Learners' Presence in VR Field Trips Depends on Design of the Media, Not Novelty

Eileen McGivney, Northeastern University, e.mcgivney@northeastern.edu

Abstract: Situating science, technology, engineering and math (STEM) education in authentic environments and practices has typically been achieved by taking learning outside of the classroom, but virtual reality (VR) is a promising tool to bring such experiences into classrooms. Using VR to situate learning relies on its ability to engender the feeling of "being there," or *presence*, in a virtual place. This study investigated features of VR field trips in STEM education that impact learners' sense of presence and how it changed over time as students participated in four VR-enabled lessons with immersive videos and videogame-like environments. The results indicate the type of VR media predicts learners' presence but the novelty of the technology does not, as there were not changes over time. These results contribute a better understanding of presence in educational VR by looking beyond just the devices and studying its impact over time in classroom instruction.

Introduction

Science, technology, engineering, and math (STEM) education is failing to meet its aim of preparing every young person to understand scientific practices and be able to engage in scientific discourse, in part because traditional schooling lacks the experiences and contexts authentic to scientific practice (National Research Council, 2012). Situated learning attends to the physical and social contexts in which learning occurs, as a process of moving from novice to expert via active participation tied to a community and context (Lave & Wenger, 1991). More authentically situated approaches improve STEM education by connecting learning to scientific practice (Kelley & Knowles, 2016). Typically, this is done by taking learning outside the classroom via apprenticeships, internships, and field trips (DeWitt & Storksdieck, 2008; Lave & Wenger, 1991). However, virtual reality (VR) technologies are promising tools to bring such authentically situated learning opportunities into classrooms with experiences like virtual field trips that are difficult or impossible otherwise in schools (Bailenson, 2018).

The potential for these technologies to provide such authentically situated learning rests on the extent to which they can make the learner feel immersed in the environment and activity (Dede, 2009; Makransky & Petersen, 2021). Sense of presence, or the feeling of "being there," is one crucial component of engendering immersion in virtual environments (Slater, 2009). It is a central focus of research on VR generally and specifically in the context of learning (Cummings & Bailenson, 2016; Makransky & Petersen, 2020). To date, this research has primarily been "hardware-focused," assessing the impact of various devices on sense of presence and subsequent learning (Jensen & Konradsen, 2018; Mayer et al., 2022). However, questions remain about learners' sense of presence in response to different types of media, rather than different devices, and in authentic learning activities in schools over time, rather than one-off experiences in the lab.

This paper presents a subset of results from a larger design-based research study on VR field trips for high school STEM classes. It aims to understand how different types of VR media predict students' sense of presence (henceforth referred to as simply "presence") and whether it changes over time as they use multiple VR experiences in their class activities. Specifically, this study asks:

1. Whether learners' presence differs in two different types of VR media (immersive videos and interactive graphical environments);
2. whether the order they use the two VR media types is associated with different levels of presence;
3. and whether presence changes over time across four VR-enabled lessons.

By investigating these questions, the study contributes important understanding of how VR experiences engender presence when used over time in classrooms, a crucial aspect of assessing the potential for immersive technologies to situate STEM learning in authentic environments.

