wang, A., Thompson, M., Uz-Bilgin, C., & Klopfer, E. (2021). Authenticity, Interactivity, and Collaboration in Virtual Reality Games: Best Practices and Lessons Learned. *Frontiers in Virtual Reality*, 2, 734083. Advance online publication. DOI: 10.3389/frvir.2021.734083

Yin, Q.-Y., Yang, J., Huang, K.-Q., Zhao, M.-J., Ni, W.-C., Liang, B., Huang, Y., Wu, S., & Wang, L. (2023). AI in Human-computer Gaming: Techniques, Challenges and Opportunities. *Machine Intelligence Research*, 20(3), 299–317. DOI: 10.1007/s11633-022-1384-6

Yu, J., Dickinger, A., So, K. K. F., & Egger, R. (2024). Artificial intelligence-generated virtual influencer: Examining the effects of emotional display on user engagement. *Journal of Retailing and Consumer Services*, 76, 103560. DOI: 10.1016/j.jretconser.2023.103560

## APPENDIX A: SURVEY QUESTIONNAIRE

Q1: What is your age group?

- Type: Multiple Choice.
- Reason: Obtaining demographic information to better contextualise the data.

Q2: What is your Gender?

- Type: Multiple Choice.
- Reason: Obtaining demographic information to better contextualise the data.

Q3: Which Faculty are you registered with?

- Type: Multiple Choice.
- Reason: Obtaining demographic information to better contextualise the data. Since this survey was performed at a University, this question was tailored towards those students.

Q4: What Education Level are you currently studying for?

- Type: Multiple Choice.
- Reason: Obtaining demographic information to better contextualise the data.

Q5: How frequently do you use virtual reality (VR) experiences?

- Type: Multiple Choice.
- Reason: Understanding usage frequency helps segment users based on experience levels, which can influence perceptions of AI integration in VR.

Q6: Which types of VR applications have you experienced? (Select all that apply.)

- Type: Checkboxes.
- Reason: Identifying the variety of VR applications used provides context for user expectations and experiences.

Q7: How familiar are you with how AI is used in VR?

- Type: Multiple Choice.
- Reason: This question segments respondents based on their baseline understanding of AI-VR integration, useful for interpreting attitudes and expectations across experience levels. Similar formats are used in technology acceptance and literacy studies.

Q8: Which AI-driven features do you find most valuable in VR?

- Type: Checkboxes.
- Reason: Identifying valued features informs developers about user priorities in AI integration.

Q9: To what extent do you agree with the statement: “AI enhances the realism of VR experiences.”

- Type: Likert scale (1 – Strongly Disagree to 5 – Strongly Agree).
- Reason: Assessing user agreement helps gauge perceptions of AI's role in enhancing VR realism.

Q10: Have you ever interacted with an AI-driven character or system in VR?

- Type: Yes or No.
- Reason: Determines user exposure to AI elements within VR environments.

Q11: How important is it for a VR system to adapt to your physical movements and behaviours in real-time? (Skip if not applicable)

- Type: Likert scale (1 – Not important to 5 – Extremely important).
- Reason: Evaluates user expectations regarding system responsiveness to physical cues.

Q12: Which types of context-aware adaptations do you prefer in VR experiences? (Skip if not applicable)

- Type: Checkboxes.
- Reason: Identifies user preferences for specific adaptive features, guiding the design of personalised and immersive VR interactions.

Q13: Would you prefer AI adaptations in VR to be automatic or user-controlled?

- Type: Multiple Choice.
- Reason: Understanding control preferences aids in designing user-centric AI systems.

Q14: Rate your overall satisfaction with AI-driven features in VR experiences you've encountered. (Skip if not applicable)

- Type: Likert scale (1 – Very dissatisfied to 5 – Very satisfied).
- Reason: Measures user satisfaction levels, identifying areas for improvement.

