Learning Across Realities

Virtual and Augmented Reality in Education

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Executive Summary

Extended Realities (XR) including Virtual Reality (VR) and Augmented Reality (AR) have the potential to transform learning. They can immerse learners in virtual worlds or bring virtual objects into their world. They have the power to create a sense of presence, of being there or an illusion of reality. Presence has the power to persuade, help overcome fears, transfer learning across environments, change how we see ourselves, help us think with our bodies, avoid hazards, think spatially, remap the world to human scale, feel together even when apart, and create joy. Media literacy is as important now as ever, to help us create, curate, and consume in ways that uplift.

To create presence, consider media forms (e.g. headsets), media content, and personal characteristics. The ideal media form is vivid and invisible, like an open window, or transformed, like a social robot, so we can focus on the experience, not the technology. It should coherently surround the senses, minimize distractions, and track our bodies responsively.

Media content should be designed for coherence, interactivity, embodied cognition, intuitiveness, and socialization. Meaningful environments with many possible actions and great body tracking, that are intuitive and social are great foundations for learning.

Experience of presence may vary across learners, so consider access and equity. People who are likely to feel more presence enjoy being immersed in decision-making, think spatially, are introverted, like getting involved in watching or reading, can build mental models, are empathetic, feeling, and sensitive, have a creative imagination, are younger, open to new experiences, and willing to suspend disbelief.

Presence and embodiment each strengthen each other. We have evolved to think with our bodies, so they are powerful tools for learning. Natural gestures reduce cognitive load, aiding focus on spatial thinking and memorization. Gestures also support conceptual understanding, like rearranging parts of an equation, creating centripetal motion, or walking the path of an asteroid.

Embodiment supports empathy, allowing us to walk in another’s shoes. Participants generally show more care and helping behaviors after embodied experiences as someone else, like abuse victims, the color blind, schizophrenics, dementia sufferers, children, and other races. We can also inhabit what we wish to become, like being a surgeon or sculptor holding a robotic pen that helps perform expert tasks with dexterity.

Schools using immersive learning should only choose experiences that replicate the classroom sparingly, if at all, and instead focus on surpassing the limitations of the classroom. Field trips can help, but often have less interactivity and embodiment. Labs can fit well, and slot in well with specific learning objectives, but can be dry and linear depending on design. Creation through project-based learning has significant potential. Flipped classrooms and station rotation can leverage class time for immersive learning. Let students be the experts.

Introduction

This report is for anyone who cares about learning and immersive media, but especially creators and curators. For educators, we'll show examples in educational contexts and recommendations for how to choose great experiences. For designers, we'll list principles and heuristics to build powerful interactions. For researchers, we'll summarize literature on critical concepts like presence, immersion, and embodiment. Both authors are educators, researchers, designers, and technologists, and we'll consider the potential of these emerging media from those perspectives.

For those of you not used to reading research papers, fear not. Though they're written for a specialist audience, we'll do our best to make their findings more broadly accessible. For the researchers, this report may still provide a valuable summary or starting point for your literature reviews, or help contextualize your work in adjacent fields. For the designers, hopefully we can save you from reinventing the wheel by quickly pointing toward high-leverage approaches and avoiding old pitfalls.

Let's start with some terms you've likely heard: VR, AR, MR, XR, immersive media, and spatial computing.

Virtual Reality

The Sensorama was arguably the first virtual reality machine, made in 1957 by Morton Heilig to engage multiple senses, followed shortly by his Telesphere Mask, patented in 1960.

Figure 1. Sensorama (left). studioargento.com/immersiva/images/sensorama.jpg
Figure 2. Telesphere Mask (right), credit: Marianne Heilig.
vrs.org.uk/wp-content/uploads/2015/12/telesphere-mask.jpg

Virtual Reality was coined in 1989 by Jaron Lanier, a product manufacturer (Krueger, 1991), so early definitions focused on hardware, "including computers, head-mounted displays, headphones, and motion-sensing gloves” (Steuer, 1992). The key was interacting with alternative worlds or simulated environments (Coates, 1992; Greenbaum, 1992).

VR can also be defined in terms of experience. “A virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence” (Rheingold, 1990; Steuer, 1992). Bavor (2016) agreed that “VR can take you anywhere.” More on presence in the next section. Bricken (1990) similarly focused on the mind when writing, “psychology is the physics of virtual reality.” Heim (1994) defined it as “an event or entity that is real in effect but not in fact.”

Even today, most people think first of the technology - VR means wearing a headset (head-mounted display or HMD) to go to a virtual world. But, the key to making and choosing great experiences, of building a medium, is the mind.

Augmented Reality

Baum (1901) wrote of augmented reality in a novel, describing electronic glasses that mapped data onto people. He called it a character marker. "While you wear them every one you meet will be marked upon the forehead with a letter indicating his or her character.”

In 1966, Ivan Sutherland created The Sword of Damocles, a hanging headset that could show virtual objects in a real environment with head tracking.

Figure 3. Ivan Sutherland and The Sword of Damocles.
Left, middle: learn.g2.com/hs-fs/hubfs/augmented-reality-history-1968.jpg
Right: youtube.com/watch?v=eVUgfUvP4uk

AR combines real and virtual, tracked together in space, with real-time interactions (Wu et al., 2013). AR adds virtual information to real life, whether sights, sounds, or other sensory stimuli. AR "can bring anything to you" (Bavor, 2016). You can use AR on a phone, like Pokemon Go, GPS navigation, or chat filters, with HMDs, like the Hololens, or with headphones.

Just as AR can add, it can also take away (Rosenberg, 1992), like hiding ads or ugly aspects of the environment. AR is built on reality, adding convenience, utility, or magic.

Mixed Reality

Mixed reality is an ambiguous term at the moment and we'll mostly avoid it in this report. Some say it's similar to AR, augmenting a real environment, but including a higher proportion of virtual to real than is typical of AR along with real-time interactions between real and virtual objects.

Milgram et al. (1994) used MR to mean the spectrum from a little virtual to mostly virtual (but not including VR). The entire range from fully real to fully virtual they called the "virtuality continuum." In their definition, MR would include AR as well as "augmented virtuality."

Microsoft references Milgram, but they've put aside "virtuality continuum" in favor of a "mixed reality spectrum" that's expanded to include VR (Bray 2020). They have also released VR headsets labeled MR. This usage seems less popular today, with more people using XR.

People have also begun to use "mixed reality capture" to mean showing a real person (not an avatar) surrounded by virtual objects or environments. So, you could take an MR capture of a VR experience.

XR

Extended reality is an umbrella term including VR, AR, and MR. There's some disagreement, because of course there is, about whether the X stands for "extended" or is a variable that can hold the values virtual, augmented, mixed, or anything else that comes along. Extended does seem more popular, though, probably because it's easier to say and explain.

Media forms made possible by XR technologies are generally called "immersive media." Technologies that use space as an input or output, like tracking devices and users in space or modeling space, fall under "spatial computing" (Greenwold, 2003).

Presence, Immersion, and Embodiment

As exciting as XR technologies are on their own, the real power comes from the experiences they enable. To understand those, we need to understand presence, immersion, and embodiment.

Presence and Immersion

We have always wanted to create and share experiences, through storytelling and conversation, through painting and music, through architecture and play, and in many more ways. Lee (2004) writes that "the ancient desire to overcome the limit of human sensory channels through the use of technological devices is the major impetus for the development of media and reality-simulation technologies (Biocca, Burgoon, Harms, & Stoner, 2001; Biocca, Kim, & Levy, 1995; Lombard & Ditton, 1997; Rheingold, 1991)." XR is our latest step on this journey, and it's magnificent.

Presence and immersion are the keys to understanding the power of these media. They have existed in other media for millenia, but XR unleashes them. Biocca (1997) writes, "most see the illusion of presence as a product of all media, and that virtual reality is the medium that at this point in time can generate the most compelling sense of presence (Biocca & Levy, 1995; Lombard & Ditton, 1997; Steuer, 1995)." Some have even defined VR in terms of presence: "A virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence" (Rheingold, 1990; Steuer, 1992). VR is a presence machine. As Arthur C. Clarke wrote, "any sufficiently advanced technology is indistinguishable from magic." XR feels like magic.

We'll unpack these words shortly, but to briefly orient you:

Presence

1. sense of being there (aka physical presence)
2. illusion of nonmediation
3. social presence: sense of being together

Immersion

1. surrounding the senses (aka perceptual immersion)
2. involvement, absorption, engagement (aka psychological immersion)

Together, presence and immersion have the power to fill our senses with whatever we can imagine, to "take you anywhere" and "bring anything to you" (Bavor, 2016). The power to "do away with hazardous and unpleasant tasks" and remap the world to human scale (Minsky, 1980). The power to think about spaces naturally (Azar, 1996; Biocca, 1997; Regain & Shebilske, 1992). The power to gather and feel together across great distances (Lanier & Biocca, 1992). The power to move in ordinary or extraordinary ways (Lombard, Reich, Grabe, Campanella, & Ditton, 1995). The power to create joy from having "entered another world" (Heeter, 1995). The power to overcome fears (Carlin et al., 1997; Hodges et al., 1996; Knox et al., 1993; Rothbaum et al., 1995). The power to persuade (Kim, 1996). The power to transfer learning across environments (Regenbrecht, 1998). The power to entertain (Lodge, 1999). The power to change how we see ourselves (Biocca & Rolland, 1998; Lee, 2000; Meyers & Biocca, 1992).

If the power of XR can uplift, it can also degrade (Steuer, 1992). These same powers could take us places we don't want to go, trigger our sensitivities, desensitize us to atrocities (Fenigstein & Heyduk, 1984; Zillmann & Bryant, 1982), crowd out mindfulness (Lang, 1992), distort our relationships, manipulate our behaviors (Kim, 1996), confuse our reality (Turkle, 1995), undermine our sense of self (Biocca & Rolland, 1998; Meyers & Biocca, 1992), and even make us sick (Alexander & Barrett, 1975; Azar, 1996; Biocca, 1992; Kennedy, Fowlkes, & Lilienthal, 1993; Kennedy, Lane, Berbaum, & Lilienthal, 1993; Parker 1964, 1971).

These powers bring with them the responsibilities to create with care, recommend with discernment, and experience with awareness. Media literacy is as important now as ever.

Defining Presence

As with many terms in research, defining a word "is an iterative process in which an initial conceptual definition is applied to operational procedures, closely evaluated throughout the research process and finally, modified to reflect the empirical reality" (Chaffee, 1991). We'll see that process unfold with presence.

The idea of presence among VR researchers grew out of controlling machines remotely. "The first crude remote-controlled mechanical hands were built around 1947 at Argonne National Laboratories, in Illinois, for handling dangerous chemicals" (Minsky, 1980). In 1979, Gibson wrote of the idea of presence as an experience of an environment built on perception rather than fact, mediated by automatic and controlled thoughts. Minsky elaborated:

> "I prefer to call this 'telepresence', a name suggested by my futurist friend Patrick Gunkel. Telepresence emphasizes the importance of high-quality sensory feedback and suggests future instruments that will feel and work so much like our own hands that we won't notice any significant difference." (Minsky, 1980)

He identified the "sense of 'being there'" as the "biggest challenge to developing telepresence" (Minsky, 1980).

The early 90s brought an explosion of attention to presence, mainly organized around a sense of being there in a mediated environment (Heeter, 1992; Held & Durlach, 1992; Reeves, 1991; Sheridan, 1992; Steuer, 1992). Even then, researchers differently emphasized the idea of being there compared to the illusion of reality. Slater (1993) described the sense of presence as "the (suspension of dis-) belief that they are in a world other than where their real bodies are located." The 90s were also a decade of moving away from "telepresence" meaning remotely accessing a real location and orienting around "presence" as an experience of either a real or virtual environment.

Not everyone was ready to limit presence only to the sense of being there, given research conducted in other fields "including communication, psychology, cognitive science, computer science, engineering, philosophy, and the arts" (Lombard & Ditton, 1997). They proposed a broader definition that could unite these disparate fields, “the perceptual illusion of nonmediation.” They described six presence metaphors, including “being there” in “presence as transportation.” Their other metaphors are social richness, realism, immersion, social actor within medium, and medium as social actor.

There are advantages and disadvantages of the narrower definition of “being there” and more inclusive definition of the “illusion of nonmediation,” and both definitions have survived and been built upon. After Lombard and Ditton (1997), researchers orienting around the narrower “being there” include Whitmer and Singer (1998), Lessiter (2001), Schubert (2001), Slater (2003), and Sas (2004). Researching building on “the illusion of nonmediation” include scholars of the Presence-L Listserv (2000), the International Society of Presence Research (2000), Lee (2004), and Thornson (2008). Apologies in advance to the many researchers left out.

Let’s keep both definitions in mind as we consider what the research has to tell us about presence:

1. sense of being there
2. illusion of nonmediation

Even researchers who chose the narrower definition of presence to build on thought something was missing, because they proposed various extensions. Heeter (1992) wrote of personal, social, and environmental presence. Biocca (1997) overlapped Heeter somewhat with physical, social, and self presence. Ijsselsteijn et al. (2000) consolidated these into physical and social presence, with physical presence aligning with the sense of being there, and social presence focused on being together. Social presence has sometimes been called copresence as well.

Updating our definitions, then, we have:

1. sense of being there (aka physical presence)
2. illusion of nonmediation
3. social presence: sense of being together

Defining Immersion

Dictionaries consider immersion a psychological state.

> Merriam-Webster: “absorbing involvement”
> Dictionary.com: “state of being deeply engaged or involved; absorption.”

Some researchers considered this too close to the idea of presence, and the two words are sometimes used interchangeably. Many have called for or offered clarification (Bente & Otto, 1996; McMahan, 2003; Slater & Usoh, 1993a, 1993b; Steuer, 1992). Lombard and Ditton (1997) embraced that overlap, counting “presence as immersion” as one of their six presence metaphors. Others, wanting to separate presence and immersion and wanting a word to describe the sensory inputs needed to support presence redefined immersion to mean surrounding the senses, especially with technology (Biocca & Delaney, 1995; Bowman & Raja, 2004; Kim, 1996; Regenbrecht 1998; Sheridan, 1992; Slater & Usoh, 1993a). To them, immersion is:

> a quality of the system's technology, an objective measure of the extent to which the system presents a vivid virtual environment while shutting out physical reality. (Slater & Wilbur, 1997)

The tension is whether to focus on immersion as a psychological state or as a technology. Others prioritized the psychological state (ISPR, 2000; McMahan, 2003; Murray, 1997; Thornson, 2008; Witmer & Singer, 1998):

> Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences. (Witmer & Singer, 1998)

They directly address their departure from the tech-only definition, "Though the VE [virtual environment] equipment configuration is instrumental in enabling immersion, we do not agree with Slater's view that immersion is an objective description of the VE technology (Slater, Linakis, Usoh, & Cooper, 1996). In our view, immersion, like involvement and presence, is something the individual experiences" (Whitmer & Singer, 1998).

