Multimodal Analytics in Virtual Reality

Handbook of Learning in Virtual Reality

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Introduction

Recent empirical work in immersive virtual reality (VR) has been bolstered by the use of multimodal technologies, ranging from auditory (Serafin et al., 2018) and haptic tools (Wang et al., 2019), to advanced psychophysiological tools that track nuanced aspects of user experience (Pugnetti et al., 2001). As immersive VR becomes more widely used in educational contexts with significant effects on learner engagement (Allcoat & Mühlenen, 2018; Hamilton et al., 2021; Hu-Au & Lee, 2017), it will be critical for teachers, researchers, and policymakers to understand how these technologies might meaningfully enhance the efficacy of learning experiences. The unique capabilities that multimodal VR learning experiences are often coupled with (e.g., haptics, spatialized sound, motion tracking) could be highly effective tools that increase the long-term impact of immersive educational experiences.

Firstly, it is important to define the term "multimodal" in the context of educational experiences, which refers to a combination of different methods, tools, or representations that produce a more dynamic form of teaching or learning compared to traditional methods (Philippe et al., 2020). For the current review, we adopt a broad understanding of the term and conceptualize "multimodality" as encompassing three key components that distinguish it from traditional "unimodal" formats. First, there are foundational tracking and display processes that enable VR to function effectively— tracking, rendering, and display technologies collectively provide users with a seamless experience that responds dynamically to movement, creating an interactive immersive environment that changes in real-time (Blascovich & Bailenson, 2011). Second, tracking can also serve social and communicative functions within VR by capturing and displaying a user's behavior in the form of an avatar (e.g., blinking, mouth movements), which can enhance the fidelity of interpersonal interactions. In some systems, more complex physiological signals, like heart rate, can be rendered into the scene to offer cues to others about the user's psychological state (Janssen et al., 2010; Li et al., 2021). Finally, from a data analytics standpoint, tracking data can be analyzed to infer mental states, such as cognitive load, that are not directly measured by the system but provide valuable insights into user experience (Siegel et al., 2021). This adds a powerful layer of interpretation to VR applications by allowing for assessments of users' mental states based on indirect tracking signals.

In this chapter, we first delve into the nature of sensory perception and survey the current evidence for how multisensory input influences the efficacy of VR applications in educational contexts, including haptics, scent, and auditory cues. These features can enhance the educational experience by increasing immersion, presence, or embodiment– distinctive qualities of virtual environments that differentiate them from non-immersive experiences (Kilteni et al., 2012; Lombard & Ditton, 1997; Slater & Wilbur, 1997). Next, we explore dynamic signals originating from the user, which could range from hand and head motion tracking, to psychophysiological signals (e.g., eye tracking, pupillary dilation, heart rate) that provide insight into the user's mental state. We also delve into how incorporating these diverse data streams may allow educators to create adaptive learning experiences that enhance learner engagement by providing insight into the momentary and long-term efficacy of immersive learning experiences. After discussing two theoretical frameworks of particular relevance within this domain, we transition to a more applied level by discussing the practical implications of this work as well as current obstacles to the widespread adoption of these techniques. Lastly, we offer a roadmap for scholars aiming to integrate these tools into their work, and discuss promising avenues for future research.

Historical overview

Humans navigate the world solely through information provided by their five senses. In other words, sensory input is the brain's only source for making inferences about the environment. Given this, it is no surprise that decades of research have focused on the nature of sensory perception, starting from sensory input and culminating in motor output, as evidenced by real-world behavior (Granit, 1955). But what is the true essence of perception, and how do the limitations of our senses similarly constrain our experiences?

An age-old allegory depicted by Plato is useful to mention here as it sets the stage for exploring multimodal (and multisensory) experiences. The Cave Allegory (Plato, The Republic) describes a group of people who are chained in a deep cave. They have never seen the outside world; only the cave wall is visible to them. There is a large fire behind them and as various figures pass near the fire, flickering shadows are cast on the cave wall. Without input from any of their other senses, these shadows are the only reality the people know, leading them to create intricate narratives about the shadows. Overall, this allegory serves as an interesting thought experiment on how our sensory perceptions shape our understanding (or interpretation, to be more accurate) of the world. It also serves as a metaphor for the limitations of our senses and the inherently fallible nature of perception, as humans rely on the sensory information available to us to construct our sense of reality in a given moment.