Q15: How intuitive do you find AI-driven interactions in VR? (Skip if not applicable)

- Type: Likert scale (1 – Not intuitive to 5 – Very intuitive).
- Reason: Assesses the ease of use and learning curve associated with AI features.

Q16: How aware are you of the ethical implications of using AI in virtual reality (VR)?

- Type: Likert scale (1 – Not at all aware to 5 – Very aware).
- Reason: Assesses the user's level of ethical awareness, informing the need for education or transparency in AI-driven VR systems.

Q17: Which ethical concerns do you associate with AI in VR?

- Type: Checkboxes.

- Reason: Identifies specific ethical issues users are concerned about, helping to prioritise responsible development and address public apprehensions.

Q18: Have you experienced discomfort due to AI in VR?

- Type: Yes, No or Not Applicable.
- Reason: Identifies potential negative impacts of AI features on user comfort.

Q19: Have you encountered technical issues due to AI in VR?

- Type: Yes, No or Not Applicable.
- Reason: Determines the prevalence of AI-related technical problems in VR.

Q20: Would you be comfortable with AI systems in VR collecting data on your behaviour to enhance experiences?

- Type: Likert scale (1 – Very uncomfortable to 5 – Very comfortable).
- Reason: Evaluates user comfort levels regarding data collection, which is crucial for ethical AI design.

Q21: Should there be rules on how AI in VR collects and uses personal data?

- Type: Yes, No or Not Sure.
- Reason: Gathers opinions on the necessity of implementing privacy safeguards.

Q22: Do you have any concerns about AI integration in VR environments (computer-made worlds you can explore using a VR headset)? (Skip if no)

- Type: Paragraph.
- Reason: Allows users to express specific worries, providing qualitative data for analysis.

Q21: What features would you like to see in future AI-enhanced VR experiences?

- Type: Paragraph.
- Reason: Collects user suggestions to guide future development and innovation.

Q22: How likely are you to recommend AI-enhanced VR experiences to others?

- Type: Likert scale (1 – Not likely to 5 – Very likely).
- Reason: Measures user advocacy, indicating overall satisfaction and perceived value.

Q23: Please share any additional comments or suggestions regarding AI in VR.

- Type: Paragraph.
- Reason: Provides an opportunity for users to offer further insights or feedback.

## APPENDIX B: PARTICIPANT SURVEY RESULTS

### User Background and VR Usage

Figure 1. Distribution of participant age groups

What is your age group?

31 responses

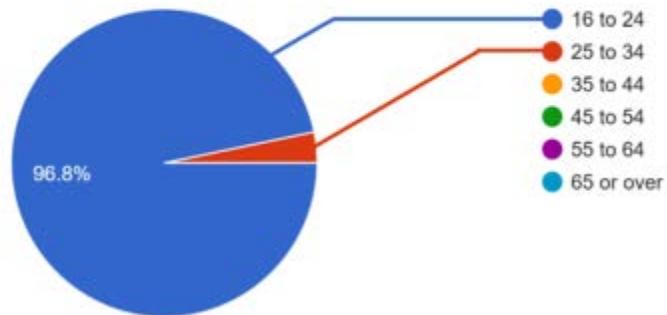


Figure 2. Gender identity of respondents

What is your Gender?