Related work

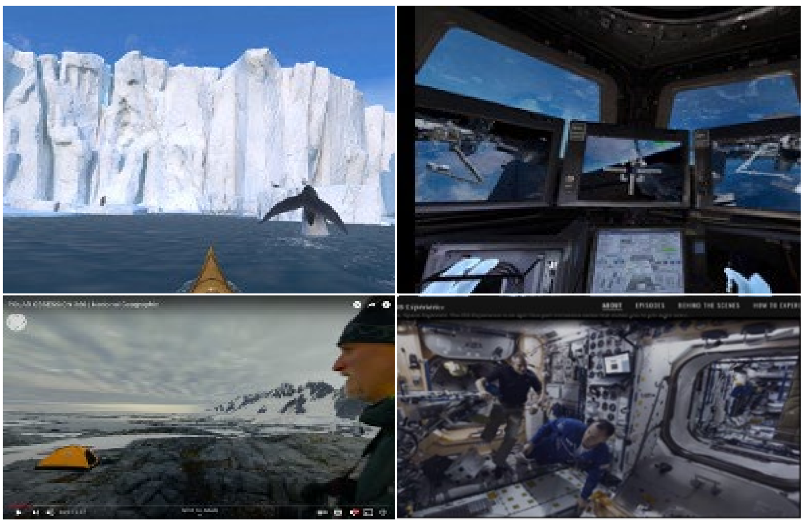
The primary affordances of VR for learning are its immersive capabilities and the heightened agency it gives learners via novel forms of interactivity. Immersion refers to the feeling of participating in a realistic experience, which technologies can accomplish by surrounding users in an image and sound that provides a realistic sensory experience (Dede, 2009). In studies of VR, immersion is often referred to as a feature of a device, and presence is one's subjective sense of "being there" in the experience, an indicator of how well the immersive illusion was perceived as real (Slater, 2009). Features of VR devices like the field of view and tracking level have a strong impact on user's sense of presence (Cummings & Bailenson, 2016). However, immersion and sense of presence are also impacted by the design of VR experiences, such as plausibility of the events, realism of the images, and ability to take action on the environment (Cummings & Bailenson, 2016; Dede, 2009; Slater, 2009). Recent research has further clarified the difference between feeling present in the environment versus in the virtual body, with implications for a learner's connection to the place and feeling like themselves (Han et al., 2023).

Despite the impact of VR media design on presence, most research on VR in education has focused on devices. Studies often compare using a learning activity in a VR headset to using it on a less immersive device, such as a video or slides (Jensen & Konradsen, 2018). These studies typically find that VR provides a heightened sense of presence and increases learners' enjoyment and motivation, but the impact on learning outcomes is mixed (Hamilton et al., 2021; Makransky et al., 2019; Wu et al., 2020). The instructional design of VR learning environments and activities surrounding them has been shown to affect learning outcomes (Mayer et al., 2022), highlighting the importance of varied design and media for optimal instructional design beyond the device (Georgiou et al., 2021). The relationship between these design decisions, presence, and learning is complex. For example, Parong et al. (2020) found that more immersive devices increased presence, and heightened presence was associated with greater spatial learning and mediated the relationship for certain types of learning outcomes. Loureiro Krassman et al. (2020) investigated media design features and found that learners had a higher sense of presence in more interactive VR environments, but not higher learning gains.

Many studies of learning with VR have been conducted in one-off laboratory or classroom experiments (Jensen & Konradsen, 2018; Wu et al., 2020). Such studies cannot attend to the impact of the technology's novelty on learning, which may increase due to the heightened effort and focus that comes from using a new technology or may decrease due to distracting learners unfamiliar with the technology (Huang et al., 2021). However, Huang et al. (2021) found that learners' presence, engagement, and learning did not decline over three 15-30 minute sessions using a VR application about the solar system that occurred over two weeks. Han et al. (2023) found, when working in collaborative VR environments throughout the duration of a course, learners' sense of presence, group cohesion, and perception of realism in the VR environment increased over eight weeks. McGivney et al. (2022) found that students using VR experiences throughout a remote course described increased feelings of mastery with the technology, providing a competing explanation to the hypothesis that as novelty wanes the impact of the technology will decrease. Studies from other immersive technologies have also raised questions about the existence of a novelty effect in 3D learning environments. Metcalf et al. (2019) found learners' motivation shifted over time when using a computer-based simulation from engagement with the technology to engagement in collaborative inquiry.

Questions remain about the influence of varied designs of the media in VR on learners' sense of presence, and how it will change over time. This study contributes to the evidence base to understand the complex relationship between VR design decisions, sense of presence, and implementation in classrooms over time.