Interestingly, elements of this philosophy resonate across diverse fields, including the constructionist approach found in contemporary affective science. This viewpoint suggests that emotions are emergent phenomena created in our minds, shaped by sensory input, bodily sensations, and past experiences, rather than pre-set templates in the brain that activate as required (Barrett, 2016). Depending upon the complexity of the sensory information our brains receive, the specificity of our prediction is also likely to increase. Similar ideas are also apparent in the writings of Maurice Merleau-Ponty, a 20th-century French philosopher, who believed that the physical body is central to the self, and that the experiential quality of life is innately tied to our senses; in other words, the perceiving body and the world it perceives cannot be disentangled (Merleau-Ponty, 2011).

Building on this idea of the inseparable connection between the perceiver and the perceived, we now turn to how these principles apply in practical settings like virtual environments. The earliest multisensory VR experience was Morton Heilig's Sensorama, which combined stereoscopic vision, familiar odors, fans (for wind), a moving chair, and binaural auditory cues (i.e., stereo sound) to simulate a motorcycle ride through the streets of New York City (Heilig, 1962). Fast forwarding over the decades, modern VR technology has become much more advanced and can now integrate highly complex multisensory input, effectively blurring the line between reality and illusion.

How prevalent are multisensory applications in modern immersive VR (beyond the baseline of audiovisual input), and do they offer substantial benefits? A recent review found that 84.8 percent of multisensory VR studies (i.e., involving haptic, gustatory, and olfactory cues) showed a positive impact of these new tools, and haptics involving manipulating the sense of touch was found to be the most commonly used approach, at 86.6 percent (Melo et al., 2022). Specifically in the domain of VR educational environments, a ten-year review (from 1999 to 2009) highlighted several studies that utilized multisensory cues to support the development of students' mental models, leading to improved conceptual learning (Mikropoulos & Natsis, 2011). We now examine distinct types of multisensory input (haptic/kinesthetic/tactile, auditory, olfactory, and gustatory cues) in the context of immersive educational contexts.

Sensory perception and multimodal signals

Haptic cues

The mechanoreceptors in our skin are sensitive to a range of sensory input, including force, pressure, texture, heat, etc. Of the different types of multisensory tools, haptics (i.e., involving tactile cues such as force, vibration, etc.) has been the most widely investigated over the decades, spanning diverse fields such as robotics, neuroscience, and biomechanics (Burdea et al., 1996; Okamura et al., 2001; Srinivasan & Basdogan, 1997; Wang et al., 2019). Haptic rendering enables users to perceive and interact with virtual, real, or remote objects using a combination of human and machine interactions (Salisbury et al., 1995, 2004). Haptic tools have primarily been utilized in educational contexts requiring precise motor skills such as aeronautic training (Abate et al., 2009), dentistry (Imran et al., 2021; Serrano et al., 2023), nursing (Butt et al., 2018; Jung et al., 2012), and surgery (Lemole et al., 2007).

Wearable haptic devices have also been applied to diverse immersive contexts (Frisoli & Leonardis, 2024). However, haptic technology has shifted from specialized external devices (e.g., force-feedback tools and haptic gloves) towards handheld controllers with vibration. This is because controllers with integrated haptic feedback, like the HTC Vive and Meta Quest systems, are widely accessible and provide sufficient tactile feedback for most VR applications. As a result, handheld controllers have become the standard for delivering haptic cues in VR, leading to more complex haptic devices falling out of favor in recent years.

Wearable haptic feedback has also been used to teach more conceptual knowledge. In a chemistry lesson context, students were provided with haptic feedback via gloves equipped with haptic sensors, with the goal of learning how hydrocarbon molecules are constructed. Both quantitative and qualitative assessments showed that this approach was effective for both teaching and learning organic chemistry (Edwards et al., 2019). Integrating haptics with immersive VR was also shown to be effective for supporting collaborative learning of cell biology (Webb et al., 2022). Some approaches have combined haptic feedback with olfactory input, though their utility remains to be seen (Richard et al., 2006). Further empirical work is needed in this domain, as some studies have suggested minimal benefits or offered no clear consensus about the advantage of incorporating haptics into virtual learning environments (Thompson et al., 2011; van der Meijden & Schijven, 2009).