31 responses

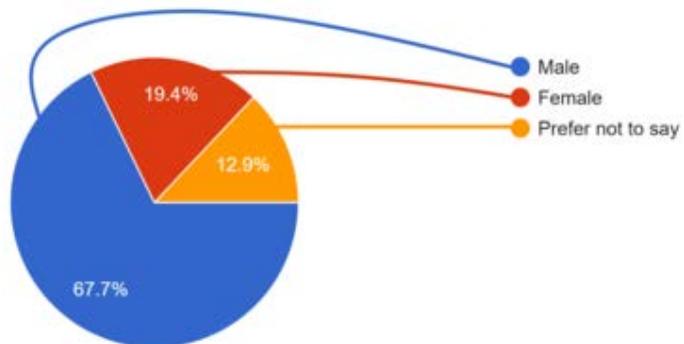


Figure 3. Faculty affiliation of participants

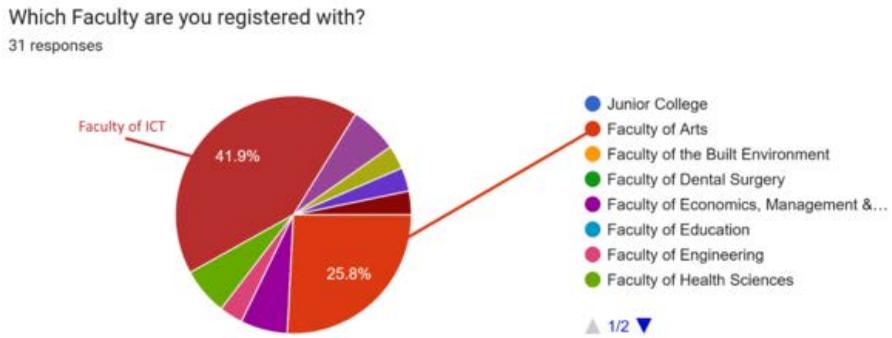


Figure 4. Current level of study

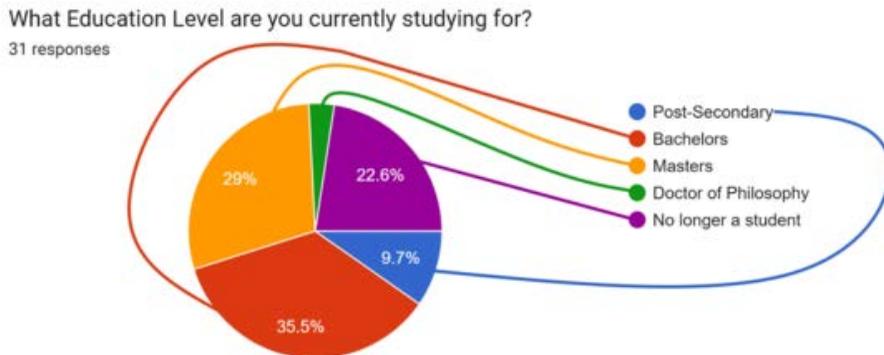


Figure 5. Frequency of VR usage among participants

How frequently do you use virtual reality (VR) experiences?  
31 responses

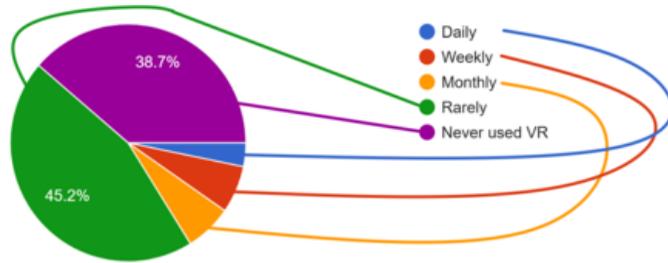


Figure 6. Types of VR applications experienced

Which types of VR applications have you experienced? (Select all that apply.)  
31 responses

