Jun 23rd, 9:00 AM - Jun 28th, 5:00 PM

Designing for playful learning in formal education: a case study of virtual reality field trips

Eileen McGivney
Northeastern University, United States of America

Citation

McGivney, E. (2024) Designing for playful learning in formal education: a case study of virtual reality field trips, in Gray, C., Ciliotta Chehade, E., Hekkert, P., Forlano, L., Ciuccarelli, P., Lloyd, P. (eds.), *DRS2024: Boston*, 23–28 June, Boston, USA. https://doi.org/10.21606/drs.2024.945

Designing for playful learning in formal education: A case study of virtual reality field trips

Eileen McGivney

Northeastern University, United States of America

*Corresponding e-mail: e.mcgivney@northeastern.edu

doi.org/10.21606/drs.2024.945

Abstract: Despite the benefits of playful learning experiences to increase students' motivation and learning, traditional classrooms lack opportunities to learn through play. Virtual reality (VR) is a promising tool to bring rich, playful contexts into classrooms, but designing instructional models that make the most of its affordances remains challenging. This paper describes a multi-year design process implementing VR field trips in high school engineering classrooms to highlight the benefits and challenges of using VR to promote playful learning in schools. In both remote and in-person classes we developed virtual field trip lessons using immersive videos and videogame-like environments. Over time, learning goals, activities, and assessments were adjusted to meet students' needs as part of an iterative design process. The benefits of VR for playful learning are discussed, along with the importance of post-VR reflection and discussion, and the persistent challenges of lacking educational content and class time.

Keywords: Learning Experience Design, Playful Learning, Virtual Reality, Education

1. Introduction

Situating learning in rich contexts and playful experiences increases learning, transfer, and motivation to learn (Plass et al., 2014). Yet in STEM education, schools are largely devoid of experiences that are playful or authentic to the practices and environments of professionals (Carlone et al., 2014; Kelley & Knowles, 2016). Indeed, classroom learning is highly decontextualized, with a focus on abstract concepts removed from their real-world application (Lave & Wenger, 1991; Lepper & Henderlong, 2000). Situating learning in more authentic contexts has typically been achieved by taking learning outside the classroom via field trips, apprenticeships, and internships (DeWitt & Storksdieck, 2008; Lave & Wenger, 1991). Virtual reality (VR), however, is a promising technology to bring such experiences into the classroom, situating learning in digital environments that makes the learner feel as though they are in a different place and allows them to take others' perspectives (Pimentel et al., 2022). VR environments encourage active exploration in line with playful learning and have been shown to increase intrinsic motivation and enjoyment of learning (Makransky & Petersen, 2021).

Despite these affordances of VR for playful learning, integrating the technology into classrooms remains a challenge. VR has primarily been developed for individual consumer use for video gaming, and there is a dearth of content that aligns to school curricula (Southgate, 2020). Further, while instructional designs incorporating media such as books and videos have been well-studied, questions remain about optimal ways to design instruction that incorporates VR (Mayer et al., 2022). Educators and designers also run the risk of repeating past educational technology failures, which have been "oversold and underused" (Cuban, 2001; Pimentel et al., 2022). Despite their aims to engage learners in transformative and playful learning, more often digital technologies reinforce rote learning and traditional teaching models (Darling-Hammond et al., 2014). It is possible VR will suffer the same pitfalls if not designed for playful learning and to make the most of its affordances.

This paper addresses the need to understand how emerging technologies can be designed and implemented in schools to facilitate situated and playful learning. Using VR field trips in high school engineering classes as a case study, the multi-year design process is detailed to illustrate lessons learned for playful instructional design.

2. Background and related work

2.1 Situated and Playful Learning

Situated learning theory attends to the social and cultural foundations of cognition and learning, opposed to models that see cognition as purely "in the head" (Rogoff & Lave, 1984). Learning is more than retaining factual knowledge, but is a process of moving from novice to expert achieved through active participation in a community of practice (Lave & Wenger, 1991). Situating learning in contexts authentic to where the learner ultimately needs to use their expertise is often achieved through apprenticeships, internships, or field trips (DeWitt & Storksdieck, 2008; Lave & Wenger, 1991).