Auditory cues

One of the benefits of VR is that it allows spatialized, stereo or binaural sound (i.e., sound originating from two separate channels to both ears), which has been shown to increase feelings of presence as well as the intensity of emotional reactions (Hendrix & Barfield, 1995; Västfjäll, 2003). Scholars have also incorporated auditory feedback and spatialized sound into immersive learning experiences with the goal of improving educational outcomes. Prior work has shown that auditory cues in VR improve learning of music genre characterization (Innocenti et al., 2019), ear training for musical note recognition (Fletcher et al., 2019), and increased learning and feelings of presence for museum attendees (Kaplan-Rakowski et al., 2024). Recent research on blindfolded sighted individuals has also suggested that auditory information from spatial sound cues are critical for supporting spatial navigation and learning (Fialho et al., 2023). Similarly, other work has shown that virtual sound localization accuracy improves with short-term training in VR (Steadman et al., 2019). Overall, a review of the use of auditory cues in VR suggested that most studies fell within the domains of entertainment, gaming, and soundscape research, with mixed evidence on how auditory cues affect feelings of presence (Bosman et al., 2024).

Olfactory and gustatory cues

Both olfactory and gustatory cues are underexplored in the VR learning literature, presenting a promising opportunity for future research (Melo et al., 2022; Richard et al., 2006). A seminal review on olfaction in VR explored the psychological effects of incorporating odors into virtual experiences, with some interesting olfactory parallels to visual features, including the "field of smell" (Barfield & Danas, 1996). VR with olfactory input was shown to enhance creativity in an educational setting but did not improve subsequent recall of video content (Andonova et al., 2023). Other work has used olfactory cues for students learning about organic molecules (Tijou et al., 2006). Prior research has also demonstrated that sensory stimulation (haptic and olfactory cues separately, but not together) increased satiation (Li & Bailenson, 2018). Some scholars have attempted to incorporate gustatory cues into virtual experiences or pair olfactory and gustatory cues together (Cornelio et al., 2022; Harley et al., 2018; Kerruish, 2019; Narumi et al., 2011; Ranasinghe et al., 2013), though to our knowledge, none exist yet specifically within the context of education. However, technical challenges remain an obstacle to the widespread adoption of olfactory and gustatory cues in VR (Garcia-Ruiz et al., 2008).

While research on multisensory VR input has revealed how incorporating input from various senses may enhance the quality of learning experiences, it is also crucial to understand the underlying physiological responses and corresponding multimodal outputs. To examine this, we now turn to the array of multimodal tools available to researchers for gaining insights into psychological processes.

Psychophysiology and other multimodal data streams

Researchers use both implicit and explicit evaluation methods to probe whether the stimuli presented in virtual scenes are having the intended psychological effect, such as eliciting emotions or capturing attention (Marín-Morales et al., 2020). Explicit methods include survey methods, like interviews and questionnaires, and require individuals to report their subjective responses (Halbig & Latoschik, 2021). On the other hand, indirect methods like psychophysiological measures track users' psychological state while eliminating the need for self-reported accounts and therefore, are not subject to demand characteristics and social desirability bias (Grimm, 2010; Moon & Lee, 2017). Given that these metrics are reliable, they may provide valuable insight into a user's psychological responses to a virtual environment that would not be able to be captured by self-report. Here, we provide an overview of the most commonly used psychophysiological tools, which range from commonly used measures like motion tracking, eye-tracking, pupillometry, and heart rate, to less widely used signals such as skin conductance.

Motion tracking, encompassing both head and body movements, has been used in a number of virtual educational contexts to track the dynamics of nonverbal behavior in collaborative settings (Miller et al., 2021; Smith & Neff, 2018; Wang, Miller, et al., 2024). A seminal study on proxemics (i.e., interpersonal distance) found that subjects kept a greater distance from virtual humans when approaching from the front compared to the back, and that they also allowed more personal space for virtual agents who made direct eye contact (Bailenson et al., 2003). There has also been evidence for significant gender differences in proxemics in virtual environments (Bailenson et al., 2001).

Interpersonal distance and synchrony have also been shown to be important metrics for understanding learner behavior in large-scale immersive educational contexts (DeVeaux et al., 2024; Han et al., 2023). Analyses of the same large-scale longitudinal classroom dataset found that the listener's and previous speaker's head pitch, head y-axis position, and left-hand y-axis position influenced predictions of individual verbal behaviors, which could have interesting implications for developing personalized and adaptive learning experiences (Wang, Han, et al., 2024). Motion tracking estimates have also been used to display an avatar to the user in third person, which has been shown to improve learning of physical movements (Bailenson et al., 2008). Within the domain of sustainability, a recent study showed that virtual climate change education was more effective as the amount of body movement and specificity of the message increased (Queiroz et al., 2023).