To resolve this tension, some researchers have begun to use "perceptual immersion" to focus on technology and "psychological immersion" to focus on the user's experience. Then perceptual immersion is "the degree to which a virtual environment ment submerges the perceptual system of the user" (Biocca & Delaney, 1995) and psychological immersion is "the degree to which users of a virtual environment feel involved with, absorbed in, and engrossed by stimuli from the virtual environment" (Palmer, 1995).

As with presence, let's keep both definitions in mind as we consider what the research has to tell us about immersion:

1. surrounding the senses (aka perceptual immersion)
2. involvement, absorption, engagement (aka psychological immersion)

Creating Presence

There are many factors that contribute to feeling present, and several researchers have broken them down according to media form, media content, and personal characteristics.

Media Form

Media form can also be considered perceptual immersion. In XR, this includes hardware and software attributes that surround the senses. Steuer (1992) called this "vividness," referring to "the ability of a technology to produce a sensorially rich mediated environment." He emphasized engaging multiple senses coherently: "the redundancy resulting from simultaneous activation of a number of perceptual systems reduces the number of alternative situations that could induce such a combination of perceptions, and therefore strengthens the perception of a particular environment.” We’ll come back to coherence.

Sheridan (1992) wrote of the “extent of sensory information.” Lombard and Ditton (1997) described perceptual vividness and included “presence as realism” as one of their metaphors. Neuman (1990) showed that higher resolution displays evoke more self-reported presence. Higher field of view (FoV, viewing angle) increased the sense of being “part of the action” (Reeves, Detenber, & Steuer, 1993). Stereoscopic images, showing a different view to each eye to create a sense of perspective and depth, increased the sense of being “face-to-face” and “in the same room” (Muhlbach, Bocker, & Prussog, 1995). Close-up views increased a sense of realism (Hatada, Sakata, & Kusaka, 1980). Visual naturalness correlated with presence (IJsselsteijn et al., 1998).

Perceptual immersion plays two roles simultaneously: providing rich stimuli to create the sense that the virtual is real, and blocking out competing stimuli from the real world. Focusing more attention on the mediated environment and less on the nonmediated increases presence, aided by more sensory input from the mediated and less from the nonmediated (Bystrom et al., 1999; Kim & Biocca, 1997; Schubert et al., 2001; Whitmer & Singer, 1998).

There is some evidence that all senses are not equal. Christie (1974, as cited in Short et al., 1976) found visual media had more impact on creating social presence than audio, and text even less. This may be why the latest headsets first trumpet visual advances in resolution, field of view, and refresh rate.

Responsiveness, control, and interactivity may be even more important. XR systems that track more of the body, with a higher refresh rate are powerful presence machines. Heeter (1992) reported when forced to prioritize between “responsiveness to motion and resolution of images, developers are choosing responsiveness as the more important factor.” Likewise, Rheingold (1991) wrote, “very close coupling between my movements and the robot's movements was more important than high-resolution video or 3D audio.” Biocca and Delaney (1995) emphasized the number of user inputs to which the medium responds as being critical. Lombard and Ditton (1997) said, “the ideal interactive medium responds in ‘real time’ to user input; the response or lag time is not noticeable.”

In summary, if presence is your goal:

- Surround the senses coherently
- Minimize outside distractions
- Imagery > audio > text
- Responsiveness before resolution
- Track more of the body

Media Content

There are many design principles to consider when selecting or creating media content for presence. Lombard and Ditton (1997) wrote of rich social cues, realistic environments and social interactions, a there to go to, a thing to bring here, people to be together with, surrounding the senses, involving and engaging experience, characters within to interact with and a media form itself that has human qualities. Let's begin with coherence.

Coherent

Virtual environments that are coherent increase presence. This could be on the level of perceptual immersion, like visuals, sounds, and movements all reinforcing each other. It could describe a world free from artificial obstacles, like invisible walls. Heeter (1992) writes "the world must exist if you can go anywhere you want in it." Free from bugs like losing limb tracking or putting your head through an object. Coherence allows people to lose themselves in a world; incoherence reminds them it's all an illusion. As we saw in Media Form, Stueuer (1992) says the number and alignment of inputs "strengthens the perception of a particular environment." Held and Durlach (1992) say, "the information received through all channels should describe the same objective world." Hoffman et al. (1998) found chess players reported more presence when looking at meaningful arrangements compared to random ones. Coherence made it more understandable and real.

Interactive

Coherence connects to the other principles in this section, including interactivity and intuitiveness, because a coherent world allows users to predict what they can do. Several researchers found a connection to Csikszentmihalyi's 1982 theory of flow (Trevino & Webster, 1992; Webster et al., 1993), where a "merging of action and awareness" helps people focus on the present and block out distractions during activities they find rewarding and well matched to their abilities. That may be why Ijsselsteijn (2005) found interactivity to be a strong factor in presence. "Thus, 'being there' has been considered by some as related to the ability to 'do there'" (Thornson, 2008).

Sheridan (1992) talks about interactivity in terms of controlling sensors, like changing the view during head movement, and modifying the environment, like moving objects. Steuer (1992) doesn't distinguish types of interaction, but calls out speed (responsiveness), range (number of possible actions), and mapping (coherence and intuitiveness).

Heeter (1992) points out the potential for virtual worlds to be even more reactive than the real one, potentially increasing presence beyond what we feel every day. "When you walk into a room in the real world, it does not verbally or musically greet you or start raining. Virtual rooms might." There may be a race between Internet of Things / Smart Homes and virtual environments to create experiences with more and more presence.

Lessiter (2001) found interactivity helped create presence in low perceptually immersive environments:

> “Interestingly, although the computer-games console condition consisted of a relatively small field of view and was low in photorealism, respondents produced relatively high Sense of Physical Space ratings. This suggests that the ability to physically control and manipulate aspects of the displayed environment (even using unsophisticated control devices) enhances the sense of being physically located in that environment.”

Embodied

Embodiment and embodied cognition, overlaps with interactivity. Thornson (2008) defines embodied cognition as “a mental representation of bodily actions as possible actions inside a virtual world.” Schubert et al. (2001) connected embodied cognition to presence. We interact with virtual worlds with our bodies, and that helps us feel present. Regenbrecht (1998) wrote: “In comparison with other VEs, our participants had a lot of floor space to move around. This interaction by walking around, which was provoked by our procedure, seems to support a fast development and elaboration of the mental model of the space.”

In other words, thinking about the space with our bodies helped people learn it quickly. Larger spaces to move around will be one of the main constraints and opportunities in interacting with virtual worlds.

Bodies are not just for doing, but also for seeing. Bricken (1991) wrote that seeing your hands in a virtual world is “convincing evidence that you're There.”

Lombard and Ditton (1997) summarized a range of research on this topic:

> It is a ‘widely accepted working hypothesis’ that ‘using our familiar sensorimotor skills to manipulate virtual objects directly by means of whole-hand input devices ... contributes to our sense of presence much more than writing programs, twisting knobs, or pushing a mouse to accomplish the same task’ [(Zeltzer, 1992, p. 129; see also Bricken, 1996; Held & Durlach, 1992; Sheridan, 1992)].

We’ll examine embodiment more in another section.

Embodiment also reinforces the sense that you have a self. Goffman (1963) explored how people experience themselves in their everyday lives. Virtual selves are mediated or constructed by technology (Biocca 1997; Mantovani 1995). Lee (2004) describes self presence as a “mental model of himself/herself or simply the awareness of self-identity inside a virtual world.” Do we feel like ghosts in the virtual world, disembodied, floating, unable to affect anything, or do we feel like powerful actors, taking up space, moving with style, changing things through our decisions and actions? Do we feel like our real selves transported, or like someone new? The design possibilities are wide open.

Intuitive

Embodied interactions can be more natural and intuitive. Strapping computers to our faces and other parts of our bodies is still unfamiliar and uncomfortable for many people. They may be anxious about a whole host of things, but intuitive designs can help smooth that learning curve and reassure. Regenbrecht (1999) observed that visitors to their lab first have to learn how their actions affect the virtual environment. If we become highly experienced with this technology, we may forget what it's like not to know. That not knowing can create barriers to feeling present as well (Lombard & Ditton, 1997).

Consider how certain objects communicate how to interact with them. Levers and handles beg to be pulled, buttons pushed, knobs twisted, doors opened, handles grasped, shiny things held, cute animals petted. Starting with what people know gives them an entry point into a new world.

Social

If we do have an embodied self and are able to interact, we may want real or virtual others to meet. Biocca (1997) wrote of social presence as a simulation in our minds, because we can experience both real and artificial beings as social entities. Indeed, Nass and Moon (1996a) found that people saw computers labeled as teammates as more cooperative and providing better information. Short et al. (1976) saw social presence as a measure of how socially rich interaction a medium supported. Can people high five, make eye contact, hear each other's voices, see head and hands moving, and more? Lee (2004) defined social presence as experiencing virtual actors as real, reminiscent of presence as illusion of nonmediation.

In summary, if presence is your goal, your content should be:

- Coherent, meaningful, redundant across the senses
- Interactive, responsive, with many possible actions that impact the environment
- Visibly embodied, with more space to move and great tracking
- Intuitive, familiar, learnable, easy, natural
- Social across senses, socially interactive

Personal Characteristics

We all experience presence differently based on many factors like who we are, how we feel, and how we think. There's a lot left to research, but here's what we know so far.

Slater et al. (2004) found people who rely more on vision felt more present, and if the experience included a virtual body, people who rely more on kinesthetics felt more present. Age may be a factor, as 10-20 year olds felt more present than 35-45 year olds (Bangay & Preston, 1998). Spatial intelligence and introversion likewise correlated with presence (Jurnet, 2005). Test anxiety in an environment designed to evoke it correlated with presence, which may be due to personal relevance and emotional activation (Jurnet, 2005). Creative imagination and empathy also correlated with presence (Sas & O'Hare, 2003), as did an orientation toward feeling and sensitivity (Sas et al., 2004). Lee (2004) speculates on the role of imagination:

> Imagination and other information-processing mechanisms simulate the remaining sensory cues and create a compelling sense of reality. That might be the reason people

can sometimes feel a strong sense of presence based solely on cognitive stimuli for imagination (e.g., written narratives) without receiving any direct sensory stimuli.

Baños et al. (1999) found a tendency to become absorbed (psychologically immersed) correlated with presence, as did Witmer and Singer (1998).

Samuel Coleridge wrote of the “willing suspension of disbelief,” a concept Aristotle said of theater could create catharsis. Several researchers have considered this an important factor in presence. “Being open to new experiences might be related to one’s ability and willingness to suspend disbelief and imagine themselves as part of whatever virtual or augmented world in which designers of such environments wish to place them” (Thornson, 2008). Actively suspending disbelief may help people suppress conflicting stimuli and focus on virtual stimuli, which Witmer and Singer (1998) connected to presence.

Thornson (2008) found six personal factors supported presence, from strongest to weakest:

1. Cognitive Involvement (active) (immersion in decision-making and judgment)
2. Spatial Orientation
3. Introversion
4. Cognitive Involvement (passive) (focus on tasks like watching or reading)
5. Ability to Construct Mental Models
6. Empathy

Thornson found some differences by gender: “males reported higher levels of active Cognitive Involvement, Spatial Orientation, and the Ability to Construct Mental Models, while females report higher levels of passive Cognitive Involvement and Empathy.”

In summary, if presence is your goal, design for people who are:

- more oriented toward vision and kinesthetics
- younger
- creative, imaginative
- empathetic, feeling, and sensitive
- introverted
- spatial
- open to new experiences and willing to suspend disbelief
- focused decision-makers
- focused observers (watchers, readers)
- able to make mental models

Presence Powers

Presence has the power to transport, to do impossible and dangerous things, to think with our bodies and understand spaces intuitively, to transfer that spatial knowledge back to the real world, to connect us with each other, to change our minds through persuasion, overcoming fears, and seeing ourselves differently, to entertain and help us escape. Let’s take a closer look at these powers.

Transport

Many people have defined presence by its ability to transport. Bavor (2016) says “VR can take us anywhere” and “AR can bring anything to us.” Bricken (1991) wrote that three hundred participants in Autodesk’s cyberspace found the most interesting part of the experience, “being inside” the virtual environment. Anecdotally, playing Lone Echo created a feeling of having been to Saturn’s rings, an experience that created a lasting memory.

Figure 4. Lone Echo from Ready at Dawn.
medium.com/echo-games-blog/lone-echo-replacement-save-files-d7408da5b610

Visiting Saturn’s rings falls into the virtual field trip pattern, which is probably the way VR is most used in schools at the moment. The presence effect was strong, from a compelling environment, interactivity, embodiment, six degree tracking, social characters in an emotional narrative, which made that adventure seem all the more real. Compared to low-resolution 360-videos with three degree tracking and no interactivity that are all too common in schools, this trip to Saturn was a revelation.

For AR and MR, there are infinite objects we want to see up close, like the touchable Surfaces on the Hololens. Any learning experience benefiting from close examination and tactile probing would be a great fit.

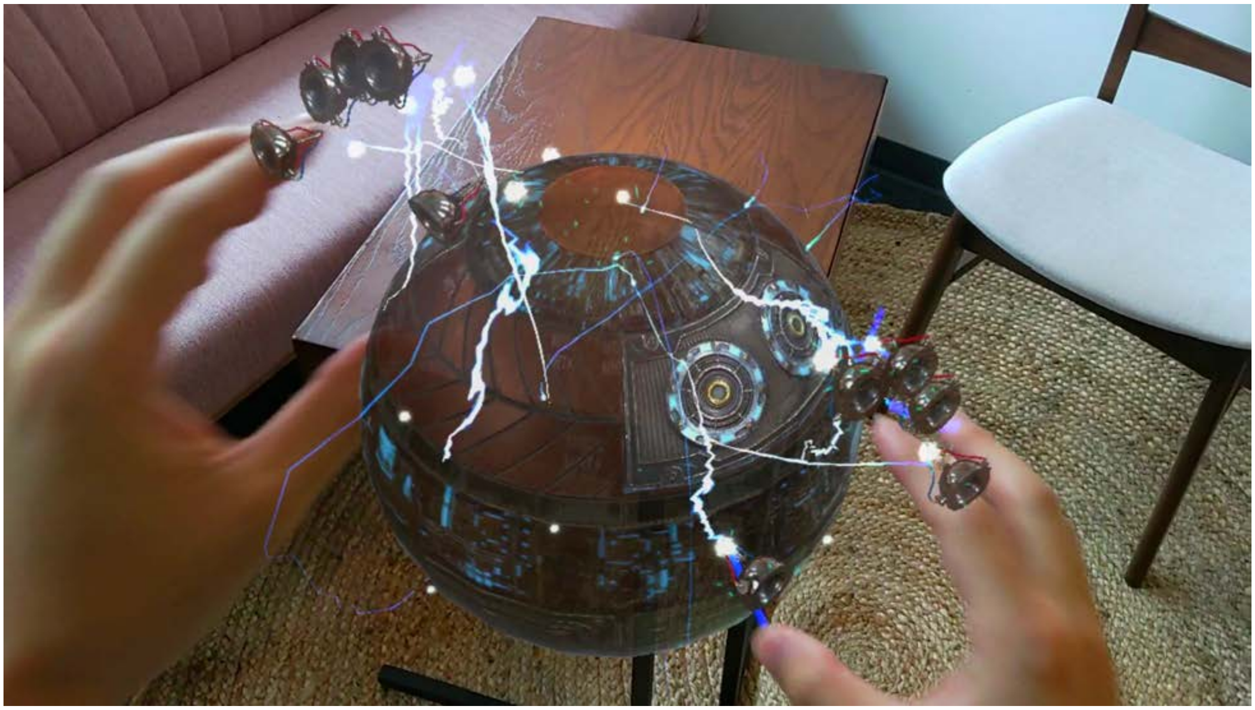

Figure 5. Surfaces from Microsoft. youtube.com/watch?v=mmlnoCV2Z7o

In another sense, transportation can mean moving people within a virtual world. This sense of actually moving through a virtual environment is called vection (Lombard et al., 1995). Vection can be thrilling or uncomfortable, depending on the design and the person. Avoiding it will be tempting for schools to increase accessibility, but much of the power of feeling present may be lost. Consider accessibility within a range of applications or roles, where some may be less accessible than others but there are compelling experiences for all. Also, consider changeable settings like smooth movement or teleportation to allow for exploration with or without vection.