Situated learning shares many qualities with playful learning. Play has long been recognized as a central activity for cognitive development, as children interact with the world to understand physical and social relationships (Piaget, 1962). Playful learning, like situated learning, is grounded in the active and sociocultural foundations of learning (Plass et al., 2014). For example, games are effective learning environments that leverage play and align with situating learning in communities of practice via active participation (Gee, 2007). Mardell et al. (2019) characterizes playful learning as social, active, joyful, iterative, empowering learners with choice, ownership, and curiosity. Despite the benefits of play for learning and development, it has not typically been acceptable as part of school, and some adults see play and learning as in opposition to each other (Mardell et al., 2019). Therefore, situated and playful learning have typically been achieved outside of schools. However, VR technologies are promising tools to bring these experiences into schools (Dede, 2009).

2.2 Virtual Reality in education

VR is a technology that surrounds the user with a virtual world of 3D images and sound in 360-degrees, typically by wearing a head-mounted display (Bailenson, 2018). As the technology becomes more affordable and widespread, there is increasing interest in using it in education (Pimentel et al., 2022). Its primary affordances for learning are its immersive and interactive capabilities that provide learners a strong sense of presence in a different place and give them agency over their learning (Johnson-Glenberg, 2018; Makransky & Petersen, 2021). As with computer simulations, video games, and virtual worlds, these characteristics can enable situated and playful learning opportunities in which students explore environments and take the perspective of scientists (Dalgarno & Lee, 2010; Dede, 2009; Gee, 2007). VR experiences can involve many of the characteristics of playful learning by giving learners choice and ownership, facilitating social interaction, and allowing for iterative active learning in low-stakes settings.

Research on learning with VR to date has largely focused on comparisons with other devices and has mixed results: At times using VR increases learning outcomes and at others it does not (Hamilton et al., 2021; Radianti et al., 2020; Wu et al., 2020). Such mixed results can be explained by the focus on hardware rather than the design of the learning experience, and on assessing content knowledge rather than other learning outcomes (Georgiou et al., 2021; L. Jensen & Konradsen, 2018; Southgate, 2020). Heightened immersion and agency can induce high cognitive load, making it more difficult to process information than with other media like slides or video (Makransky et al., 2019; Parong & Mayer, 2018). VR may be more effective at enhancing affective dimensions of learning such as enjoyment and motivation, but these benefits have been less well-studied (Hamilton et al., 2021). Other questions remain due to the short duration of experiences and experiments conducted in lab environments not comparable to classroom learning (Wu et al., 2020). Therefore, although the affordances of VR can engender playful learning situated in rich contexts, little research has yet explored this application in formal learning environments.

2.3 Design-based research in formal education

Design-based research (DBR) is a common methodology commonly in the learning sciences to account for contextual factors of the classroom while studying how people learn and create designs of educational activities and tools that will work in the classroom rather than only in the lab. Collins et al. (2004) describes DBR as:

> a way to carry out formative research to test and refine educational designs based on theoretical principles derived from prior research. This approach of progressive refinement in design involves putting a first version of a design into the world to see how it works. Then, the design is constantly revised based on experience, until all the bugs are worked out. (p.18)

The research is therefore focused on theory and practice. It helps avoid pitfalls of lab-based research too focused on experimental design to provide results that will generalize to messy classroom environments, and of practice-oriented studies that do not provide rigorous evidence to be applied in other contexts (Dede, 2005).

DBR has been used in the design and development of educational technologies, including desktop-based virtual environments for science learning. River City, a virtual environment that situates learning in an authentic scientific inquiry, was developed and studied over multiple classroom implementations (Nelson et al., 2005). The EcoLearn projects also employed DBR to develop and test learning in virtual ecosystems and using augmented reality in real-life ecosystems (Dede et al., 2017, 2019; Grotzer et al., 2015). These studies resulted in important understanding of how young people reason with scientific evidence, what motivates them to learn science, and how immersive technologies can be incorporated into classroom instruction. While DBR is often used to design new technology applications, it is also a fruitful methodology to understand instruction with existing technologies and commercial applications through iterative implementation in formal learning environments (Squire, 2005).