Figure 1
VR Applications. Top: National Geographic Explore and Mission: ISS (Interactive Graphical Environments). Bottom: Polar Obsession and Space Explorers (Immersive Videos)



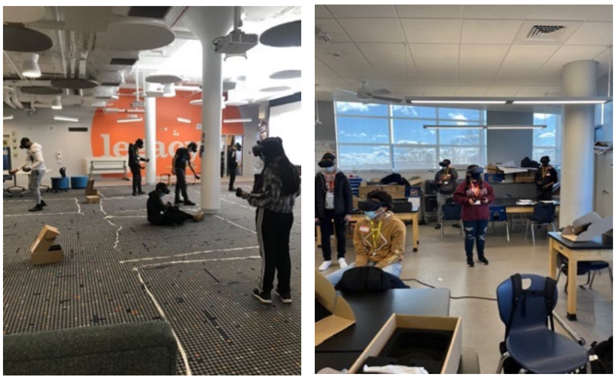
Materials and methods

Materials

The goal of the lessons was to help students develop the skill and disposition of problem-finding and articulation, which is the first step of the engineering design process and a persistent challenge in engineering education (Lucas et al., 2014). The lessons were based on an experiential learning framework (Dede et al., 2017; Kolb et al., 2014) in which students engaged in planning (a pre-work activity about the environment), acting (participating in a VR experience), and reflecting (written reflections and small group discussions). Students used applications about the International Space Station (ISS) and Antarctica and were asked to write about problems they saw that engineering could solve. For a full description of the design process for developing these lessons see McGivney (2023).

Four VR experiences were used that are available via the Oculus Store and YouTube, depicted in Figure 1. Two applications are interactive graphical environments and two are 360-degree videos. All experiences were pre-loaded onto Oculus Quest 1 headsets to work offline, ensuring they did not rely on the school's Wi-Fi. In the interactive graphical environments, students could pick up objects and move their bodies, and actively engaged in completing tasks. In *National Geographic Explore* they kayak through Antarctica, climb an ice wall, set up a base camp, and photograph wildlife. In *Mission:ISS* they operate a robotic arm to dock a shipment of supplies on the ISS and conduct a spacewalk. In the immersive videos, they engage with the scene by moving their heads to change their viewpoint and focus while they observe a narrative of people in the environment. Students using an interactive graphical environment were given a 7-foot-square area to move around in, while students using immersive videos used a stationary boundary. Students in the latter condition were asked to stand but allowed to sit if they requested to. See Figure 2 for a depiction of the two groups' implementation.

Figure 2
Classroom Implementation. Left: Interactive Graphical Environment. Right: Immersive Video



Participants

Table 1
Survey Instruments

Measures		Description/Sample Items
Pre-survey	Demographics & Experience	Gender, Racial, and Ethnic Identity, Age, Birthplace, Parents' Birthplace, Prior VR Use
Post-Survey	VHIL Sense of Presence: 5-point Likert scale (Han et al., 2023) *Place Presence (3 items): Mean alpha =.72* *Body presence (3 items): Mean alpha = .79*	Place Presence: "It felt like I was inside the virtual world" Body Presence: "When something was happening to my avatar, it felt like it was happening to me."

This study was conducted at an urban public charter high school in the Boston area, serving low-income students of whom 67% are classified as low-income and 76% as high-needs. Participants were from two high school engineering classes with a total of 30 11th and 12th grade students, age 16-18. 5 students identified as female. 28 students were second-generation Americans whose parents were born outside the U.S., and 1 student was born outside the U.S.: 23 from Latin America and the Caribbean, 5 from Africa, and 1 from Europe. All students (and their parent or guardian if under 18) consented to the study; they were informed that participation in the study was not required to participate in the VR field trips. This study was approved by the Harvard University Institutional Review Board.