Eye tracking data has numerous components that shed light on a user's internal state related to attention, effort, and cognition. These metrics include pupillary dilation, gaze duration, and blink rates. Gaze behavior (sometimes as a proxy of head position) has been a metric of interest for studies of social perception, distraction, and the quality of student-teacher interactions in virtual educational contexts (Bailenson et al., 2002, 2008; Beall et al., 2003; Harris et al., 2021; Hasenbein et al., 2022; Rahman et al., 2020). A foundational study incorporating gaze behavior in educational VR contexts found that providing teachers with visual warnings (about students who were not receiving enough teacher eye gaze) was effective in improving the quality of the educational experience (Bailenson et al., 2008). Augmented gaze (i.e., a transformation in which another user's gaze is directed simultaneously at multiple users, but perceived as only directed at oneself) has also been used to study persuasion and memory recall in VR (Bailenson et al., 2005).

Related to eye-tracking, another physiological metric that can provide insight into an individual's psychological state is pupillometry, which involves tracking the size of the pupil and how it changes upon exposure to a stimulus. In addition to responding to changes in light and near fixation, pupillary dilation has also been shown to be modulated by changes in cognition (Mathot, 2018). A large body of literature has been demonstrated that pupillary dilation is a reliable index of attention (Wierda et al., 2012), emotional arousal (Bradley et al., 2008) and can also be used to measure cognitive load in a range of scenarios, including educational contexts (Abdurrahman et al., 2021; Eckert et al., 2021; Lee et al., 2024; Mitre-Hernandez et al., 2021; Souchet et al., 2022). It has also been used to evaluate reading comprehension and memory recall in virtual learning experiences (Orlosky et al., 2019; Sakamoto et al., 2020).

Scholars have also explored the use of heart rate and heart variability measures, which can be tracked in VR either using standalone wearable devices (e.g., Firstbeat, as used in Vesisenaho et al., 2019), or photoplethysmography (PPG) sensors that use optical tools to track pulse as a proxy for heart rate (e.g., the HP Reverb G2 Omnicept headset). Prior work has found that incorporating heart rate measures with mental workload was valuable in evaluating the effectiveness of VR applications in the context of medical education (Hsin et al., 2023). Other research has used heart rate measures to track sensitivity to stress in performing musicians (Orman, 2003). A particularly promising domain for future work is virtual biofeedback, which would involve real-time display of a user's heart rate or other physiological measure, with the goal of allowing the user to learn how to modulate their physiological responses to decrease stress and maintain the balance of the autonomic nervous system (Chen et al., 2017; Gradl et al., 2018; Rockstroh et al., 2019). Studies on heart rate rendering have shown that rendering a sound of a heartbeat to an avatar can increase feelings of social presence, social connectedness, empathy, and perceived other-arousal, suggesting that psychophysiological cues are impactful tools for affective signaling (Janssen et al., 2010; Li et al., 2021).

Other psychophysiological tools could also be useful for evaluating the efficacy of immersive educational experiences by tracking more complex neural signals. Recent work has shown that in comparison to a traditional desktop lesson, viewing a biology lesson in immersive

VR induced greater emotional arousal, cognitive load, and less engagement as measured by EEG, though there were no significant group differences in heart rate or skin conductance (Parong & Mayer, 2021). Other EEG research has suggested that learning in VR required higher cognitive engagement, though subjects performed better on a knowledge test afterwards (Baceviciute et al., 2022). Functional magnetic resonance imaging (FMRI) has also been used in conjunction with VR to track changes in blood flow to different regions of the brain and study the neural underpinnings of spatial navigation, visuospatial processing, and reward-based spatial learning (Marsh et al., 2010; Pine et al., 2002; Wong et al., 2014), though some concerns have emerged about the ecological validity of studying such behavior in the absence of actual locomotion or motor output (Taube et al., 2013).