The desire to escape is another reason to rely on presence to transport. Maybe the real environment is too distracting or overwhelming, and escape can offer focus or rest. VR creates a stronger form of escape, but AR also can block or simplify elements of the real world.

Avoid Danger

Minsky (1980) wrote of “telepresence” (e.g. remote controlled robots + cameras) for safety. “Teleoperation will do away with hazardous and unpleasant tasks,” like maintaining nuclear reactors during meltdowns. Education and XR have focused more on virtual experiences than controlling real machines, but the principles are the same. XR can simulate such situations, and the sense of presence will apply whether the remote machines are real or virtual. Like riding a bike or driving a car, our sense of ourselves in space adapts to include what we can do with machines.

Change Scales

Even more than dangerous situations, XR lets us move across impossible scales. Where a microscope lets us look closely at cells, XR can bring us inside. We can also speed up or slow down processes in a simulation, while maintaining connection with a realistic environmental context. We can remap information to human scale, like visualizing wavelengths beyond human sight or feeling tactile pressure while performing dexterous tasks. Minsky (1980) wrote, "when any job becomes too large, small, heavy, or light for human hands, it becomes difficult to distinguish the inertia and elasticity of the instrument from what it's working on." XR can fix that.

Surgery may be human scale, but there's still room for better tactile feedback especially during training. Consider Fundamental Surgery and HapticVR using a force feedback pen. That kind of feedback can help understand how much pressure an incision takes.

Figure 6. HapticVR and Fundamental Surgery.
[*opnews.com/wp-content/uploads/2019/10/Fundamental-surgery-news-800x500_c.png*](opnews.com/wp-content/uploads/2019/10/Fundamental-surgery-news-800x500_c.png)

Think with Space and Bodies

Surgery relies on thinking with our bodies, or embodied cognition, and haptic feedback supports it. We'll go deeper in embodiment in a later section, but briefly, XR allows us to bring our bodies into experiences as tools to naturally think about spaces (Regain & Shebilske, 1992) and movements, reduce our cognitive load, and feel present. Biocca (1997) writes that "physical presence is critical in applications that must involve spatial cognition." Azar (1996) reports that trainees using VR to learn routes in real buildings performed almost as well as those who trained in real buildings and much better than those who looked at pictures. Presence likely played a role in aiding that transfer: "applications that involve a knowledge transfer between the experiences in virtual and real environments seem to need a high degree of presence" (Regenbrecht, 1998). Biocca (1997) agrees that presence enables the "transfer of spatial models from the virtual environment to the physical environment.

This author has played around a hundred hours of Echo VR, a frisbee-throwing team sport in zero-G, and can report that great embodiment and tracking inspire the same desire to hone physical skills we see in real-world sports. The community discusses optimal angles for throwing motions and devoted players run drills to build muscle memory, as with any other sport.

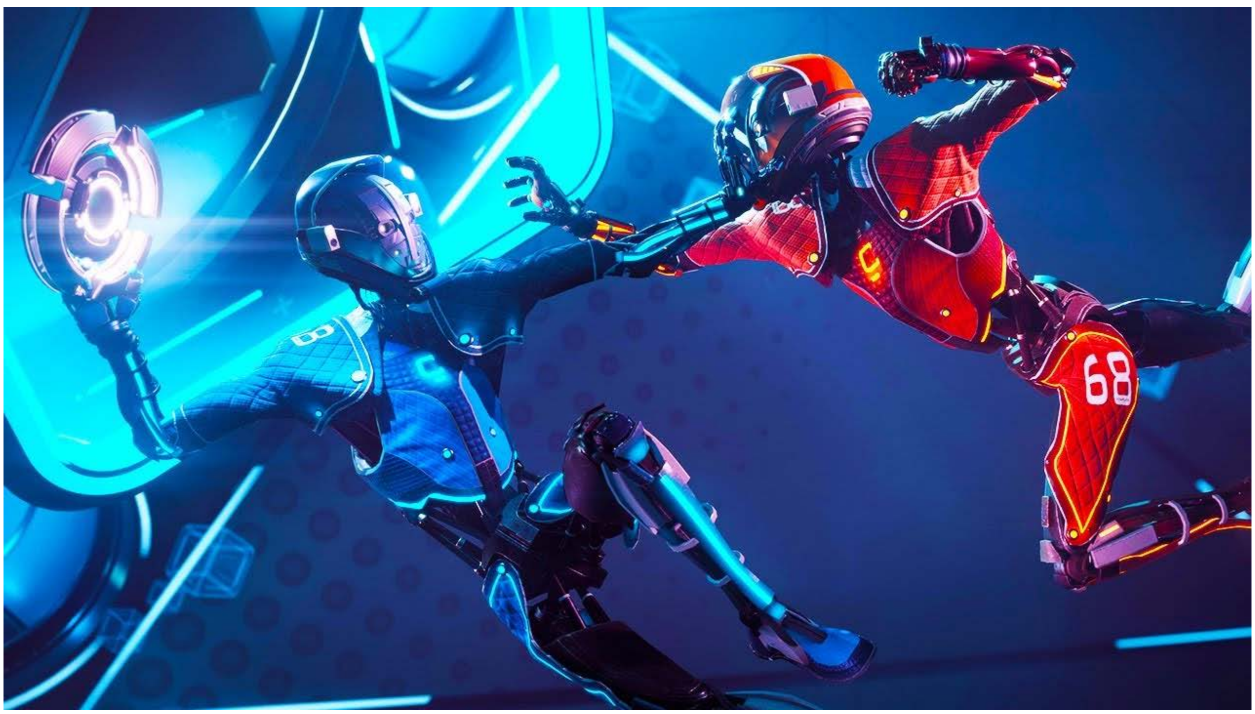

Figure 7. Echo VR. wallpapertip.com/wmimgs/158-1589665_echo-arena-vr.jpg

A critical consideration for educational settings hoping to take advantage of embodiment is the amount of space available. Playing in a gym or outside is a completely different experience than sitting in a chair or even standing within arms reach of people or hard surfaces. Consider space in the context of the experience, not only thinking that desks or even VR labs have the full answer. For designers, consider the spaces that may be available when choosing the movements you inspire. It's rare for an Echo game to finish without someone shouting, "ow, I just punched my wall."

Socialize

The broader definition of presence, an illusion of nonmediation, includes social presence. The illusion of nonmediation allows real people at a distance to feel close by, even in avatar form. It also allows us to suspend disbelief that computer characters aren't real.

Figure 8. Sitting around a campfire in VRChat. [*pbs.twimg.com/media/EiIBZ1GX0AAzPIe.jpg*](pbs.twimg.com/media/EiIBZ1GX0AAzPIe.jpg)

Part of the power and requirements for social presence is high bandwidth of social information. Lombard and Ditton (1997) call this "presence as social richness" and note that higher social richness "allows interactants to [...] more precisely adjust the overall level of intimacy." We use these cues to decide and communicate that level of intimacy - how close should we stand, what topics should we discuss, handshake or hug? Without those cues, we feel uneasy, and have difficulty establishing trust or comfort. Media supporting high presence are seen as better suited for sensitive personal interactions (Perse & Courtright, 1993; Rice, 1992; Short, Williams, & Christie, 1976). Lombard and Ditton (1997) speculate "that tasks and activities which involve ambiguous verbal and nonverbal social cues and sensitive personal information take greater advantage of a medium's potential to offer presence than do simple nonpersonal tasks." Might there come a day when instead of saying, "better to do that in person" about personal interactions, we say, "better to do that in VR?" Lanier and Biocca (1992) suggest this social power to bring people together is the greatest potential of VR. That may be true of AR and MR as well.

Change Minds

Persuade

Some initial studies linked presence to a change in brand preference. Kim (1996) had participants view infomercials in immersive or nonimmersive settings. The ones in the immersive condition said they felt more presence and also were more confident in their brand preference.

Advertisers will immediately see the potential. Many educational contexts don't take learner interests as strong inputs in shaping learning activities. There is a tension between meeting standards and allowing learner curiosity to drive, with standards generally winning. The research shows that learning, propelled by intrinsic motivation, benefits greatly in the long term from autonomy, mastery, and purpose (Pink, 2011). XR can play a powerful role in discovering interests. In contexts allowing learner autonomy, like well-functioning marketplaces, persuasion takes on increased importance.

Overcome Fears

A slew of researchers have found evidence for presence creating therapeutic conditions with some exposure to phobias in a way that desensitizes over time (Carlin et al., 1997; Hodges et al., 1996; Knox et al., 1993; Rothbaum et al., 1995). Rothbaum et al. (1995a, 1995b) found VR useful for treating acrophobia. They had participants ride a virtual elevator, stand on a virtual bridge, etc. and increased the intensity over time. Regenbrecht et al. (1998) summarizes, "This technique, called systematic desensitization, is a common and successful psychological treatment method traditionally used with imagined or real-world fear-producing situations."

Figure 9. Richie's Plank Experience. cdn.shopify.com/s/files/1/0053/6572/7335/products/plank2_1296x.jpg

Carlin et al. (1997) studied fear of spiders, Hodges et al. (1996) and North et al. (1997) investigated fear of flying, and Knox et al. (1993) looked at test anxiety. North et al. (1997) found presence can support therapy. Regenbrecht et al. (1998) expect the potential extends beyond these specific phobias: “that even our nonclinical patients developed mild anxiety and arousal indicates the potential of VR treatments for phobias, especially because the treatment success is highly dependent on the arousal reached in the confrontation.”

Desensitization isn’t always desired, though. Heyduk and Fenigstein (1984) and Zillmann and Bryant (1982) found prolonged exposure to violent and sexual content decreased viewers' sensitivity and increased callousness, though they didn’t specifically look at a connection to presence.

Change Self Image

To the extent that the way we see ourselves is shaped by what we can do, what we feel, and how we look, XR can change our self image. Minsky (1980) wrote of an experiment that changed how you look around. “The most sensational thing Moulton did was to put a two-to-one ratio on the neck so that when you turn your head 30 degrees, the mounted eye turns 60 degrees; you feel as if you had a rubber neck, as if you could turn your ‘head’ completely around!” Lee (2000) wrote, “distortions in body schema—the mental model of one’s own body—could occur after exposure to both immersive (Biocca & Rolland, 1998) and nonimmersive (Meyers & Biocca, 1992) technologies.”

Figure 10. VRChat avatars. hello.vrchat.com/press

One also might begin to prefer or identify with one body more than another, for better or worse. Turkle (1995) worried about identity or reality confusion resulting from strong presence in virtual bodies, especially for young people, though one could also think of it like wearing different outfits or costumes. Identity exploration and definition is one of the responsibilities young people undertake, and immersive media could facilitate that.

Engage

This power is self evident, but should not be overlooked. Both VR and AR have grown up as entertainers. Pokemon Go, the most popular AR game, has grossed over $4 billion. VR HMDs are already looking like tomorrow's game consoles. What surprised this author, though, was reaching for an HMD to watch Netflix for the immersiveness, comfort, and convenience.

Even back in 1995, Heeter found VR users who felt they had "entered another world" had much higher enjoyment. Lodge (1999) agreed that "this illusion can be entertaining." Regian et al. (1992) saw more engagement and accurate performance in people who learned to navigate large environments in VR compared to 2D.

There may be an instinct among some parents and educators to see this power as a negative, as a distraction to be managed or suffered. We challenge that perspective by reminding that play is an important, powerful, primal activity through which we learn (Gee, 2003), challenge ourselves, grow, relax, and socialize. Play sustains us.

Immersive Learning

Where does this framing of presence and immersion lead us when we talk about immersive learning? Immersive learning was a term used before the rise of XR technologies, and some have focused on design. For example, Pagano (2013) emphasized allowing "learners to practice in context, apply their knowledge, and improve their skills and competence." Others might call this situated learning (Lave & Wenger, 1991) or task-based learning (Ellis, 2003).

Because VR supports immersion so well, when educators and designers speak of immersive learning today, they more likely mean learning in VR or possibly XR. While perceptual immersion was only one way of thinking about immersion, with immersive learning, it is more likely to be a defining characteristic today. VR replaces more of the real with the virtual than AR, increasing perceptual immersion. VR may also create more psychological immersion, by surrounding users in a novel environment, focusing attention, removing distractions, and deeply absorbing. That's why, when speaking of immersive learning, educators likely think first of VR in learning. However, AR also has potential to immerse, especially as it holds attention with compelling visuals, sounds, interactions, narratives, or emotions.

We see great potential in XR to support immersion in all its meanings, and we're excited to explore and share that potential with you in this report. For these reasons, we'll constrain our use of the term in this report to XR and not desktop or non-technical approaches.

Immersive Learning: learning while immersed in virtual environments with XR

Limitations of Immersion

In case we've created the impression that immersion is always superior to the alternatives, let's consider some cases where it may not fit.

Imagine a scenario where users value presence with others in real space, deep immersion could pull people away from each other. Some day, we will have avatars that perfectly track and represent us. For now, we have poor copies of ourselves, lacking the capacity for most body language. Being with each other, we regain that high-bandwidth, nonverbal communication that supports calibrating intimacy (Lombard & Ditton, 1997) and building trust.

Or imagine another scenario where users should be responsive to interruptions and a wide range of stimuli, both virtual and real. In that context, focused attention in a highly immersive environment may undercut the goal.