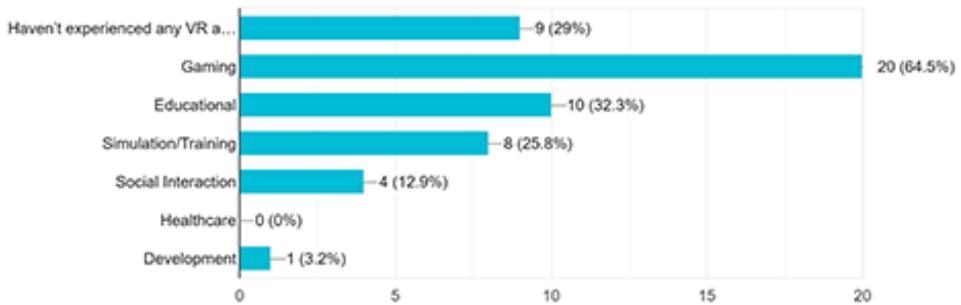


Figure 7. Familiarity with AI use in VR

How familiar are you with how AI is used in VR?  
31 responses

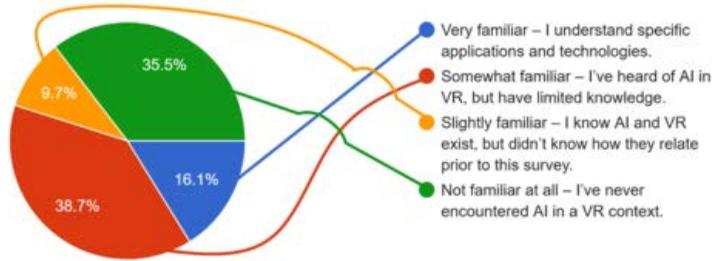
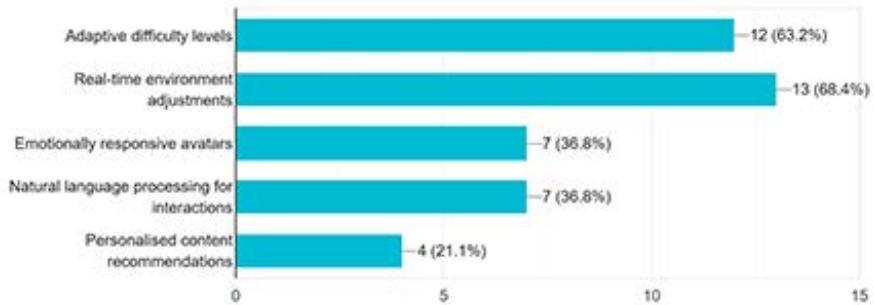


Figure 8. Most valued AI features in VR (multiple selection)

Which AI-driven features do you find most valuable in VR? (Select up to three)  
19 responses



## Perceptions of AI in VR

Figure 9. Agreement with the statement: “AI enhances the realism of VR experiences”

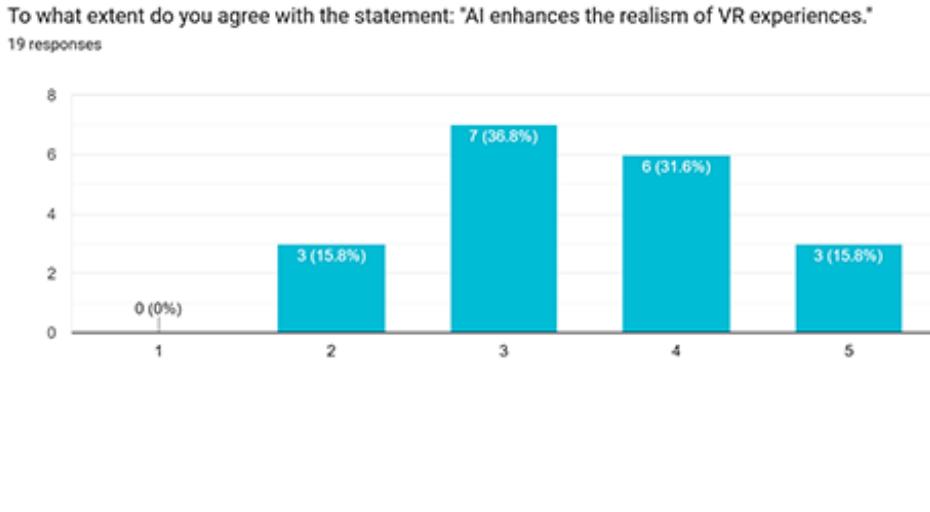


Figure 10. Experience with AI-driven characters or systems in VR

Have you ever interacted with an AI-driven character or system in VR?