A key challenge in integrating neuroimaging techniques into VR research is that the hardware must be MRI-compatible, without electromagnetic components that could disrupt the scanner setup or compromise data quality. However, using FMRI provides significant advantages, offering excellent spatial and temporal resolution that enables accurate localization of neural regions recruited during psychological tasks. FMRI research has suggested that integrating spatial auditory cues into visual training in VR increased changes in brain activity related to multisensory integration, leading to improved performance on a visuomotor learning task (Alwashmi et al., 2024). Some scholars have even created fMRI-compatible haptic gloves for administering tactile vibration cues during VR experiments (Ku et al., 2003).

There are also a number of psychophysiological tools that have been widely used in cognitive science and psychology, but have yet to be integrated into virtual contexts. For instance, skin conductance, or galvanic skin response (GSR) is one of the oldest tools used to track attention, stress and arousal in response to a diverse range of stimuli, including auditory and visual cues (McCleary, 1950; Montagu & Coles, 1966). Prior research has combined pupillometry and skin conductance measures to track and manipulate autonomic activity as a result of virtual experiences (Juvrud et al., 2018). However, it has only rarely been used in the context of immersive learning experiences, though some studies have suggested that it can be used to create adaptive learning systems in VR (Hardy et al., 2013).

One important consideration in the context of these multimodal technologies is whether they also help to shed light on how immersive learning experiences could have unintended consequences in some contexts (Makransky et al., 2019; Parong & Mayer, 2021), such as worsening learning outcomes or inducing feelings of distraction and higher cognitive load. A review of the literature suggested that VR was most effective for education in the following domains: cognitive skills, including spatial memory, psychomotor skills, such as visual scanning, and affective skills, focused on emotion regulation (Jensen & Konradsen, 2018). However, VR did not confer any advantages outside of these contexts (i.e., less immersive technologies or traditional instruction) and sometimes was even counterproductive due to simulator sickness, technical difficulties, or an increase in distraction. Together, these results suggest that VR-based multisensory training is a promising approach for improving cognitive function, and further investigation will be required to empirically determine their efficacy in diverse learning contexts.

Theoretical frameworks

A range of theoretical models have also sought to offer new perspectives for understanding learning in virtual contexts. Mayer's Cognitive Theory of Multimedia Learning (CTML) is founded on three key principles drawn from cognitive science, and provides a theoretically grounded foundation for how to deploy multisensory immersive learning experiences. The three elements are as follows: (1) humans process information through two separate channels for visual and auditory inputs, (2) these channels have finite processing capacities, and (3) effective learning requires the integration of various cognitive processes (Mayer, 2005). The CTML emphasizes the importance of designing learning materials (i.e., multimedia content) that are intentionally crafted to effectively manage the cognitive load that learners encounter during the educational experience. This framework may provide valuable guidance when creating immersive learning experiences that incorporate multisensory information, with the goal of reducing the existing elements to only the most critical, while foregoing those that are likely to add unnecessary cognitive load.

Makransky's Cognitive Affective Model of Immersive Learning (CAMIL) is also particularly relevant in the context of multimodal analytics in virtual learning experiences, as it categorizes cognitive and affective features that play a role in immersive learning. As psychophysiological tools can be used to shed light on both affective and cognitive aspects of learning, the CAMIL may help to delineate which measures would be most useful for assessing the efficacy of different elements of the learning process.

Specifically, the CAMIL proposes that the insights gleaned from non-immersive learning methods do, in some cases, generalize to immersive contexts. Makransky and Petersen (2021) argue that "media interacts with method" and that particular learning techniques will be more or less effective in immersive VR depending on a range of factors. Further, the model holds that the general psychological affordances presented by VR are presence, or the feeling of being physically there (IJsselsteijn & Riva, 2003), and agency, or the feeling of being able to generate and control actions (Moore & Fletcher, 2012). As such, the model details how these two affordances impact six cognitive and affective factors that give rise to VR-based learning outcomes: interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation.

Lastly, the CAMIL makes specific predictions about how these associations contribute to different learning outcomes.

Moving forward, the CAMIL may be a useful tool to apply to a greater array of immersive learning contexts, especially as it seems to be one of the few frameworks that take affective attributes into consideration. A large body of psychological research has shown that affective factors play a critical role in educational contexts (which should also generalize to virtual contexts), specifically through the effects of constructs such as intrinsic motivation (Cordova & Lepper, 1996) and flow states (Csikszentmihalyi, 1975). The CAMIL also offers opportunities for future research related to immersive learning. For instance, research has yet to reveal which environmental or contextual factors dictate whether cognition or affect plays a larger role in learning experiences. Does the affective quality of content being learned have a direct impact on which psychological factors would most robustly promote learner engagement and retention? Accordingly, how might this knowledge enable educators to create virtual educational experiences that improve long-term learning outcomes?