In a third example, explorers in a dangerous virtual environment might feel scared with high immersion, for example triggering feelings of vertigo. Depending on the goals of the experience, this could be positive or negative.

Immersion is a powerful tool, underused in our opinion, but a tool nonetheless. Like any tool, we should choose the right situation to use it. As creators or curators, ask yourselves what experiences you want and what level of immersion supports those goals. If VR-level immersion doesn't fit, consider AR.

Examples of Immersive Learning

All of this may seem a bit dry and abstract, and probably not very immersive. So, let's dive into some examples of what immersion does or could like in learning across a few contexts: schools, homes, museums, and pervasive.

Immersive Learning in Schools - Cellverse

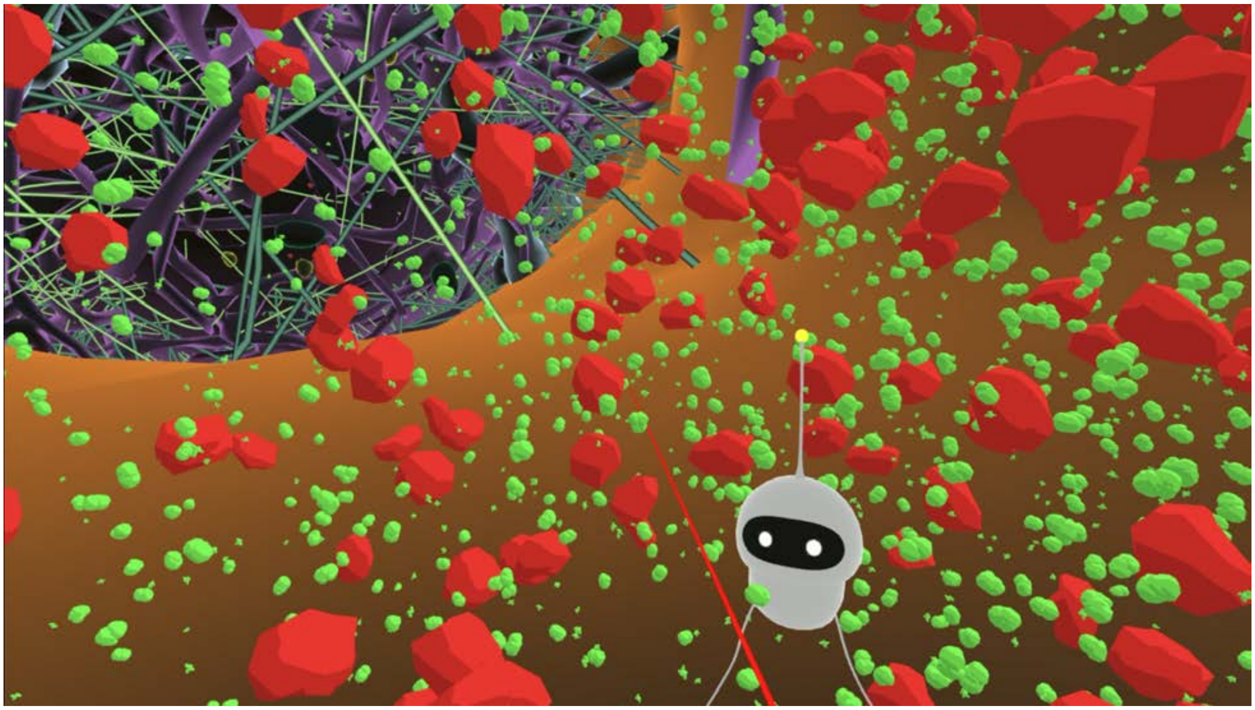

Figure 11. Cellverse, credit and courtesy of: Dan Roy.

Cellverse is a research prototype we designed at MIT for learning high school biology. It puts players inside a detailed cell in VR, where they explore to find clues of a genetic disease. The engaging, collaborative gameplay in a rich, virtual environment make it a good example of immersive learning. Seeing a cell is more absorbing when the cell surrounds you, fully replacing the real with the virtual. You're free to focus on the details of the virtual environment, from large organelles like the nucleus to tiny proteins floating around. The environment is complex and visually noisy, privileging authenticity of size, scale, shape, number, position, and orientation. It's the kind of model that allows learners to ask, "are there enough channel proteins on the cell membrane, or is that a symptom of a mutation?" We chose those aspects both because they are spatial concepts well suited to immersive computing and because they're typically simplified in traditional representations so much that learners develop misconceptions. Students typically react when trying Cellverse, "wow, I had no idea there were so many mitochondria in a cell," and "I've never seen a cell like this before."

To implement Cellverse in schools, we first contacted the biology teacher and confirmed their interest. Then, we identified spaces where we could set up VR computers with enough room to move around. Generally, this was another room near the classroom, though it could also work in the classroom. If designating one corner of a classroom the VR space, fewer students would be able to use it at a time, and in a station rotation model they might need to limit their use to shorter sessions. We designed Cellverse to fill a typical class period and include enough learning objectives that teachers could devote several classes to it. Playing multiple times also gives students a chance to switch roles, if they started on the tablet but wanted to try VR.

If making an AR version of Cellverse in a large space like a museum, school gym, or outdoors, we could do an inside-out view, as we did in VR. But, for smaller-scale AR contexts like classrooms or homes, this representation combined with an inside-out view wouldn't be as good a fit, because the complexity of the virtual environment would compete with detail in the real environment for attention. If making an AR version for those contexts, we might do an outside-in perspective or a much smaller model of a cell to address that issue. We actually built that representation, not with AR but with a tablet, and it worked well.

Figure 12. Collaboration in Cellverse: Monitor: inside-out VR view; Tablet: outside-in view. Image courtesy of the MIT Education Arcade

This is an example of how VR and AR, or monitor-based displays like desktops, phones, and tablets, can work together, providing different views with different strengths and weaknesses that support a wider range of uses. In our experience, not everyone was comfortable wearing a VR headset, and having alternate views helped make the experience more inclusive. Reading text was also easier outside of VR.

Immersive Learning at Home - Mission:ISS

Figure 13. Mission:ISS view from outside the station.
i.computer-bild.de/imgs/9/0/8/2/2/7/5/fc1e02adc5301ed2.jpg

Mission:ISS lets players explore the International Space Station in VR. There are a few scripted challenges, like operating a Canadarm from inside the Cupola to help a shuttle dock. The most compelling aspect was simply exploring the inside and outside of the station after completing all the scripted challenges. The highly detailed virtual environment, VR headset, and novelty of exploring the inaccessible created an immersive, memorable, inspiring experience. It succeeded in making us more interested in space, technology, and the ISS in particular.

While this could fit in schools, we appreciated experiencing it at home without distractions or time limits typical of the classroom. One lesson for schools considering VR then could be providing dedicated spaces with the potential for quiet or noise canceling headphones. Similarly, schools without bell schedules or with some flexibility in how long students stay on a particular task will allow the uninterrupted immersion to take a journey off-world and reflect on its magnificence.

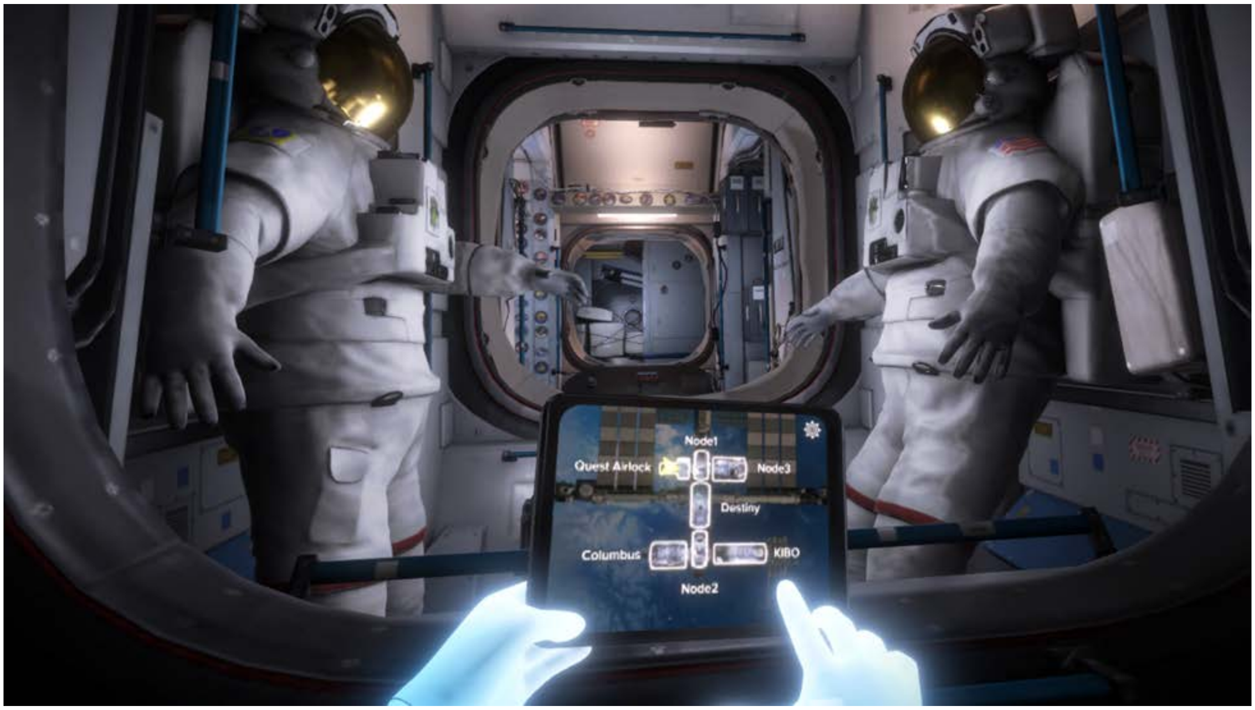

Figure 14. Mission:ISS view from inside the station, with virtual tablet map.
cdn.geekwire.com/wp-content/uploads/2017/03/170309-iss-2.png

We suspect an AR version of Mission:ISS, if it existed, would be less awe-inspiring. Having a high degree of immersion and presence is critical here.

Immersive Learning in Museums - Connected Worlds

Figure 15. Connected Worlds exhibit. nysci.org/home/exhibits/connected-worlds

New York Hall of Science describes their Connected Worlds exhibit as an immersive installation. Cruz-Neira et al. (1992) would call it a CAVE, a recursive acronym for CAVE Automated Virtual Environment that describes using projectors to cover the surfaces of a room with a virtual space. They apparently took inspiration from Plato's cave.

CAVEs or immersive installations are great fits for museums, because they don't require users to wear or carry any special hardware. They avoid a host of issues around comfort, device management, teaching controls, isolation from other users, and friction to get in and out of VR. They do take a fair amount of initial setup, and likely design and development specific to that space, but museums are often able to overcome these hurdles.

Connected Worlds invites visitors to immerse themselves in several ecosystems that all depend on a common water supply. Participants can move physical logs and virtual rocks to redirect or unblock rivers. While doing so, they might reflect on concepts of sustainability and connection, as sending all the water to one ecosystem deprives the others. They can also use gestures to interact with each ecosystem, for example planting a new tree.

Figure 16. Connected Worlds gestural interactions. [*nysci.org/home/exhibits/connected-worlds*](nysci.org/home/exhibits/connected-worlds)

The integration of both gesture and physical object manipulation increase the immersion, as does covering the floor with rivers. They could have done more with the ceiling, but that surface would be harder to interact with due to its distance.

Experiences designed for large groups in museum settings, such as this, inevitably give up some depth and control for an individual user. It's hard to imagine something like Mission:ISS in this setting, where floating around and exploring inside and outside are so satisfying. You likely wouldn't want to move the camera at all (i.e. change perspective), or if you did, it would move in the same way for all users. You also might want to limit the experience to 15 minutes or so, compared to a home-based experience that could last hours and multiple play sessions.

Embodiment

Why Embodiment?

Virtual experiences allow users to be in a body in new ways. What are the effects of being “embodied” in a body? What about being embodied in a body different than your own? Philosophers and psychologists studying embodiment have long explored this question, and recently advances in VR allow us to explore new questions, such as what happens when people take on body parts that are new (such as having robot arms) or inhabit new bodies other than their own (such as having a different gender or body type).

Humans are organisms whose experience is within bodies that have senses and capabilities for action. Our senses allow us to perceive the world in specific ways - for example seeing a limited set of wavelengths of the electromagnetic spectrum perceived as different colors. Our capabilities for action allow specific kinds of behaviors - for example our hands and fingers allow manipulation of a few objects at a time, that are within a short distance away from our bodies, our legs allow us to change our distance and perspective to farther objects, our brain development allows us to think of problems only up to a degree of complexity. And our shapes influence how the environment reacts to us - for example, exceptionally tall people taking the subway may draw inquisitive stares from strangers and may have trouble in spaces designed for average height.

Psychologists, philosophers and linguists who study the field of embodied cognition believe that even abstract human thought is grounded in the body’s form and its interaction with the external environment. It has been hypothesized that many patterns of thinking are developed from basic physical experiences. That is, our ways of thinking are rooted in the physical experience of having human bodies. This effect is visible in examples from linguistics, for example the notion that physical orientation is tied to more abstract concepts of: happiness (hence the expression of “I’m feeling down”), time (ex: “that even is coming up”), and amount (ex: “my funds went up”) (Lakoff & Johnson, 2008).

These observations speak to the powerful relationship between the body and our experience of reality, which can be tapped into through immersive experiences. In the sections below we discuss how virtual environments replicate the feeling of being embodied in a human body, and what are the effects of embodying different kinds of bodies.

Presence of the Body

There are different forms of embodiment, that can be designed for in virtual and augmented reality experiences. In the most basic form, the mere act of seeing one’s hands in a virtual environment is in itself impactful to the user. For example, research shows that looking at oneself and not seeing a virtual body causes decreased sense of presence and immersion, and in memorization and spatial thinking tasks the presence of a body improves learning as participants perform gestures to reduce cognitive load (Steed et al., 2016). The presence of limbs to manipulate the environment allows thinking to be offloaded into the world. For example, we use our bodies to think with the environment when we use sticky notes to organize brainstorming ideas, or when we use hands to move jigsaw pieces around to see if they fit, or when rock climbing and trying to see if we can reach a grab point. In such examples, being embodied in a physical form allows one to think by acting with the environment.