19 responses

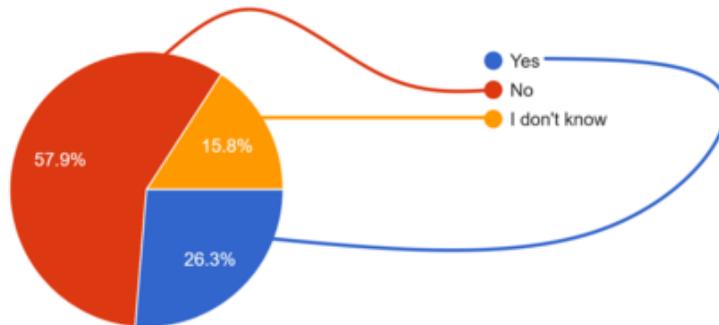


Figure 11. Importance of real-time physical behaviour adaptation

How important is it for a VR system to adapt to your physical movements and behaviours in real-time? (Skip if not applicable)  
17 responses

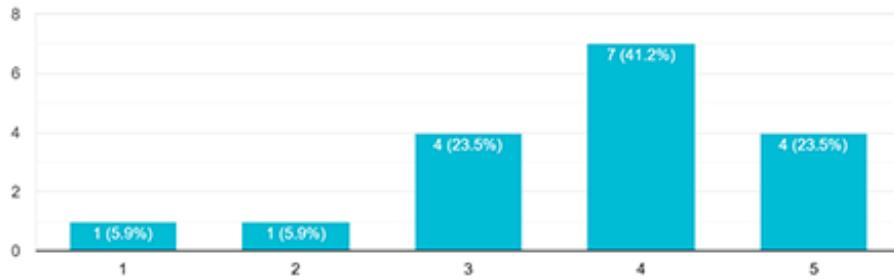


Figure 12. Preferred context-aware adaptations in VR (multiple selection)

Which types of context-aware adaptations do you prefer in VR experiences? (Select all that apply) (Skip if not applicable)  
17 responses

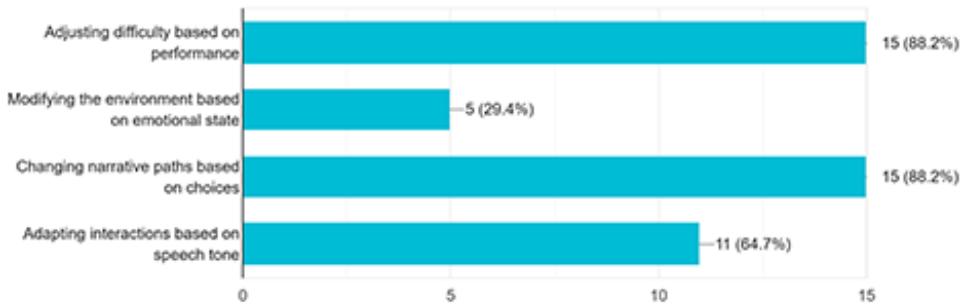


Figure 13. Preference for automatic vs. user-controlled AI adaptations

Would you prefer AI adaptations in VR to be automatic or user-controlled?

19 responses

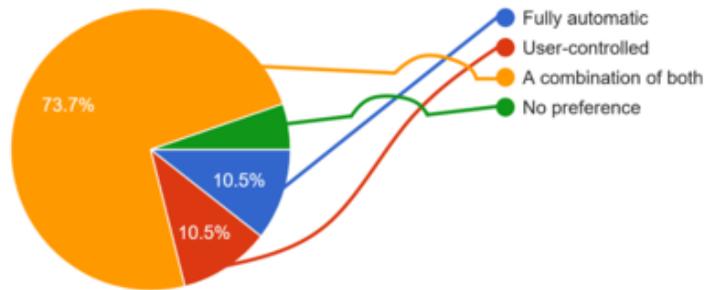


Figure 14. Overall satisfaction with AI-driven VR features

Rate your overall satisfaction with AI-driven features in VR experiences you've encountered. (Skip if not applicable)