DBR is a promising methodology to respond to recent calls for more research on VR for learning that investigates the "state of the actual" rather than the "state of the art" (Southgate, 2020). Doing so addresses deficiencies of VR learning research to date by focusing on meaningful learning experiences, aligning with educators' needs, and adapting to classroom constraints (McGivney, 2023).

3. Case study: VR field trips for engineering education

Here I describe the process of partnering with a high school engineering teacher to implement VR in classroom instruction. The research was conducted at an urban public charter high school in a low-income city in the greater Boston area. 67% of students at the school are classified as low-income, 76% as high-needs, and 87% identify as Black or Hispanic. The students who participated in the research came from the two upper-level engineering classes in a three-year sequence across three academic years from 2020 to 2023. 20-30 students participated each year. Across the three cohorts, all but one student came from an immigrant background—their parents or themselves immigrating to the United States—primarily from Latin America and the Caribbean. In each cohort three to five students identified as female and the others as male.

Students, and their parents if under 18, consented to participating in the research and data collection; they were informed that participation in the study was not required to participate in the VR activities. This study was approved by the Harvard University Institutional Review Board.

The project took an iterative and participatory approach to design instructional activities that would address the learning needs of students, constraints of the classroom and school, and help to answer research questions. The process took place over three academic years, beginning during remote education during the COVID-19 pandemic and continuing through two years of in-person schooling. The design process is described for each stage of the iteration.

3.1 Phase 1 (2020-2021): Incorporating immersive media in remote schooling

Initially, the teacher and I decided to collaborate out of a shared interest in using VR in education. The teacher was primarily interested in exposing his engineering students to the latest emerging technologies, and my interest was in researching how diverse young people responded to and learned from immersive media. While we planned to use Oculus Quest headsets during in-person instruction, when the school announced it would be teaching remotely for the year, we pivoted the implementation to use Google Cardboard headsets over Zoom lessons. We distributed the low-cost VR viewers with other educational materials, and students could use them to watch 360-degree videos with their smartphones at home.

The first use of VR with the students was conducted outside of class time in one-on-one Zoom meetings between myself and five students. During these meetings, students chose two or three destinations they wanted to take a virtual field trip to, and they watched 360-video content from producers such as National Geographic and the New York Times. I observed them via Zoom as they used each experience and then interviewed them after. This pilot helped to highlight how well the technology worked in this format and what we needed to do to prepare lessons for in-class instruction.

Over the course of three months, we then conducted four whole-class lessons using the VR viewers and 360-videos. The first VR experience was a career exploration from Google of an aerospace engineer, Tiera Fletcher. The second was a virtual dive from The Hydrous to observe the effect of climate change on coral reefs. In the third lesson, students met in breakout rooms with their peers to choose among the virtual field trips offered in the initial pilot phase.

Following each immersive video, students were placed in Zoom breakout rooms to discuss what they had seen and learned. Members of the research team facilitated and recorded these discussions as focus groups. For the final lesson, students created their own 360-photo using Google Street View and then shared why the place they photographed was meaningful to them with a peer in a Zoom breakout room.

During this implementation, some of the benefits and challenges of using immersive technologies began to emerge. As far as benefits, students described feeling immersed and engaged in the activities via focus, control, and interest. They described being able to focus better than when using other devices because they felt immersed and the VR viewer blocked out external distractors. They also described feeling a sense of control over their experience, being able to look where they wanted and choose from multiple viewpoints in the 360-degree environments, and that the VR experiences tapped into their own interests, for example learning about the work of aerospace engineers or seeing places they want to visit. The findings suggested VR could be a powerful tool for observational learning, allowing young people to learn through social information. Results of this study are reported in McGivney (2021).