Figure 17. The Climb player reaching for a zipline. theclimbgame.com/blog

Consider the virtual reality game The Climb (theclimbgame.com) which creates the experience of climbing rock faces (Figure 17). In this game, the player takes the role of a rock climber scaling breathtaking vistas, and the only part of their body visible is their hands, whose location is mapped directly on the physical VR controllers. The player moves up the rock face by placing their hands on grab points, some which requires the player to reach by stretching, or to clean virtual debris before grabbing, and may even require jumping to reach. The presence of virtual hands and their match to the player's physical body generates a sense of embodiment into the virtual character, and it is emphasized by the fact that player movements in the virtual world must match the physical world (ex: in order for the virtual player to reach a grab point, the player's real hands must stretch the same degree in the physical world). The sense of embodiment would be much less if these mechanics were missing: for example if the player simply pointed at grab points with a laser ray from their fingertip without having to stretch their hand, or if the player didn't even see their virtual hands. Further, it is worth noting that this game develops the sense of being in a human body by simulating body functions such as fatigue and stress. If a player holds onto a spot for too long with one hand, that hand will become tired and lose its grip. Or, if the virtual player moves too fast and becomes tired, there are gasps and increased heartbeat, as well as increased sweating which can cause the grip to slip. All these mechanisms contribute to the player's sense of being embodied inside the virtual body.

A sense of embodiment is created when the user can see themselves inhabiting a body, and when the virtual environment allows the use of that body, in a way similar to the real world, such as by permitting grabbing onto objects. The way the user's body is designed and acts is influenced by the technology capabilities (e.g. the amount of degrees of freedom in head tracking, the capabilities for hand or body parts tracking). However, even if the body is provided a virtual representation, the way the body looks and the way the virtual environment corresponds to the user's background in the real world, will influence the sense of embodiment, as will be discussed next.

Forms, Gestures and Expectations

The way we interact and learn from interactions with the world are influenced by the way our limbs look, and the actions they can perform with the world. James Gibson (1966) coined the term "affordance" to describe the opportunities for action that an environment provides to an animal. For example, the handle on a cooking pan provides affordances for being "grasped" by a human hand, or for being "walked on" by a caterpillar. These opportunities for action are created by the relationship between the object (i.e. the pan and its handle) and the actor (i.e. a human with hands that have fingers). What this means for virtual environments is that even if one can see their limbs in a virtual experience, the way the limbs are shaped influences the subjective perception of action possibilities, and the efficiency of performing actions. For example in research by Akkoc et al. (2020), the researchers changed the appearance of the user's hands, to either mimic real hands with fingers or to provide capsule-like stubs, and asked them to move their hand toward the pot handle (Figure 18). In both conditions, users learned to identify with the observed hands and considered them to be their own. When users had the stub hands, they were faster at initiating the action of moving to the pot handle, likely because the stubs simplified the opportunities for action - users could simply move toward the handle, whereas a hand with multiple fingers encouraged more complex options for how to reach and grab the pan handle.

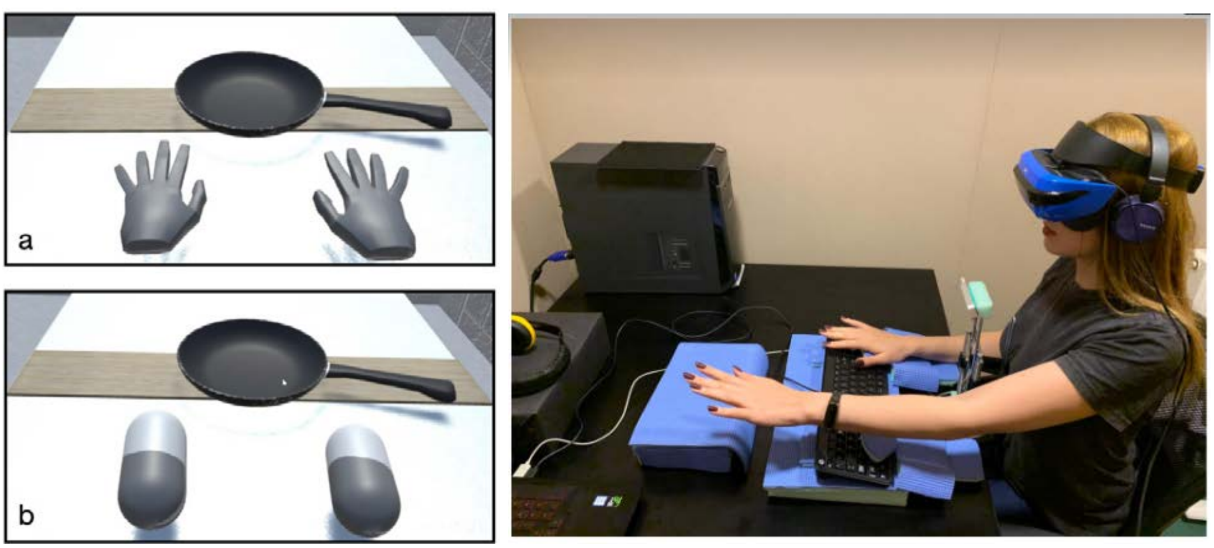

Figure 18. The experimental setup from Akkoc et al. (2020) where the user could see complex articulated hands or simple stubs.

Another important consideration in designing for embodiment is the design of gestures. The way a virtual environment responds to user gestures can enhance or detract from the learning that occurs. Research in non-immersive settings shows that encouraging users to physically enact educational content leads to stronger learning effects. For example, in mathematics education, students do better on math problems when their teacher gestures during the lesson (Goldin-Meadow et al., 1999), and students do better when they are allowed to gesture the actions of rearranging equations (Broaders et al., 2007). For physics education in mixed-reality environments, students learn the concepts of centripetal motion better when they are controlling circular motions with their hands rather than operating a linear slider scale (Johnson-Glenberg et al., 2016). And such links between gesture and conceptual understanding have been found with even higher abstraction concepts, such as research that shows users prefer to link the concept of increased happiness with gestures of upward motion (Koch et al., 2011), or link the concept of musical pitch to changes in proximity to the sound-producing objects (Antle et al., 2008).

In virtual reality environments, designers have freedom to link a user's gestures to arbitrary effects in the environment - for example, making an upward hand movement in the virtual world could cause changes in weather commensurate with the movement (such as in the Crow: The Legend where a hand wave causes snowfall); or tilting a virtual glass of liquid could cause its contents to spill upwards against gravity. In these examples, the user has expectations of what will happen as a result of these gestures, and these expectations are brought in from experiences in the real world. When a virtual environment is designed to match the user's expectations, there is a "congruence" between the gesture and its effects, and the sense of embodiment is increased. As an example, consider the game Hololab Champions (Figure 19). In the game, the user manipulates chemistry lab apparatus, such as scales, beakers and burners, to perform virtual chemistry experiments. The game is designed to emphasize high congruence - for example, when users pick up a virtual beaker, the liquid inside reacts to the speed and direction of movement; or when liquids are mixed together, they behave as if they were real. The virtual experience is simulating the physics and chemistry of the real world, allowing the user to practice lab activities in a safe environment; yet, due to the high congruence, the user is learning how to manipulate chemistry lab instruments, and this knowledge is transferable to the real world.

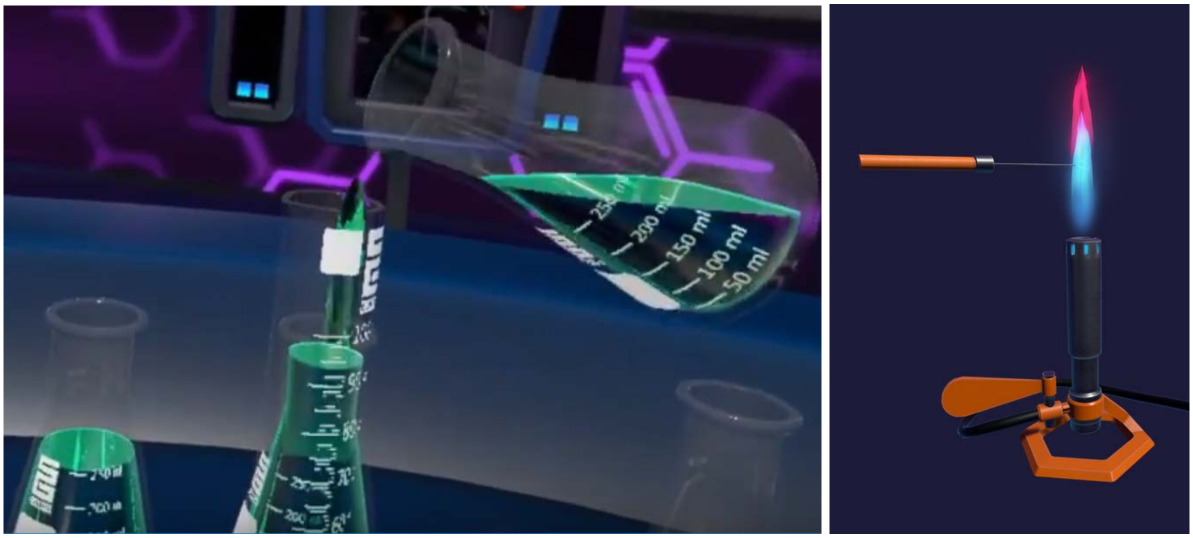

Figure 19. Pouring virtual liquids and observing flames, in Hololab Champions. [*hololabchampions.schellgames.com*](https://hololabchampions.schellgames.com)

When virtual content is embedded into the real world contexts, such as through the use of augmented reality (Figure 20), user actions become constrained by the affordances of the real world objects, and the virtual learning content becomes meaningful through association with objects familiar to the user. For example, in (Radu & Schneider, 2019) the learner interacts with a physical speaker system which converts electricity into sounds by vibrating a paper cup, while observing virtual overlays of audio waves, magnetic fields and electric signals. Because the virtual content is anchored to physical objects, the learner's interactions are constrained to manipulations of the objects (such as sliding the speaker cup close/far, flicking switches, and swapping components). This physicality reduces the need for the 3D experience designer to train the user on what actions are appropriate. Additionally, the familiarity and physicality of the objects serves to ground the learning and provide haptic information as users manipulate the objects. This leads to improved learning and transfer about phenomena invisible to the naked eye, better collaboration and communication between team members, and improved self-efficacy towards engaging in STEM physics activities (Radu & Schneider, 2019; Unahalekhaka et al., 2019).

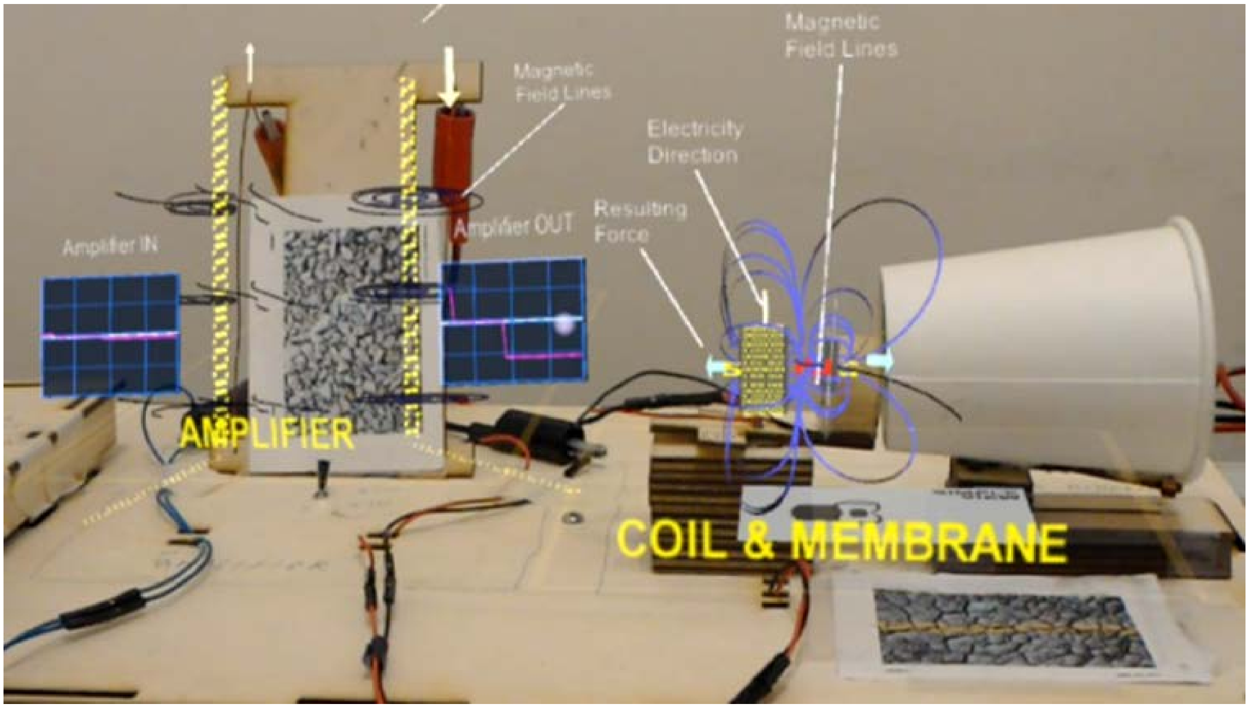

Figure 20. An augmented reality speaker system, connecting physical objects to virtual overlays of electricity and magnetism (Radu & Schneider, 2019).

The presence and form of the user's body, and the way the environment looks and reacts to the user, influence what people want to do and what they gain from the experience. Virtual and augmented environments can be designed to encourage gestures that match the real world, such as when learning how to perform physics laboratories, or to encourage gestures for interaction with less concrete concepts, such as when learning about numerical concepts. But what if the goal of the experience is to learn to be another thing altogether?

Becoming Different People

Beyond just replicating familiar body activities, immersive environment can allow users to inhabit different bodies, and even different things. Research in non-immersive settings show that children remember a story better when they are asked to physically enact the story from the perspective of the characters; and children learn computational concepts better when they are asked to embody the characters they are programming (Papert, 1980). In these cases, the act of being in the perspective of another entity causes a deeper understanding of events. But this is not limited to only experiences of becoming living beings. In the projection-based system presented by Lindgren & Moshell (2011), students walked along the path of asteroids that were traveling in space, in paths influenced by gravity. Students who embodied the asteroids showed deeper understanding of motion trajectories, than compared to students who did a similar activity but on a computer screen; learning tests showed that children in the high embodiment group focused on deeper characteristics of asteroid motion, while the control group focused more on surface features of the visual appearance of objects. This research shows that taking the perspective of a thing causes a deeper understanding of that thing. But can this be applied to more deeply understanding and relating to other people?

Virtual reality has been called the “empathy machine” (Bertrand et al., 2014), because of its ability to stimulate empathy for things we are unfamiliar with. For example, experiencing a virtual reality episode in the shoes of a victim of emotional abuse can cause observable changes in brain function (Seinfeld et al., 2020), where users showed enhanced emotion recognition abilities and observable changes in fMRI brain scans. Researchers have created experiences for becoming someone else completely, such as a person who suffers from color-blindness (Ahn et al., 2013), schizophrenia (Formosa et al., 2018), dementia (Wijma et al., 2018), or who is a different race (Olson and Harrell, 2020). People who try these experiences typically show not just increased empathy for the kinds of people they embodied, but also show changes in behavior such as more willingness to donate to a charity, or to save for retirement, or simply to help those kinds of people, although the effect of the experience is mediated by the user’s previous experiences and existing biases.