Study design and data collection

This study employed design-based implementation research to both develop lessons utilizing VR field trips and build an understanding of learners' experiences with them in an authentic classroom environment (Fishman et al., 2013). The design balanced answering research questions about the impact of interactivity on sense of presence with the educator's desire to give all students meaningful learning experiences. Therefore, students were divided into two groups: Group A (15 students) used interactive graphical environments in the first two lessons, then immersive videos in lessons three and four. Students in Group B (15 students) did the reverse, using immersive videos in the first two lessons and then interactive graphical environments. See McGivney (2023) for a full description of how the lessons were codesigned. Students completed a pre-survey with their demographic information one month prior to the first VR field trip lesson. Following each VR lesson, students completed a post-survey that included six questions on their sense of presence. Table 1 describes the survey.

Analysis

Random effects models were used to estimate the association between the type of VR (interactive graphical environment or immersive video) on students' sense of place and body presence, controlling for their group, the environment (ISS or Antarctica), and individual characteristics gender and age, allowing a random intercept for individual student variation.

$$Presence_{it} = \beta_{0i} + \beta_1 VRType_{it} + \beta_2 VREnvironment_{it} + \epsilon_{it}$$
$$\beta_{0i} = \gamma_0 + \gamma_1 Gender_i + \gamma_2 Age + \gamma_3 Group_{it} + u_i$$
$$\epsilon_{it} \sim N(0, \sigma_y^2)$$
$$\beta_{0i} \sim N(\mu, \sigma^2)$$

For both dependent variables a random slope model was also run, but a likelihood ratio test did not find these models to be significantly better (Place Presence: $\chi^2(2) = 1.7, p = .56$; Body Presence: $\chi^2(2) = 1.23, p = .54$). Fixed effects models were also run as a robustness check, controlling for all student-level variation, and the associations between presence and VR type were similar in magnitude and significance.

A longitudinal growth curve estimated change over time in students' sense of agency across the four lessons:

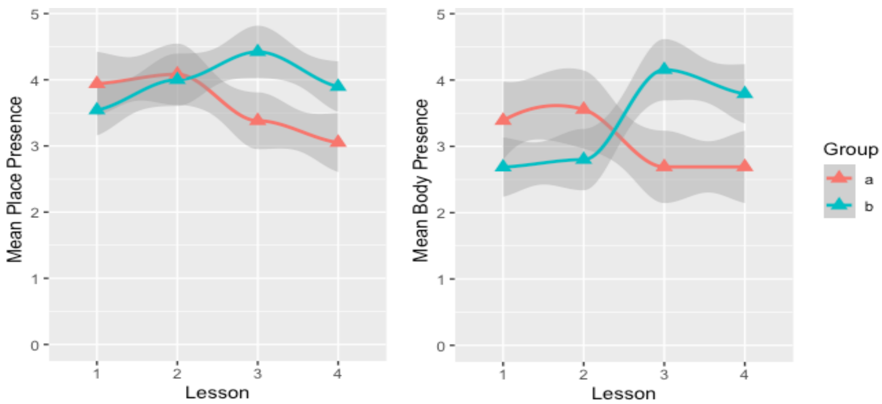
$$Presence_{it} = \beta_{0i} + \beta_{1i} Lesson_{it} + \epsilon_{it}$$
$$\beta_{0i} = \gamma_{00} + \gamma_{01} Gender_i + \gamma_{02} Age + \gamma_3 Group_{it} + u_{0i}$$
$$\beta_{1i} = \gamma_{10} + u_{1i}$$
$$\epsilon_{it} \sim N(0, \sigma_y^2)$$
$$\begin{matrix} u_{0i} \\ u_{1i} \end{matrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{matrix} \tau_{00} & \tau_{01} \\ \tau_{01} & \tau_{11} \end{matrix}\right]$$

Results

Figure 3 depicts the mean values for students' sense of place and body presence across the four lessons. For place presence, students in the two groups felt similar levels in the first two lessons, but when they switched to the other

Figure 3

Mean Sense of Place (left) and Body (right) Presence by Group and Lesson



type of VR media their levels diverged. Students who used the interactive graphical environments first (Group A) had a decline in their sense of presence when they used the immersive videos. Those in Group B, who used immersive videos first, reported an increase in sense of presence when they used the interactive graphical environment. This suggests the order in which the VR media types are used impacts place presence.