The immersive media also became a powerful tool for connecting peers and encouraging reflection. Breakout rooms with peers and small-group discussions were scarce in typical instruction, and the immersive media was effective at eliciting discussion and reflection. Giving them tools to create and share their own media was particularly beneficial, but all the experiences helped students reflect on their interests and understanding in community, which has been shown in studies of other educational environments (McGivney, 2021; McGivney et al., 2022).

There were also challenges in implementing the technology within the formal learning environment. One major challenge was time, as class periods were shortened to 45 minutes for remote learning it was difficult to both utilize the VR experiences and conduct activities to support their learning and reflection from them. Another was appropriate content related to the curriculum. While the educator was interested in exposing students to the technology rather than using it to promote a specific learning goal, it was challenging to incorporate it into the engineering class to align with what students were learning.

3.2 Phase 2 (2021-2022): VR field trips with varied levels of interactivity

The next phase built on what we learned in the first phase. The teacher and I spent time to codesign lessons that would use more immersive VR devices due to the return to in-person learning and a donation of 30 Quest 1 headsets from the Facebook Reality Labs. The aim was to build lessons with VR field trips that better aligned with the course's curricular goals, leveraged instructional designs to maximize student learning, and continued to investigate the findings that emerged from the remote lessons with 360-degree videos. Some of the research areas of interest included learning with more- and less-interactive media to assess how their feelings of engagement and control would vary from the videos used in the first phase to more interactive videogame-like experiences.

The first issue addressed was how to better incorporate the VR experiences into relevant curricular goals. The teacher identified engineering problem statements as a persistent challenge, the first step in the engineering design process and a component of the Next Generation Science Standards for engineering education (NGSS, n.d.) Other educators and researchers have also identified this challenge: young people struggle to identify and articulate problems that engineering could solve (Lucas et al., 2014).

Therefore, we designed the lessons to help students practice identifying and articulating problems. The ability to observe and role play as scientists in VR environments would help students develop and apply their understanding of problems engineering could solve in these environments, leveraging the richness of the media and interactivity. To address research questions about varied VR media types and levels of interactivity, VR experiences were chosen that allowed for observation of real scientists with 360-degree immersive videos and that allowed for embodied role play as the scientists with videogame-like interactive graphical environments. Four experiences were chosen, two that covered Antarctica from National Geographic, and two that covered the International Space Station produced by NASA. These four experiences are pictured in Figure 1.