9 responses

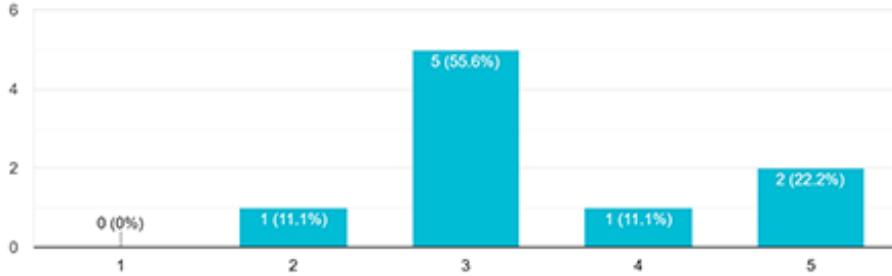
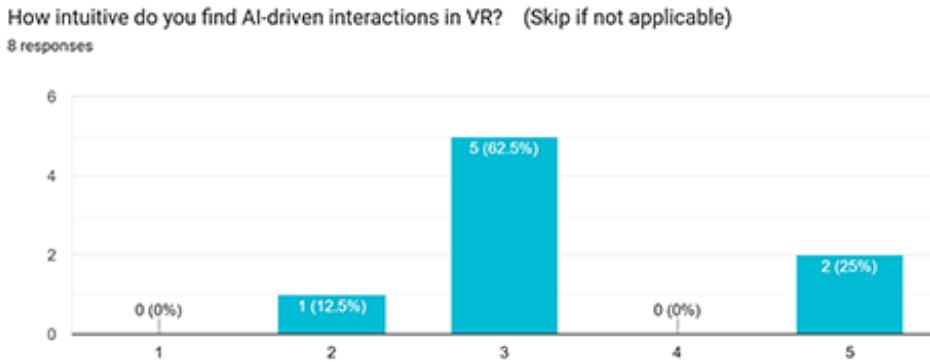


Figure 15. Intuitiveness of AI-driven interactions in VR



## Ethical Considerations and Data Privacy

Figure 16. Awareness of ethical implications of AI in VR

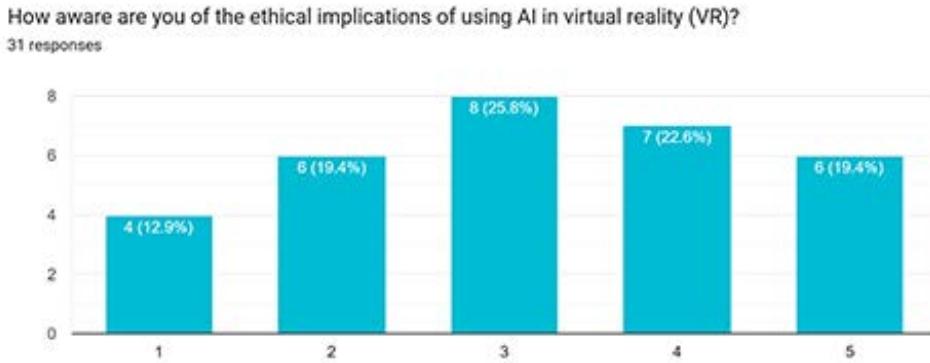


Figure 17. Ethical concerns associated with AI in VR (multiple selection)