Becoming things through immersive experiences can be pushed into radically different bodies, such as becoming small children, or becoming part of nature. The game Wolves in the Walls depicts the player as a child’s imaginary friend, which arrives into existence as the child draws their outline. In the game, the child first draws the player as adult size, then erases them and redraws them at the child’s same height, creating the feeling that the player has shrunk into the child’s world. Mel Slater and colleagues have a series of studies where the VR user is exposed to the experience of being a child (Hamilton-Giachritsis et al., 2018). Through immersive VR technology that can track the user’s whole body, an adult user can see themselves as a 4-year old child whose body they control. Mothers who participated in the study showed increased empathy for the child when exposed to a virtual parent who expressed aggressive behaviors towards the child. In such research the connection between the user’s body motions and that of the child is important and emphasized through the experience of watching oneself in the mirror (Figure 21). But these empathetic reactions are not limited to VR environments with full body tracking. For example (Radu et al., 2021) used a less immersive, cheaper technology of 360-video interactive narrative to depict the experiences of a young child who struggles with reading difficulties. Using a 3-dof device users could not see their hands but could see videos recorded from the perspective of the child. Even through this lower-cost experience, users showed enhancements in empathy and willingness to donate to causes helping such children.

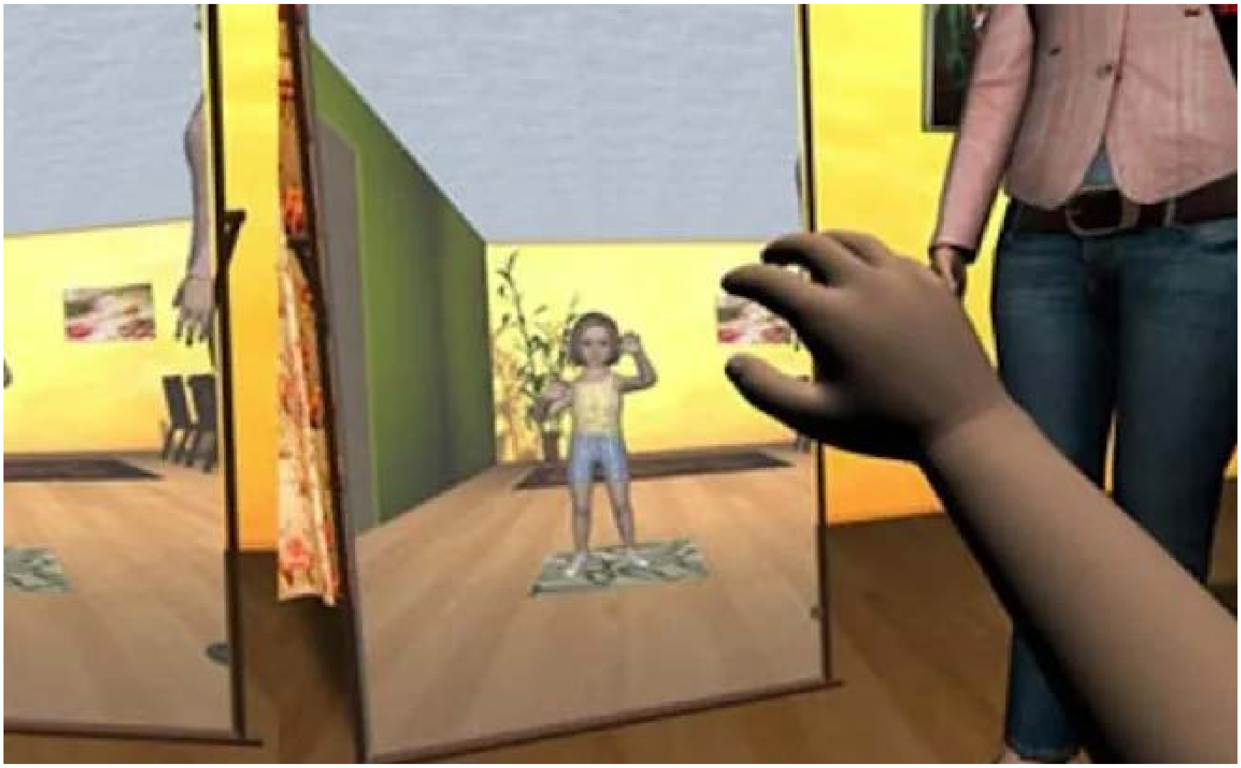

Figure 21. Seeing oneself as a child in a fully virtual environment (Hamilton-Giachritsis et al., 2018).

Figure 22. Being talked down to by a parent, in a 360-video (Radu et al., 2021).

Through the ability to inhabit other bodies, virtual environments can help people develop understandings for things they may otherwise be unfamiliar with, such as the motions of asteroids or the struggles of children. Such experiences are enhanced by a sense of ownership of the new body, and by a feeling of personal connection to the experiences depicted.

Beyond the Present

These experiences hint at the possibilities that VR has huge potential to connect humans in ways no other medium has been able to. As shown above, experiencing the life of someone else through VR can make people create a stronger relationship with people who are depicted in those experiences. However, these experiences also have detriments, since users may find the depicted reality to be highly disturbing, and it is worth involving psychologists in the design of such experiences. It is envisioned that in the future, VR media could allow humans to experience firsthand the reality of many other types of human lives, and make us to better relate to each other and to understand that each human experience has its own unique value. But it is worth thinking about how much we can change our perceptions of other things beyond humans. There are other projects that try to use VR to embody other living things. For example the TreeSense project u et (Lial., 2017) and the Acron: Attack of the Squirrels game both allow a user to experience being a tree - experiencing the growth and movement of tree limbs controlled by one's arms, experiencing visits from other animals in the forest ecosystem, and in TreeSense experiencing the cutting of limbs through tree logger's chainsaws.

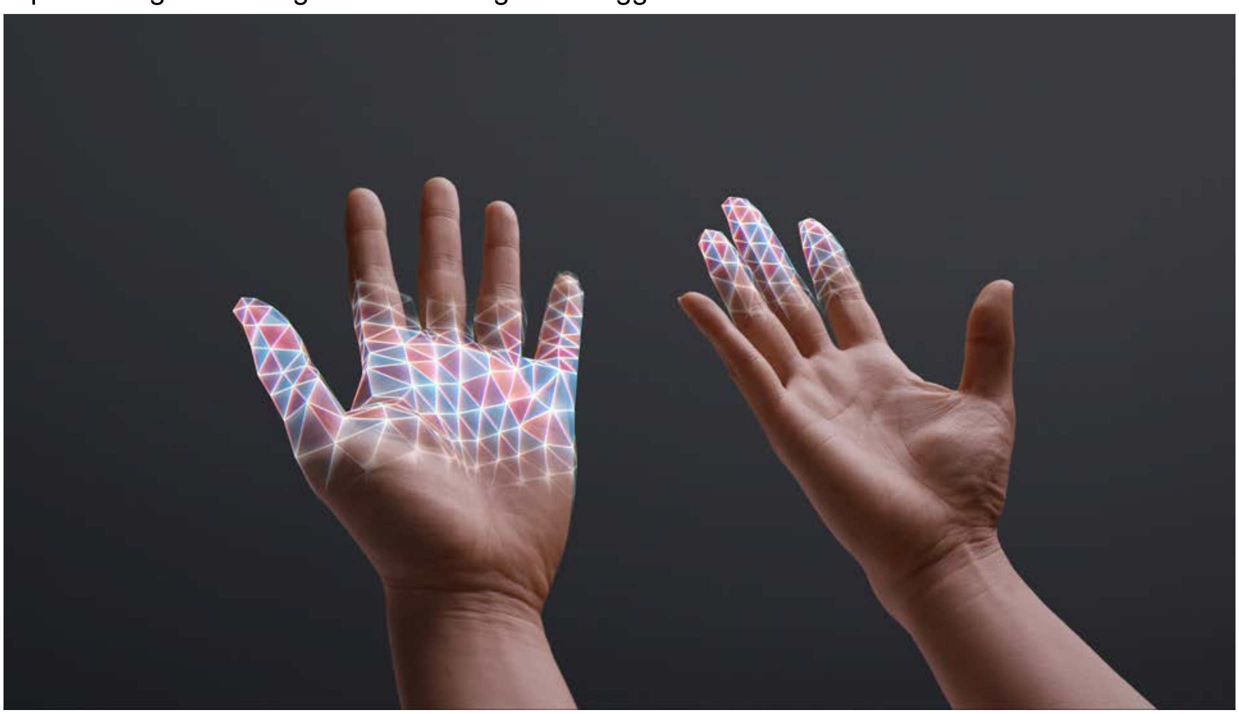

Figure 23. Augmented reality view of one's hands, through Hololens2 hand digital meshes. twitter.com/_tim_hutton_/status/1120996313187999744

We also wish to acknowledge the role of augmented reality in embodiment as another being (what is sometimes called re-embodiment). With augmented reality the user can see their own body in the real space, and can interact with real physical objects that are in the space (Figure 20, 23). Re-embodiment in AR is more difficult to do because the presence of the real world limits the sense of being another thing. For example, even if an AR experience can be created to give the sense that the user is a small child or an octopus, the presence of the real world would break that illusion. Thus there is a lack of experiences using AR for empathy towards becoming a whole different body. However it is possible that in the future AR tracking technologies may allow users to look at their hands and see a different skin color or different gender, or AR may be used to add filters to the physical reality of the user, such as color blindness, or diminished ability to read text, or introducing hallucinations simulating schizophrenia. Furthermore, AR may allow us to see the world as experts do, with AR systems that highlight important features of the environment that an expert may focus on. AR experiences can also be designed to enhance a user's body, for example the Phantom haptic device is a robotic pen that can be held in the hand (Massie and Salisbury, 1994) - and it can be used to enhance the user's ability to perform dexterity tasks, such as simulating that the user is a surgeon or a sculptor. As AR smart glasses become commonplace, we expect to see more experiences such as these, but also an increased need for caution, as such experiences may cause people to experience disturbing versions of reality and may require expert supervision to ensure users' lives become enriched in the process.

Finally, it is worth noting that maximizing embodiment may not always be desired. For example, some experiences place the user in the role of an expert. In the Guitar Hero game the player creates music by playing simplified haptic instruments; in this case, the game provides embodiment through gestures and tangible feeling of playing instruments, but simplifies the experience so the player can generate melodic sounds without being an expert. Similarly, in the astronaut adventure game Lone Echo, the act of gliding through space can cause the player's virtual body to do certain behaviors such as their legs bending, which do not mirror the player's real legs. These deliberate design choices sacrifice full embodiment in order to generate certain experiences (e.g. being a music expert, or floating in space). Thus, designers should carefully consider what degree of embodiment is necessary for the desired experience.

Design Guidelines

What principles should XR designers keep in mind? How should educators curating quality experiences evaluate candidates? Let's summarize what we've discussed so far.

Fill the Senses

People pay attention to what their senses tell them, and on some level trust that information as real. Fill the senses with virtual stimuli, and their sense of that reality will grow. Simultaneously, reduce real input to the senses, like distracting lights, sounds, and objects. Most people rely first on visual cues, so make sure there's something interesting to look at, the sounds reinforce the visuals, and text is used sparingly. Making virtual stimuli believable requires responsiveness, so track body movement with a high refresh rate even at the expense of visual detail.

Make Worlds Believable

Virtual worlds don't need to be realistic in the sense of matching the real world, but if they are believable they will invite users to imagine themselves there. Worlds should be coherent, seeming to abide by consistent laws. This allows users to understand the worlds and find meaning in them. Stimuli from all senses should seem consistent and redundant, reinforcing the sense that this world is real and solid. Environments should invite plenty of interaction and respond as users expect. Bodies should be represented and tracked at least to some degree, making actions more natural, familiar, and learnable. Other people or characters in the environment should interact naturally with users and each other across the senses.

Design for People

Understand that people will experience virtual worlds differently. People who are open to new experiences will be more likely to embrace this adventure, willingly suspending disbelief, a trait more common among the young. Similarly, people who enjoy focusing on decisions or observations, like chess or TV, can focus their attention on the virtual more readily. Creative people more easily see virtual worlds as real and complete, filling in gaps with their own imaginations. Sensitive people aware of their feelings and able to empathize with others will likely feel virtual worlds and characters more deeply, adding to the sense of meaning. Those people are often introverted, as it takes a lot of energy to feel everyone's feelings. People who think spatially, orient by vision and movement, and are able to make mental models become familiar with new environments more quickly. Different experiences will work better for different people, so consider learning contexts that allow learners to design or select their own experiences.

Transport

Virtual environments can bring users somewhere else or bring things to them. In education, it's common to use 360° videos as virtual field trips, but they often have limited body tracking, interactivity, and social affordances. Consider experiences that track more of the body, allow for more interactivity and meaningful connections between people. For virtual experiences that bring objects to us, anything benefiting from close examination and tactile probing would be a great fit. Consider allowing users to move through virtual worlds, while understanding that this may cause discomfort for some. Rather than revert to a lowest-common-denominator solution, consider comfort settings like smooth movement or teleportation, smooth rotation or snap rotation. This may not be possible in every context, so also consider accessibility within a range of applications or roles rather than foregoing everything that makes anyone uncomfortable. This ability to transport can empower learners to escape a noisy classroom when they need to focus or rest.

Do the Impossible

The promise of virtual worlds is overcoming real limitations. Consider topics that are impossible to experience in the same way in the real world, like the hazardous environment inside a volcano, changing scales to go inside cells, changing time to traverse solar systems in a moment, remapping wavelengths to the visible parts of the spectrum, and remapping very large or small forces to make them detectable by human touch.

Think Spatially

When learning about real spaces, analogous virtual spaces support transfer, like learning about building escape routes. Similarly, we can use bodies in virtual environments to learn spatial skills that transfer, like surgery. Spatial skills and knowledge have meaning even without transfer, as with embodied esports. Consider the real environments that support virtual experiences. Classrooms are convenient, but are also filled with tables, chairs, and people, limiting movement. Consider clearing a corner of the classroom for freer movement, combined with a learner-led or station-rotation model. Also explore other spaces, like labs, media centers, libraries, courtyards, parking lots, fields, gyms, community centers, and homes. Larger spaces allowing more movement may also provide better exercise. Location-based AR experiences like Pokemon Go are a great way to take advantage of all the public outdoor spaces in a community.

Connect People

Design social settings, including hangouts, collaborations, competitions, and showcases to take full advantage of these media to connect people. Build as much social richness as possible, including body tracking, expressive avatars, voice, eye contact, gesture, and touch. Tasks relying on ambiguous verbal cues or body language, or sensitive personal information, will shine in immersive media compared to lower-bandwidth options. Remember to keep people safe in social settings, giving them tools to limit social richness at certain times, in certain contexts, or with certain people.