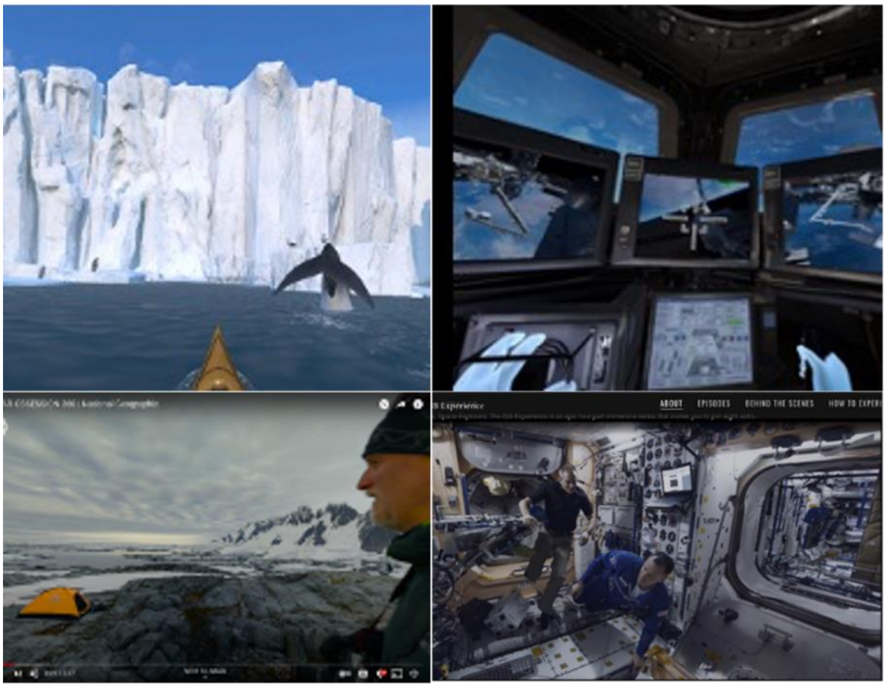

Figure 1 VR applications. Top, Interactive Graphical Environments: National Geographic Explore [National Geographic] and Mission: ISS [Magnopus & NASA]. Bottom, Immersive Videos: Polar Obsession [National Geographic Society] and Space Explorers [Felix & Paul].

Each student used all four experiences, but the order in which they used them varied. Half of the students used interactive graphical environments in the first two lessons, then immersive videos. The other half used them in the opposite order. This helped answer research questions about student reactions to the different types of VR media and instructional design decisions on student learning, while also addressing space constraints of the school and the teacher's requirement that all students experience every activity.

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

Table 1 Lesson Plan for Antarctica Lesson

Activity	**Time (minutes)**
Warm-up: Individual written response, then whole-group discussion. *What is one thing you know about Antarctica?* *What is one question you have about Antarctica?*	10
VR Setup: Distribute headsets, split into two groups, arrange space, navigate to application, troubleshoot technology.	10
VR Experience: Polar Obsession 360-Video or National Geographic Explore VR.	15-25
Reflection Activity: *See, Think, Wonder*. Using post-it notes, students reflect and write one thing they saw in the VR experience, what they thought about that, and what they wonder.	5-10
Small Group Discussion: Students share their see, think, wonder and build on each other's responses. Facilitator prompts them to draw on those thoughts to discuss what problems engineering could help solve.	10-15
Clean up	5
Wrap-up: Whole-group discussion	5
Assessment in the Following Class Period: Write an engineering problem statement related to the VR environment.	10

Table 1 provides a snapshot of the lesson plan, illustrating how students participated in a warm-up exercise, engaged in the VR experience, and then participated in reflective activities. In the following class period, they wrote an engineering problem statement based on something in the environments as their learning assessment.

This implementation provided further understanding of the benefits and challenges of using VR in the classroom. We found that the immersive experiences helped students generate curiosities about the work of scientists and what it means to do science. Students expressed strong emotions such as awe, curiosity, enjoyment, and even fear in response to the environment. With proper scaffolding, they could articulate ideas of how engineering could solve problems facing STEM professionals in these environments, such as better equipment to prevent dangers to astronauts on space walks or developing electronic devices that can survive harsh conditions in Antarctica.

We identified challenges related to instructional design as well. One challenge was time, as we found students needed as much or more time to process what they had learned after using VR as they spent in the VR experience (see Table 1). Without sufficient time for small-group discussions their earlier problem statements were often incomplete or irrelevant. Also, comparing the experiences of the two groups showed that using an immersive video prior to using an interactive graphical environment could help scaffold learning, as the students in this group expressed less confusion and frustration in the more open-ended interactive environments.

3.3 Phase 3 (Spring 2023): Condensing lessons and scaffolding learning

For the third iteration of the VR field trip lesson design, we condensed the lessons into one weeklong set of activities. We aimed to create a lesson structure more easily adoptable by other educators, with all students participating in the same version of the lessons. All students engaging in the same activities meant the lesson was run by one teacher without needing multiple facilitators. This phase was less focused on research as well, making it more aligned with instruction in a typical classroom. Figure 4 depicts the whole class engaging in the same VR activity together.