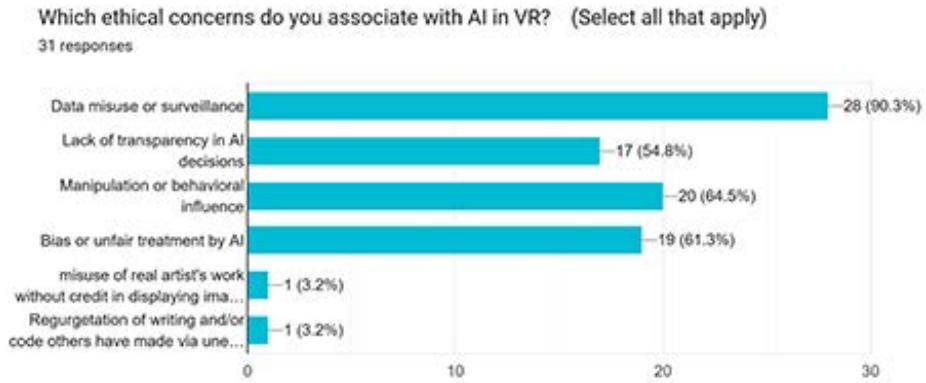


Figure 18. Discomfort experienced due to AI in VR

Have you experienced discomfort due to AI in VR?

31 responses

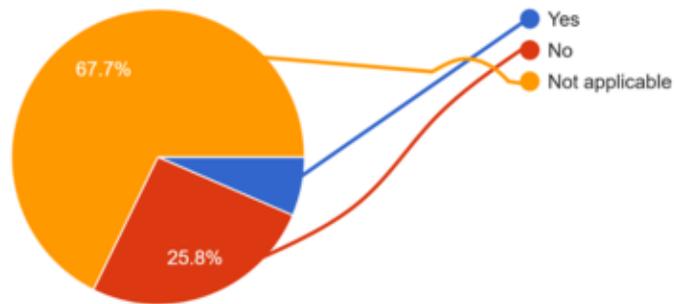


Figure 19. Technical issues encountered with AI in VR

Have you encountered technical issues due to AI in VR?

31 responses

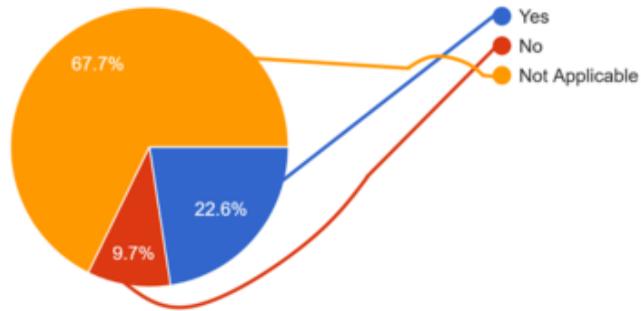


Figure 20. Comfort with behavioural data collection for personalisation

Would you be comfortable with AI systems in VR collecting data on your behaviour to enhance experiences?

31 responses

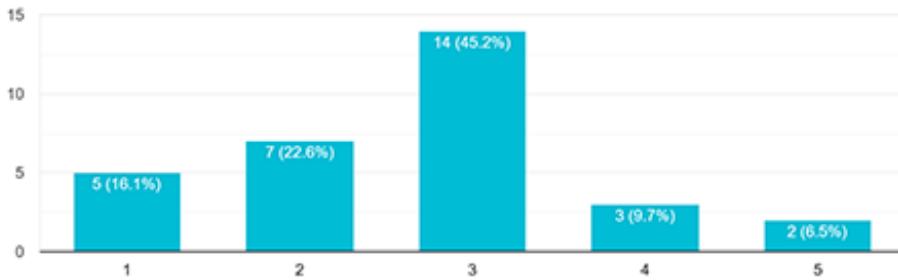


Figure 21. Support for rules governing AI data collection and usage in VR

Should there be rules on how AI in VR collects and uses personal data?  
31 responses

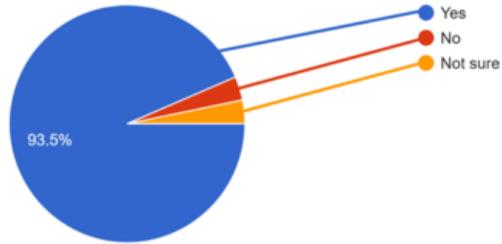


Figure 22. Likelihood of recommending AI-enhanced VR experiences to others

How likely are you to recommend AI-enhanced VR experiences to others?  
23 responses