Discover Interests

Learners may develop affinity for the people, spaces, movements, and concepts they encounter in virtual worlds. Take advantage of this power to introduce topics learners have not yet formed opinions about, re-introduce topics of which they have negative views. Build intrinsic motivation, prioritizing autonomy, mastery, and purpose over short-term efficacy metrics like test gains. When possible, allow learners to explore apps of their own choosing or create their own, building on prior interests.

Overcome Fears

Situations that create fear and anxiety can be rehearsed in virtual environments to systematically desensitize participants. Some of these may be common, like public speaking, and can be deployed at a class or school level. Others may be more individual. Consider obstacles that groups and individuals face and the opportunity for immersive experiences to help overcome them. Many phobias may not have immersive treatments available, and learners can find meaning in creating them.

Explore Selves

The work of youth is partly to discover and define identity. Virtual selves create opportunities for exploration and discovery. Experiences that use avatars can allow customization, and social experiences can provide different roles and interactions to fit a range of moods and personalities. Beyond cosmetic changes, consider virtual re-embodiment in bodies with different abilities.

Engage

Playful, fun, engaging, immersive experiences can be powerful ways to learn systems, stories, problem solving, collaboration, identity, confidence, and many other skills and concepts. Don't fear entertainment as a distraction, or limit learning to serious behaviors. Also consider games not marketed for learning, especially as a way to inspire and build media literacy in a learning context that encourages creation. When choosing or creating an experience for learning, also value its ability to entertain.

Create

Creation may seem obvious in a set of design guidelines, but consider the many ways to unleash creativity through immersive media. We encourage educators who may not have the time or background to build their own immersive experiences to still invite their students to do so. This easily fits in project based learning models and learner-led settings, but even educators working within more traditional models may be able to substitute making an interactive experience for a paper or straightforward coding exercise. The benefits span engagement, intrinsic motivation, interdisciplinary thinking, collaborative learning, career preparation, media literacy, and sense of empowerment. Given that creative people are likely to feel more present, we have an opportunity to leverage that creativity. Consider building or suggesting immersive applications in painting, modeling, animation, storytelling, coding, dance, music, architecture, and other creative forms of expression.

Use Body Affordances

Not having a body limits the sense of presence and agency felt in immersive experiences. We encourage the use of experiences in which the user feels like they are inside a body, even if that body may not be human. Users will try to leverage the actions they see possible with their bodies, so acting through virtual hands and gestures is also encouraged for increased embodiment, rather than abstract interactions like point-and-click. But too much body movement can be tiring, especially if users hold up their arms to interact too often, and sometimes non-gestural interactions are more suitable, such as when interacting with far away objects.

Think with Gestures

Most immersive experiences try to replicate real world activities, where the user performs gestures to manipulate things that behave like in the real world. But what if users are learning about concepts that are highly abstract, such as “happiness” or “equality?” In these cases, designers are encouraged to represent abstract concepts as physical entities to be interacted with, and create meaningful links between gestures and the manipulation of the abstract concepts, such that gestures are congruent with mental operations. And sometimes these may be counterintuitive to user expectations, when the designer’s goal is to cause surprise, or to change how people are used to doing things.

Create Empathy

Experiences are usually designed to be familiar to users. But immersive experiences are a powerful medium for creating empathy and for understanding the world from the perspectives of other beings. If empathy is the goal, we encourage creators to design experiences where people inhabit bodies different than their own, and where the virtual world replicates the experience of being someone else. In these cases, designers must be careful to not bring their own biases into the experience, and, if the immersive experience has the potential to be traumatic, it is suggested that users be to be accompanied by narratives and support staff that ensure the experience is not jarring.

Provide Support

Immersive experiences can change the way we experience the world, providing us with new worlds to inhabit, new bodies and new ways of being alive. But these may be unfamiliar or even traumatizing to people. Designers must take great care to provide warnings and prepare the users beforehand so they self select themselves out of the experience, or to make sense of the experience while it happens. Furthermore, designers may wish to support users after the experience, to help integrate the experience back into the user’s real life.

Immersive Learning in Schools

How are educators using XR, and what are their strengths and weaknesses? Let's review some of the models according to our design guidelines.

Field Trips

This is currently the most common use. Educators can take a whole class on a virtual trip together, using low-cost hardware, while students are sitting at their desks in the same room. The production costs are relatively low. The implementation costs are relatively low. The learning curve is relatively shallow. For these reasons and more, virtual field trips are generally the first way educators use XR.

Access Mars is an example of a virtual field trip that lets learners follow the path of the Curiosity rover and see what it saw.

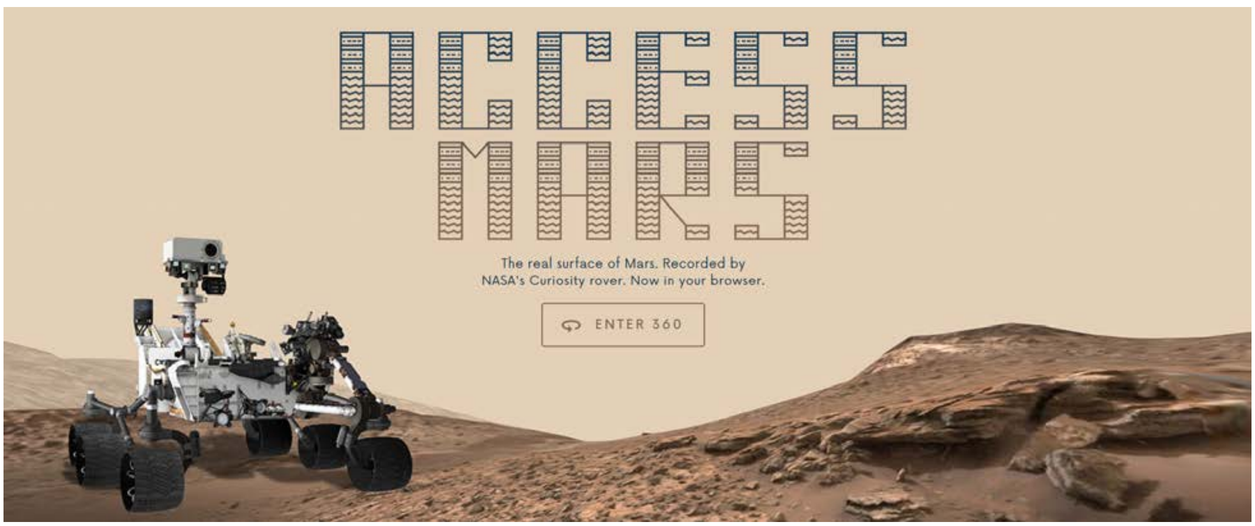

Figure 24. Access Mars. accessmars.withgoogle.com

Cornell School District in Pennsylvania used VR to visit a refugee camp in Syria, the Great Wall of China, and ancient Rome. Melinda Lohan's class at Medfield High School in Massachusetts visited the the Tenement Museum to learn about the industrial revolution, and Normandy Beaches and the Holocaust Museum to learn about WWII history.

Danvers Public Schools used virtual field trips to help special needs students get comfortable with different spaces they would need to navigate:

> When school psychologists reported that some students felt **anxious about visiting new places that came with unfamiliar sensory experiences**, the district purchased a 360-degree camera to **create virtual tours** of various locations — from the district's middle school to the city's downtown area. (Castelo, 2020)

Virtual field trips can be a convenient on-ramp to using VR. They are limited today, but may improve over time. Today, they are generally low on interaction, disembodied, and solo, resulting in less immersion, presence, and engagement. Fitchburg Public Schools in Massachusetts have used virtual field trips extensively, and are hungry for the next level. FPS Assistant Superintendent Paula Giaquinto said,

> Right now, the field trips are mostly guided — we would like to have students fully participating in this. Right now the way we have used virtual reality is strategic, but it's more like parallel play. We want to have students take information and try things and test things out in the virtual world. (Thompson, 2018)

Let's look at virtual field trips as they are today according to the design guidelines laid out in the previous section. Keep in mind, as technology and practices evolve, the meaning of virtual field trips may change to address some of these limitations.

Fill the Senses: Field trips generally have interesting things to look at and hear, so they are stimulating the senses. But, they often don't track students extensively, often relying on 360° videos, 3DoF (degree of freedom) headsets, or photospheres, which reduces the sense of presence in the virtual environment.

Make Worlds Believable: Field trips often start with real places, whether modeled or recorded with video, so they are realistic, coherent, and understandable. But, they generally lack interaction, don't track bodies, and are experienced alone, reducing the sense of being in real worlds.

Design for People: Doing the same thing with a whole class of students at a time likely can't take into account individual differences well. People will experience different levels of presence, engagement, interest, and have different willingness to suspend disbelief. When people choose their own field trips, or medium, or learning direction, they may find it more meaningful and motivating.

Transport: This would seem to be the strength of field trips, since if they do anything at all, they transport, but even this is limited due to reduced presence and embodiment. For example, movement often relies on teleportation, which is comfortable and accessible but reduces presence and is generally less exciting.

Do the Impossible: Field trips created by recording 360° videos or photospheres will be somewhat limited to the real, but they can certainly take people into dangerous or impractical situations like space or under the sea. They may also take people to possible places that are impractical for them, like a beach. To change scales or see things that are not visible to humans, field trips may need to be animated. Regardless, "doing" will be limited due to generally reduced interactivity.

Think Spatially: Field trips often show real places, so they are a decent way of learning about those spaces. Still, being disembodied and less interactive, there will be fewer ways to think spatially. Even just sitting at a desk in a classroom limits movement and spatial thinking. Consider larger spaces and field trips or other immersive applications that support more movement.

Connect People: Virtual field trips are generally solo and disembodied, so connections between people probably happen before or after the immersive experience. Even if a field trip does embody people, it may be structured more like a tour, limiting interaction.

Discover Interests: Field trips are certainly better than nothing at discovering interests, but even better would be allowing people to choose where they want to go and preferring interactive, embodied, social experiences that can make a stronger case for the topic. Rather than going as a group, consider letting learners choose, build mastery through more interactive environments, and connect with a larger purpose of theirs.

Overcome Fears: Systematic desensitization requires finding the right level of fear at that moment, which will be different for different people. For example, fear of heights would be increased with more body tracking, though less fear with less tracking might be better for some. Fear of speaking in public would probably benefit from seeing yourself and others with avatars, which field trips often don't support.

Explore Selves: Without body tracking and avatars, there are limits to how much people can explore different selves, but they may still be able to see environments people like them normally wouldn't access.

Engage: Compared to less immersive media, virtual field trips may be more engaging. Compared to more interactive, embodied, playful, social experiences, field trips are likely to feel relatively dry and passive.

Create: Field trips themselves generally don't allow people to create. The exception would be people creating their own field trips. That could be a great activity for the right people, though the immersive aspect may be incidental.

Use Body Affordances: Field trips often don't have avatars and are disembodied. Ones with avatars often don't have much to do with those bodies other than follow a guide.

Think with Gestures: Without bodies, there are no gestures. There might be pointing or selecting by gaze, but those gestures are highly limited.

Create Empathy: It's hard to empathize with a differently embodied person without embodiment.

Provide Support: Though people going on virtual field trips may not need as much support, depending on the topic, it will be easier to give them support. If the whole class is doing the same thing at the same time, it's easier to provide context to everyone up front, and debrief as a group.

Labs

Virtual labs are another common way to use immersive media in schools for a few reasons. They are discrete activities, often completed by individuals. They're interactive, and often hands-on. They may take place outside of regular class time and in a special lab space. They're convenient for remote learning when students may not have equipment at home. They may be cost effective if they avoid using more expensive equipment. Educators know how to slot them into their existing schedules.

On the other hand, depending on how they were designed, they may be less engaging. If they see themselves as an exact replica of a school lab experience, they may value seriousness over play, and end up linear and dry. They also may replace activities that are already feasible and inexpensive, adding relatively little value compared to impossible or dangerous activities.

Brownsburg High School in Indiana did a unit on public speaking in VR, where students had to deal with distractions and got feedback on how much they made eye contact (Kast, 2019).

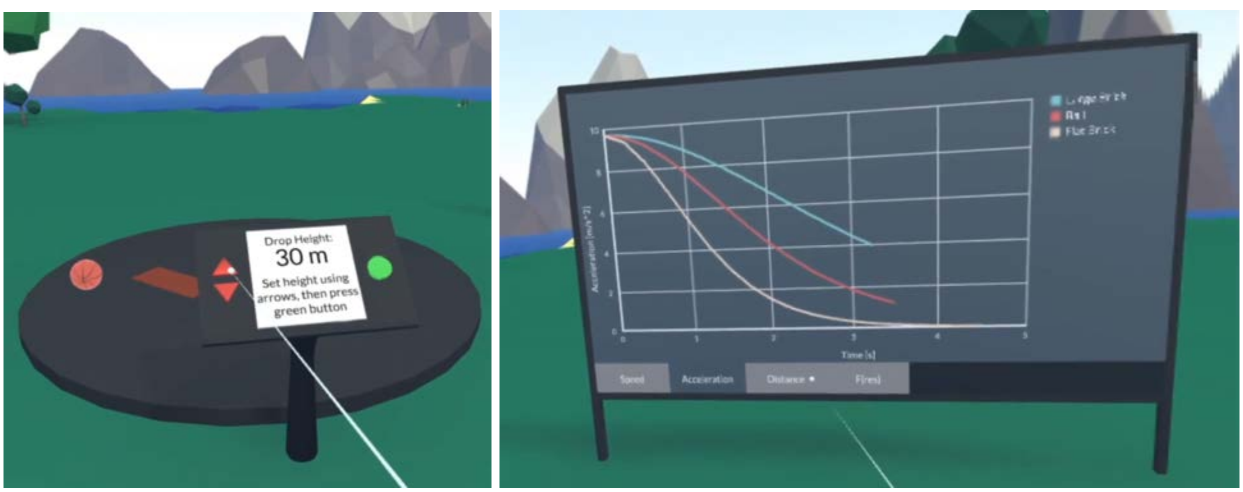

Figure 25. Science Simulations by Kosmos School. sidequestvr.com/app/190

Let's look at how virtual labs match up with our guidelines.

Fill the Senses: They may be VR or AR, filling some or more of the senses. The lab environments may be limited, providing fewer stimuli. They often include responsive body tracking, though not always.

Make Worlds Believable: Labs generally have limited worlds, focusing on the task at hand. That can create a sense of being in a shallow world, reducing presence. But those worlds are interactive, making them seem richer in some ways. They are often solo activities, lacking social interaction that would support presence.

Design for People: Like field trips, labs are generally not designed with particular people in mind other than grade level. Letting learners explore and choose labs or other activities will help. Otherwise, expect variable results for different people.

Transport: Transporting isn't usually the main goal, with experiments often happening at tables or fixed environments where a specific phenomenon can be observed in detail and data collected. But some labs may create an interesting environment and a sense of transportation.

Do the Impossible: Labs may overcome some obstacles around availability of equipment, cost, room reservations, and other practical issues, but often recreate very possible and ordinary activities already going on in schools. Don't forget to look for labs that would be impossible to do outside of immersive media.