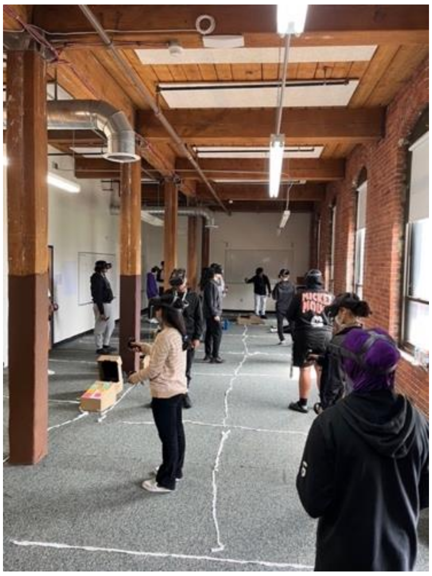

Figure 4 Whole-class VR Implementation in Phase 3

The implementation consisted of using four VR field trips over the course of two lessons. Building on the finding from Phase 2 that immersive videos could scaffold learning in a more interactive environment, all students used an immersive video experience, participated in a reflective activity with peers, then used an interactive experience of the same environment. These activities were preceded by a warmup activity to learn about the environment, and followed by a whole-class discussion.

The lessons utilized the same Antarctica experiences as Phase 2. For the second field trip, students participated in virtual dives about the ocean and coral reefs. This adjustment was due to technical issues with the ISS experiences. Figure 4 depicts the ocean VR field trip experiences. Both VR experiences utilized interactivity via controllers: Explore VR asks students to identify manta rays and types of coral reefs and Ocean Rift allows for free exploration via an ocean safari with the opportunity to touch and interact with some of the marine animals.

Figure 5 Ocean VR experiences. Left: The Hydrous Presents: Explore VR [The Hydrous]. Right: Ocean Rift [Picselica].

The learning goal was also adjusted, due to the challenge of teaching problem finding and articulation within these short lessons. Instead, they focused was students' curiosity about the environments and scientists. This was based on the evidence in Phase 2 that the experiences provoked feelings of awe and increased their curiosity about what it means to do science in these environments.

This phase demonstrated that VR field trips could be utilized as whole-class activities, and it was feasible to structure lessons with less interactive experiences as scaffolds before using more interactive experiences. Students did not complain of frustration or confusion in this implementation. As for the instructional design, the students were able to engage in multiple reflective activities that built on each other as they used the multiple VR experiences. However, students' reflections were not as deep or rich as witnessed in the prior phase, which could be due to the condensed format, lack of discussion facilitators, or the change to the content of the lessons. From their written reflections and group discussions, students did not appear to express as much curiosity about the work of scientists and STEM professionals in these environments as they had in phase 2.

4. Discussion: What can we learn for designing for playful learning?

4.1 VR field trips can bring playful learning experiences into classrooms

The VR experiences engaged students in many aspects of playful learning. For example, Mardell et al. (2019) describes playful learning as active, engaged, joyful, promoting choice, curiosity, and wonder. The way students used and responded to the VR field trips exhibited many of these characteristics, including that the students were actively participating in the activities and felt a sense of agency while using them. They described having fun and feelings of delight and wonder.

Some aspects of playful learning, however, came from activities they engaged in around the VR rather than the VR experiences themselves. For example, the *Characteristics of Learning through Play* model also emphasizes helping students make meaning of what they are doing and engaging in social interaction with peers and adults (H. Jensen et al., 2019). As VR is a very stimulating environment, students needed time to process what they were learning and make meaning of how it applied to their ideas about engineering, which is where post-VR reflection and discussion was helpful. It was through these discussions that the students engaged in social interaction as well, with both peers and educators. The VR experiences themselves were solo, meaning each student was engaging in an activity or viewing an immersive video without seeing others in the environment. However, it became clear that students wanted to engage with each other and have more social interaction. Students often called out to each other to describe what they were seeing and doing, and they were eager to share their experience with each other when they removed the headset.