Practical implications

Cooper and Thong (2018) identified four key elements that make VR a valuable educational tool: (1) *Experiencing*, which refers to students' ability to respond both physically and emotionally to various stimuli; (2) *Engagement*, as the immersive, multisensory nature of VR can boost student engagement; (3) *Equitability*, addressing how VR can accommodate both similarities and differences in school settings; and (4) *Everywhere*, which highlights the potential of VR to transcend traditional boundaries of location, time, and the learning process. These four elements may prove useful in categorizing the benefits offered by immersive learning tools. Are particular combinations more feasible to target over others, and if so, how might we evaluate them empirically in the field? Regardless, some significant barriers remain in the way of widespread adoption of multimodal and multisensory VR education, including the high cost of devices equipped with these capabilities and the lack of support during hands-on learning (Sanfilippo et al., 2022).

We now highlight two key practical implications that emerge from our review of empirical work in the domain of multimodal analytics in VR. First, this domain of research would benefit from the implementation of more systematic and well-controlled approaches to studying psychophysiology in VR. The complexity and dynamic nature of virtual environments pose a challenge for researchers aiming to achieve a functionally and temporally precise understanding of which elements of the scene give rise to psychophysiological changes (Sterna et al., 2021). As such, we would advise a pared-down approach that involves altering incremental aspects of the virtual scene (while keeping others constant), which would more effectively allow researchers to identify the specific features that are most likely to be influencing sensory measures.

Secondly, the literature currently lacks a database of virtual stimuli organized by the psychophysiological measures they have been reliably shown to elicit. Similar to the International Affective Picture System, or IAPS (Lang & Bradley, 2007) or databases for emotionally evocative videos (Koelstra et al., 2012), a pretested compilation of virtual stimuli that robustly influence psychophysiological responses would be a tremendous resource to the field. Just as the IAPS has become a key resource in affective science and cognitive psychology, we believe that a similar database would establish a standardized approach for eliciting and probing psychophysiological responses to affectively salient virtual stimuli.

Future directions

The current chapter provided an overview of empirical work on immersive learning experiences that leveraged multimodal tools to gain a deeper understanding of teacher and learner experience. This work included a wide array of methodologies, including spatialized sound, haptics, and psychophysiology. Taken together, the literature illustrates that harnessing these tools can enhance the efficacy of immersive learning experiences by offering insight into the users' experience beyond what is possible with conventional self-reported techniques. The use of multimodal tools could help to build personalized learning experiences that analyze users' gestures, eye gaze, and physiological cues with the aim of customizing learning experiences to enhance the learning experience. In a similar vein, multimodal tools may also make it possible for educators to receive real-time feedback based on learner's engagement and responsiveness and adapt their teaching strategy to better suit the needs of the learner. This may also have implications for identifying barriers for students with disabilities and optimizing course content and style to create more inclusive learning experiences. Extending beyond student experiences, VR could also be leveraged to improve teacher education (Billingsley et al., 2019).

Based on our literature review, we identify three key opportunities for future research in this area: (1) Adaptive learning systems for personalized learning during pedagogy (including predictive analytics for early identification of students who may require more support); (2) Data integration across multiple modalities to achieve a more holistic understanding of learner experience; and (3) Longitudinal or large-scale studies that evaluate the effects of long-term VR use in educational contexts. As education is a relatively new domain in which multimodal immersive technologies are being deployed, it likely has the potential for rapid growth in the coming years and could have an immediate impact on the efficacy of educational experiences.

Our review underscores the need for more empirical work that uses multimodal tools to shed light on how virtual technologies influence behavior, especially in the context of education and instructional design. As VR technology becomes more advanced, it will be important for researchers to test the reliability of these metrics in a longitudinal manner and evaluate their utility to the field. Creating scalable versions of immersive multimodal experiences (e.g., the Las Vegas Sphere) will likely increase their impact and provide new insights for research scholars, educators, and policymakers. Ultimately, in-depth exploration of the psychological effects of immersive technologies—not only VR, but also AR and MR (see Bailenson et al., 2024)—will be a crucial step toward their responsible use and hopefully ensure that they support psychological well-being.

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