Think Spatially: Labs often have a spatial component, like volume or velocity. They often involve body movement, like picking up and pouring beakers.

Connect People: Virtual labs generally are individual activities, though if you find group labs, take a closer look.

Discover Interests: Labs may not present a topic in the most compelling way, focusing more on following the proper steps and collecting accurate data. Some labs may involve more exploration, play, and discovery, so look at the quality of the design.

Overcome Fears: Some labs may help people avoid situations they're afraid of, like dissecting a virtual frog instead of a real one. Otherwise, labs generally don't elicit much fear.

Explore Selves: The main point of labs for most students should be to help learners think like scientists, see themselves as scientists, and enjoy the process of doing science. Linear labs where students follow prescribed steps given to them by someone else don't replicate the experience of being a scientist, so look for labs that allow more freedom to explore and experiment. Students who already identify and think as scientists may prefer other features, like sensitivity or authenticity of measurement tools.

Engage: For engaging labs, look for highly interactive, playful, embodied experiences, with exciting sensory stimuli, where failure leads to delightful surprises, and phenomena explored inspire awe and curiosity. Not all labs are created equal.

Create: Some labs may lead students to create interesting things within them, though generally they are more limited. Consider encouraging learners to design and create their own immersive labs, ideally on a topic of their choosing.

Use Body Affordances: Labs often involve picking up and manipulating virtual objects. Haptic feedback and gloves can help a lot here, though they are not common today. Some labs rely on simple point and click mechanisms that will reduce presence and embodiment.

Think with Gestures: Labs that involve gestures allow us to think with our bodies. Look for how labs use body movement, as many of them may mainly involve clicking buttons.

Create Empathy: Labs may create empathy for being a scientist, or perhaps for the subject of the experiment. Imagine varying avatar features and measuring helping behaviors to see how the world responds to people like that.

Provide Support: Labs may not require as much support as some experiences that have the potential to be more traumatic. But if people get lost or stuck, they may not want to constantly take headsets off. Look for labs with feedback and help systems that are creative, engaging, and supportive.

Project-Based Learning

Immersive media have enormous creative potential, from using visual tools to draw, paint, model, and animate, to building entire immersive experiences. Creative people already feel more present in immersive media, and as people strengthen their creativity, they may strengthen that sense as well.

Creation can be a great way to unlock not only creativity but also interest and engagement in any topic. Whole learning philosophies have sprung up around it, like constructivism and constructionism. It’s a great fit for any environment set up for project based learning, but other environments can consider offering the flexibility to substitute a learner-led project or creative expression for a standard assignment.

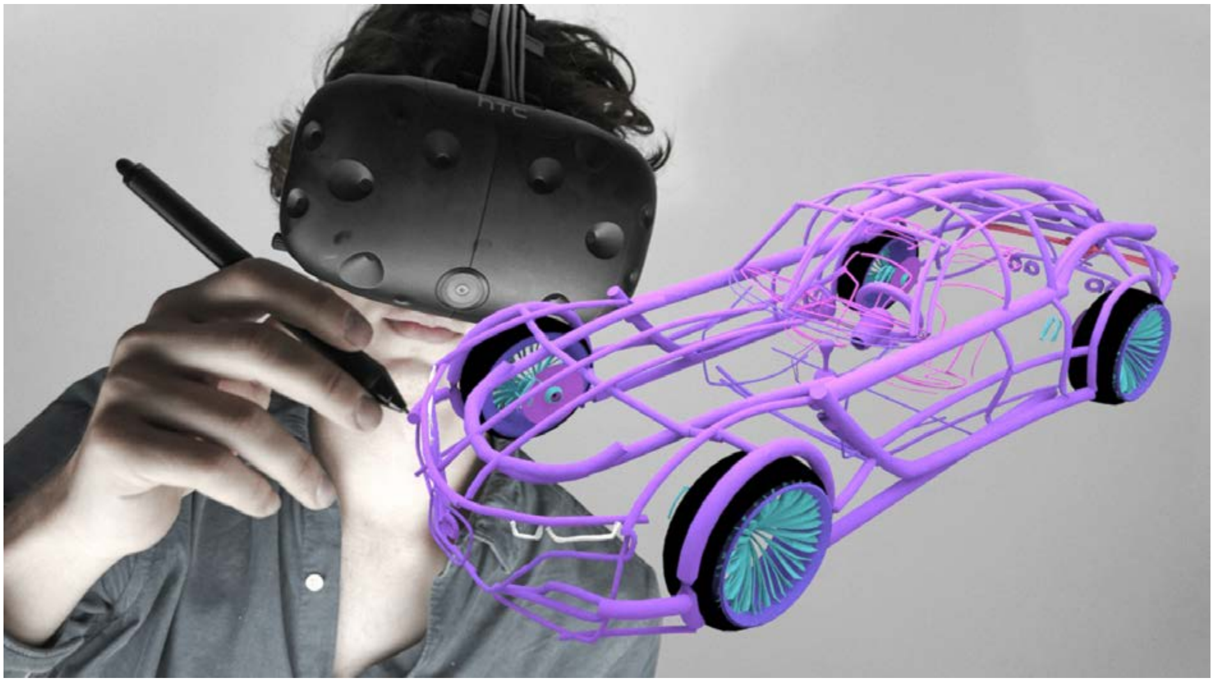

Figure 26. Gravity Sketch. gravitysketch.com

Creation can fit in most classes. Educators can offer example projects or show galleries of past student work. They can also invite learners to imagine their own projects, either building from set learning objectives or more open-ended.

Younger kids or beginner creators may enjoy blocks-based programming languages that let them create worlds that come alive with natural language. They're great introductions to computational thinking. Older students or more advanced programmers may appreciate the power of tools like Unity and Unreal Engine, which can directly translate into career skills in technology and creative industries.

Gus Halwani used Unity with his students at the Fay School in Massachusetts to great effect. "My highlight so far is mentoring students who developed an app through Unity that helps fellow students practice public speaking in an exposure-therapy sort of framework" (Halwani, 2020).

Figure 27. Cospaces. cospaces.io/edu


Figure 28. Unity, showing ALPS VR. roadtovr.com/alps-vr-unity-screenshot-1024x512

When inviting students to do creative project work, consider allowing more time with small checkpoints along the way, so they can build interest as they see their work develop. Depending on the kind of work, one-week projects may be too small to be interesting, whereas projects spanning months or years can become the center-pieces of portfolios.

Creative project work is also a great context to learn teamwork. Consider allowing but not requiring students to work together with their preferred partners. Matching activities where people brainstorm and pitch projects and others join based on skills, interests, and personalities can work well, similar to how many game jams work. Consider giving credit for student participation in events like the Global Game Jam.

Figure 29. Map of Global Game Jam locations. globalgamejam.org/status

Another benefit of creation is building media literacy skills. These skills are valuable in careers both established and emerging. They're valuable for creative expression, enjoyment, and fulfillment. And, they help people become discerning consumers of experiences that will become more common and may impact them in profound ways.

Educators sometimes feel uneasy about introducing activities that rely on media literacy skills they themselves may not have fully mastered. This can be a growth experience for students and educators alike, and it's ok for students to take the lead.

Let's look at how our principles align with creation.

Fill the Senses: This depends on what people create. Longer projects that allow creating fuller virtual worlds will be stronger here.

Make Worlds Believable: Again, longer projects will allow creators to get more involved with their worlds. Encourage interactive, stimulating, coherent projects. Consider having your students read this report.

Design for People: Creation shines at meeting people where they are, because different people can create experiences that are meaningful for them. They can also create for others, including people unlike themselves. Encourage students to consider who they're creating for during project conception.

Transport: This depends on what they create. They might make an object, viewed through a smartphone or tablet, or a whole world, viewed through a headset. There's no wrong answer.

Do the Impossible: If encouraging students to create experiences that align with learning objectives, consider experiences that would not be possible in the real world. This doesn't need to be a limitation, but an opportunity to consider projects they may not have imagined.

Think Spatially: Consider designating a part of the learning environment for activities that require more movement. For example, if students can create, but only at their desks, they will likely create experiences without much movement. If they have a space where they can walk around or at least swing their arms, the experiences they create will be more varied. Advise students to consider movement and space in their creations, and if they're old enough to supervise themselves, let them explore to find appropriate spaces around the community and test their apps.

Connect People: Group projects already connect people, but their immersive experiences can also be social. Social experiences may require more work to build in networking, but they can also consider low-tech social like one person in VR and another outside with a laptop or piece of paper doing collaborative problem solving. Social could also mean sharing their creation and getting feedback from classmates or other communities, even on otherwise individual projects.

Discover Interests: Creation is a perfect way to discover what's interesting about a topic, or to deepen a pre-existing interest. Critically, creators need some autonomy in choosing their topics, collaborators, and approach. The creation process should be at the right level for them to advance their skills and knowledge, further developing mastery. And, if it can connect to a sense of meaning or purpose in their lives, like getting an interesting career or solving a social issue, it can motivate lifelong learning. Another important input in discovering interests, even through creation, is using immersive applications other people have created. Especially the great ones, which may not be specifically for learning. Creators often learn more about the potential of the medium by using other applications than through their own creations, taking inspiration home to their own projects. Provide opportunities for this free exploration, including applications not designed for learning.

Overcome Fears: Fears related to creation may relate to competence, with beginners fearing they don't know enough to start, and anyone fearing toward the end that the scope of the project they initially imagined is too ambitious. Taking on creative project work can help build skills and confidence to overcome these fears. Educators may fear giving more freedom to students and wondering if they'll learn enough. Having the courage to take a risk and address issues as they arise can lead to overcoming that fear. Another way to think about overcoming fear is creating experiences that help them or others overcome phobias via systematic desensitization.

Explore Selves: This would be a great theme for student projects or a game jam. Consider creating experiences that embody people in unfamiliar ways to explore identity. The act of creation is itself an exploration of self as creator, building confidence and identity as creative, technically competent innovators.

Engage: If there are challenges around engagement with creation, they tend to come with people who don't have an idea of how to begin. Generally, one they've begun and are deep into creation, they're attached to the vision and want to see it through. Exceptions can occur if courseloads are too heavy, team dynamics break down, or there are too many other projects starting up. Allowing students to start and stop projects according to their needs and goals will help.

Create: That's what this whole model is about!

Use Body Affordances: Consider advising students to use their whole bodies in immersive experiences they create. That's not to say they can't make photospheres or something with a lower barrier to entry, but as they advance, bringing more of the body in will allow them to think and teach in more compelling ways. Use pointing and clicking sparingly and intentionally, considering more embodied ways of interacting like pulling handles first.

Think with Gestures: There are so many gestures ready to build immersive experiences around. Learning sign language, public speaking with gestures, esports, changing an environment with a magic wand, etc. Start early concept brainstorms with movement in mind.

Create Empathy: What is it like to be someone else? Someone who moves differently, looks different, has different access to the world? Immersive experiences as someone else can be profound, yet there are many potential and few actual experiences created. That's an opportunity for students to step in and add their voices or raise someone else's.

Provide Support: This is where many educators get stuck, because they realize this kind of hands-on, project-based learning with emerging media will take skills that they may not have fully developed themselves. Yes, students need some support. No, they don't need educators to know everything. Support can look like asking the right questions of what they need, what's blocking them, and where they can look for help, along with allowing them the time, space, and flexibility to focus on creation. That might mean standing up for the value of student work in conversations with anxious staff or parents.

Replicating the Classroom

One of the first things people do with any new medium is replicate the familiar, like putting a camera in front of a theater stage in the early days of film. VR is no exception. There are many versions of virtual classrooms popping up. The main advantage of this model is being remotely together without needing to rethink what we do together. There are certainly times that this is the best way to interact. Sometimes you just want to stand in the same room and draw on a whiteboard while talking together. But we're likely to overuse this model, because it's familiar, creating dull spaces oriented around receiving information from lecturers. Educators who consider using this model often should ask themselves if there's another approach that might meet their goals. The main exception to this advice is recreating classrooms that are already highly active, collaborative, creative, inspired, and engaging. Educators in that situation don't need us telling them what to do.

Students as Experts

We discussed this idea briefly in the context of creation. Students may have more time and interest to dive deep into projects or technologies, quickly becoming experts relative to the educators supporting them. This is an amazing opportunity to build their confidence and identity as valued contributors within the institution. Individual students, classes, or clubs can identify compelling applications, models, and technologies, and introduce them to educators. They can also support educators directly by setting up stations, facilitating sessions, creating quick-start guides, and mapping out alignment between learning objectives and applications. David Kaser of Barberton High School in Ohio has had tremendous success with this model. For example, his VR students taught a chemistry teacher how to use Nanome VR (Kaser, 2019). Kaser et al. (2019) wrote in detail about setting up a student-led VR class to support teachers in their free book Envisioning Virtual Reality, including practical advice on supplies, logistics, and costs.

Flipped Classroom

This model of lectures or readings as homework and group work or hands-on activities in class is a great fit for immersive learning. It allows class time to focus on collaborative, social activities like multiplayer games or project-based learning, access to technology and space students may not have at home, and individual or small-group guidance from educators.

There may be times that the homework is also immersive, if the technology is available, like capturing 360° video outside of school or completing a single-player tutorial before a collaborative play session, as in Cellverse.

Station Rotation

This may be the only way to create enough space in many classrooms for immersive media that involve moving around. One or two corners of a room can be separated to create a safe space to move around with a headset on, but only a few students will be able to use the space at a time. Rotation allows everyone who wants to experience it that chance.

Consider making stations optional, as some may want to spend longer and others may want to skip. Also consider stations outside the classroom, like libraries, media centers, hallways, and labs that may allow for more movement and fewer distractions.

Projecting One Headset

Sometimes, having one person use an application, with the rest of the class watching on a projector and discussing, makes the best use of space, equipment, and time. This will severely restrict most people's interactivity, and destroy their sense of presence, but will still allow some awareness and participation in the larger discussion.

Be careful with head movement, as students looking at a moving display without moving their heads can create discomfort. This may be difficult for the person wearing the headset to remember as they are fully focused on the immersive experience, so observers may need to self-regulate by looking away.

This may be a way to increase accessibility, if some students are unable or unwilling to use the technology on their own.

Conclusion

Immersive learning has tremendous potential to inspire, illuminate, transport, and connect. Immersive media and technology are evolving quickly, so educators and designers will need to keep learning along with their students to keep up. This will come more naturally to some than others. If you are the educator who enjoys staying on the cutting edge, consider your role within your institution as ambassador, connector, and role model. If you are an educator curious about new learning methods but unsure if you can adapt on your own, let your community know about your interest. You may discover someone willing to collaborate. If you are a designer, know there are plenty of gaps in compelling content and learners eagerly waiting for your creations.

Remember, our goal is to inspire the next generation. We've been handed a set of powerful tools to do just that. It's up to us to use them.

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