4.2 Instructional design choices impact playful learning with VR

The three phases of this implementation highlight the challenge of designing instructional models that make the most of the playful aspects of VR field trips and also help students learn. While greater interactivity increased learners' active engagement and choice in the environments, it was also at times over-stimulating and confusing. Using immersive videos to help introduce students to the environment before asking them to engage in open-ended embodied tasks is one promising method to help scaffold learning so students can make meaning of the more playful environments. This finding aligns with prior work that finds VR induces a greater cognitive load than less immersive media (Makransky et al., 2019), and that designing the learning experience around the VR can scaffold learning (Georgiou et al., 2021; Mayer et al., 2022).

Further, giving students opportunities to reflect on what they saw and did in VR with their peers was a particularly fruitful instructional method. This format worked well in both remote and in-person contexts. The small group discussions helped students connect with each other to feel as though they had a shared experience and gave them an opportunity to process their learning in community. It also helped them to express their curiosities and demonstrate what they were learning that could not be captured on a traditional written assessment.

4.3 Content and time remain challenges in teaching effectively with VR in schools

Across all three phases, finding high-quality content aligned to the curriculum remained a challenge. On one hand, there were not options for VR field trips that allowed the engineering students to explore environments engineers typically work in, but rather more extreme environments. One reason is currently more interest in entertainment experiences that can "wow" the user by making them feel as though they are in outer space or the depths of the ocean. This highlights another challenge with the VR content currently available: It is primarily used for entertainment such as gaming and therefore the experiences are not built upon sound learning design. In our implementation we addressed this by creating instructional activities around the VR field trips but having educational content that was designed to help achieve learning goals would make them stronger. A related technical challenge was utilizing headsets with groups of students, requiring many workarounds to get them on secure accounts and only using applications that work offline, highlighting how the design of the devices for individual consumer gaming is also a barrier to VR's feasibility in the classroom.

Second, another challenge that persisted across all phases was having enough time to implement the lessons and support students' meaning making. The cost of VR is often discussed as a barrier to implementing it in schools, but time is just as important a resource. Consistently across the three phases of implementation we struggled to have enough time to set up the equipment and get students into it, use the VR experiences, and have sufficient time for reflection and discussion so they could consolidate what they were learning. While Phase 3 did tackle the implementation within one week and incorporating multiple VR experiences and reflection activities into each lesson, it was not clear this was as effective at encouraging deep reflection.

5. Conclusion

This paper described an implementation of VR field trips in high school STEM classes to illustrate how these immersive media can be tools to bring playful learning into formal education. The design process showed how the VR experiences exemplified many aspects of situated and playful learning that can be difficult to achieve in traditional classrooms, giving students agency over their learning, promoting feelings of joy and curiosity, and providing opportunities for social interaction and meaning-making in peer discussions about the VR. Further, the phases iterated how VR was incorporated into instruction and surfaced ways to promote learning from them, such as using immersive videos to scaffold learning in interactive VR. The project highlights challenges as well, particularly a lack of appropriate and high-quality educational content, and having enough time to implement these types of experiences.

Further research should continue to investigate the potential for VR to bring playful learning to schools and test the effectiveness of varied instructional models and types of VR content in an experimental design. Such studies can build on the findings here to adapt lessons with VR field trips to other contexts and test different designs with larger groups of students. The empirical analysis of Phases 2 and 3 is currently underway, and these findings are forthcoming. Therefore, the focus of this paper is on the design process and broad lessons learned, and it cannot speak to the results comparing varied types of VR on learning outcomes.

Future work should build on this study by comparing VR field trips to other media or business-as-usual instruction, which would answer questions about VR's unique benefits or challenges related to alternative activities. Future research should experiment with isolating the impact of interactivity by manipulating the VR experiences, and with instructional designs that utilize VR over a more extended time. Such research should document challenges in other contexts, such as the optimal amounts of time for varied lesson plans, and other technical or resource constraints that may not have surfaced in this school.

This was a small case study of VR in one context, and while all findings may not generalize to other contexts, they do provide useful guidance for incorporating VR into many schools as a tool for playful learning. The instructional designs used for the VR field trips are likely to work across contexts to help students explore and process their learning. The benefit of using 360-video before more interactive activities provides a model of how activities can move along the spectrum from guided to free play, scaffolding learning in more agentic activities. Utilizing reflective small group discussions is a fruitful way to help students make meaning of their learning in community following VR and any playful learning activity. And considering lack of content and time as barriers is informative for understanding why situated and playful learning are not more widespread in formal education.