The pattern for body presence indicates the type of VR media may more directly impact this sense of presence than just the order they are used in, as the difference between the means of the two groups in the first two lessons is more distinct. This difference becomes more pronounced in the second two lessons, driven by the higher mean levels of body presence reported by students in Group B when they used the interactive graphical environments following the immersive videos.

Table 2 displays the predictors of place and body presence. A higher sense of place presence is associated with using an interactive graphical environment over an immersive video. The order in which students used these types of VR media is also a significant predictor, although to a lesser extent. Students in Group B, who used the immersive videos and then interactive graphical environments, had a higher sense of place presence, controlling for individual and VR characteristics. Only the type of VR media predicted sense of body presence: the use of an interactive graphical environment was associated with a heightened level of presence in the virtual body. The order in which the students used the two media did not have a significant association with changes in their body presence.

Table 2
Predictors of Presence

Predictors	**Place Presence** Estimates *CI*	**Body Presence** Estimates *CI*
Intercept	1.90	1.68
	-2.69 – 6.49	*-4.74 – 8.09*
Interactive Graphical	**0.56** ***	**1.02** ***
Environment	*0.28 – 0.84*	*0.73 – 1.31*
Group B	**0.37** *	0.28
	0.01 – 0.73	*-0.23 – 0.79*
VR Environment: ISS	-0.05	-0.02
	-0.33 – 0.22	*-0.30 – 0.27*
Male	0.25	0.14
	-0.24 – 0.74	*-0.54 – 0.81*
Age	0.07	0.05
	-0.20 – 0.34	*-0.33 – 0.43*
Random Effects		
σ^2	0.54	0.60
τ_{00}	0.10 $_{\mathrm{ID}}$	0.33 $_{\mathrm{ID}}$
ICC	0.16	0.35
N	30 $_{\mathrm{ID}}$	30 $_{\mathrm{ID}}$
Observations	112	114
Marginal R^2 / Conditional R^2	0.165 / 0.295	0.238 / 0.506

* *p*<0.05 ** *p*<0.01 *** *p*<0.001

Table 3 shows that there were not significant changes over time, indicated by the “lesson” variable, in students’ sense of place or body presence when controlling for individual characteristics and the order in which they used the types of VR media. This suggests there was not a significant change over time in how present students felt in the virtual environments.

Discussion

As part of a larger study of implementing VR field trips in classrooms, this research investigated students’ sense of presence in virtual environments and bodies across four VR-enabled lessons. Specifically, this study asked whether students’ sense of presence in the virtual place and in their virtual body was associated with different types of VR media by comparing interactive graphical environments and immersive videos, and whether the order in which they used these different VR experiences predicted their sense of presence. The study also asked whether students’ sense of presence changed over time as the novelty of the VR technology waned.

The results indicate that the type of VR media used is a significant predictor of both place and body presence. Students reported a greater feeling of “being there” in the environment and in their virtual body when using an interactive graphical environment that they could move around in and interact with via controllers. This indicates that the level of interactivity and ability to engage with the environment is important for feeling present in the VR, perhaps more than the realistic visuals central to immersive videos. This type of interactivity was especially important for feeling present in the virtual body. These findings align with prior work that also found interactivity increased learners’ presence within VR environments (Loureiro Krassmann et al., 2020).

Table 3
Change in Presence Over Time, Longitudinal Growth Curves

Predictors	**Place Presence** Estimates *CI*	**Body Presence** Estimates *CI*
Intercept	2.27	2.16
	-2.37 – 6.90	*-4.32 – 8.64*
Lesson	-0.06	0.12
	-0.22 – 0.09	*-0.07 – 0.31*
Male	0.24	0.17
	-0.25 – 0.74	*-0.52 – 0.85*
Age	0.08	0.03
	-0.20 – 0.35	*-0.35 – 0.41*
Group B	0.36	0.21
	-0.01 – 0.72	*-0.30 – 0.72*
Random Effects		
σ^2	0.55	0.70
τ_{00}	0.39 $_{ID}$	0.94 $_{ID}$
τ_{11}	0.05 $_{ID.lesson}$	0.13 $_{ID.lesson}$
ρ_{01}	-0.87 $_{ID}$	-0.83 $_{ID}$
ICC	0.23	0.41
N	30 $_{ID}$	30 $_{ID}$
Observations	112	114
Marginal R^2 / Conditional R^2	0.059 / 0.279	0.027 / 0.425

* *p<0.05* ** *p<0.01* *** *p<0.001*

The results also indicate that the order in which students used the types of VR was important for their sense of place presence, above and beyond the type of VR itself. This confirms what Figure 1 illustrates: students who used the immersive videos first felt a boost of presence in the second two lessons when they switched to the interactive graphical environments. The average level of presence in those VR experiences for this group was higher than it had been for the students who used the interactive graphical environments first. This finding aligns with Huang et al. (2021), who found that learners who used a less interactive device for two lessons and then switched to a more interactive device experienced an increased sense of presence in the third lesson. It is possible that using a less interactive version of a VR experience first may help lessen some of the negative effects of interactivity other studies have found that make the environment more overwhelming (Loureiro Krassmann et al., 2020).

The longitudinal analysis did not find a significant change over time in either place or body presence, controlling for individual characteristics and the order in which the VR experiences were used. This suggests that there is not necessarily a change in students’ sense of presence as the device’s novelty wanes. This is promising evidence for the potential of VR to continue to promote situated learning as the devices become more commonplace and are used in classrooms over time, as the sense of presence the students felt in the place and virtual body did not depend on the technology being new to them. This finding supports other recent research that has investigated learning with VR across multiple uses, including Huang et al. (2021) who did not find evidence of a novelty effect on learners’ experience and motivation across three lessons, and Han et al. (2023) who found place and body presence increased over eight weeks of using VR in a course. While waning novelty is often seen as a threat to the effectiveness of VR, learners’ experience may improve as they gain more mastery over the technology and can better make sense of what they see and do in a VR experience (McGivney et al., 2022). However, four instances of VR usage are still limited and future research should study more prolonged use.

These findings point to fruitful directions for future research and immersive learning technology design. The results reported here are limited in their generalizability, as the methodology was not a highly controlled experiment that can isolate the causal impact of interactivity on presence. The implementation was iterated throughout, and the research was limited by commercially available VR content. Future research should aim to identify the impact of interactivity by manipulating VR experiences and testing them in a randomized controlled study. Future research should also investigate the impact of multiple VR experiences with larger sample sizes and in different school contexts, as the 30 engineering students and their charter school environment may not generalize to all settings and learners.

Questions also remain about the impact of these feelings of presence on learning outcomes, as this study was not designed to be able to assess the impact of presence on learning. The focus of this paper is only on sense of presence as an outcome, and analysis of the learning outcomes is currently ongoing. Early results indicate that immersive videos, while providing a lower sense of presence, were more effective at delivering didactic information. The more interactive environments, in which students felt greater presence, may have helped students connect with scientific practice, an outcome more aligned with situated learning.

The findings here are informative for designing lessons with VR field trips because the study was conducted under authentic classroom conditions and using the technology within lessons over time, rather than a one-off or laboratory experiment unrelated to the curriculum. Educators and VR designers should consider the type of VR media and order in which it is used to engender a strong sense of presence. Interactive graphical environments may provide heightened presence and better accomplish situated learning, while immersive videos may help acclimate students to the environment. This evidence is promising for designing VR to situate STEM learning in authentic environments and practices, and may even suggest ways of engaging learners in legitimate peripheral participation by combining varied types of media over time (Lave & Wenger, 1991). Doing so may be a key tool for all learners to have meaningful engagement in STEM education.

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