Acknowledgements: I am grateful for every student who participated in these studies for being generous with their time and thoughts. I also owe a huge thanks to the teacher I partnered with over three years to conduct this work, which would not have been possible without his enthusiasm and flexibility. I thank Chris Dede, Tina Grotzer, and Jeremy Bailenson for their support and advice throughout this work. I also acknowledge the many research assistants who made these studies possible: Emily Gonzalez, Kris Hsu, Tessa Forshaw, Joanna Li, Melissa Dearborn, Chandanie Orgias, and Tanya Manchanda. Funding was provided by the Harvard Graduate School of Arts and Sciences. Harvard Graduate School of Education, the Radcliffe Institute for Advanced Study, and Facebook Reality Labs headset recycling program.

6. References

Bailenson, J. (2018). *Experience on Demand: What Virtual Reality Is, How It Works, and What It Can Do*. W. W. Norton & Company. https://www.amazon.com/Experience-Demand-Virtual-Reality-Works/dp/0393253694

Carlone, H. B., Scott, C. M., & Lowder, C. (2014). Becoming (less) scientific: A longitudinal study of students' identity work from elementary to middle school science. *Journal of Research in Science Teaching*, *51*(7), 836–869. https://doi.org/10.1002/tea.21150

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design Research: Theoretical and Methodological Issues. *Journal of the Learning Sciences*, *13*(1), 15–42. https://doi.org/10.1207/s15327809jls1301_2

Cuban, L. (2001). *Oversold and Underused*. Harvard University Press. http://www.hup.harvard.edu/catalog.php?isbn=9780674011090

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

Darling-Hammond, L., Zielezinski, M. B., & Goldman, S. (2014). Using technology to support at-risk students' learning. *Stanford Center for Opportunity Policy in Education. Online Https://Edpolicy. Stanford. Edu/Publications/Pubs/1241*.

Dede, C. (2005). Why Design-Based Research Is Both Important and Difficult. *Educational Technology*, *45*(1), 5–8.

Dede, C. (2009). Immersive Interfaces for Engagement and Learning. *Science*, *323*, 66–69.

Dede, C., Grotzer, T. A., Kamarainen, A., & Metcalf, S. (2017). EcoXPT: Designing for Deeper Learning through Experimentation in an Immersive Virtual Ecosystem. *Journal of Educational Technology & Society*, *20*(4), 166–178.

Dede, C., Grotzer, T. A., Metcalf, S., & Kamarainen, A. (2019). Designing immersive authentic simulations that enhance motivation and learning: EcoLearn. In R. Feldman (Ed.), *Learning science: Theory, research, practice* (pp. 229–259). McGraw Hill.

DeWitt, J., & Storksdieck, M. (2008). A Short Review of School Field Trips: Key Findings from the Past and Implications for the Future. *Visitor Studies*, *11*(2), 181–197. https://doi.org/10.1080/10645570802355562

Gee, J. P. (2007). *What Video Games Have to Teach Us About Learning and Literacy. Second Edition: Revised and Updated Edition* (2nd edition). St. Martin's Griffin.

Georgiou, Y., Tsivitanidou, O., & Ioannou, A. (2021). Learning experience design with immersive virtual reality in physics education. *Educational Technology Research and Development*. https://doi.org/10.1007/s11423-021-10055-y

Grotzer, T. A., Powell, M. M., M. Derbiszewska, K., Courter, C. J., Kamarainen, A. M., Metcalf, S. J., & Dede, C. J. (2015). Turning Transfer Inside Out: The Affordances of Virtual Worlds and Mobile Devices in Real World Contexts for Teaching About Causality Across Time and Distance in Ecosystems. *Technology, Knowledge and Learning*, *20*(1), 43–69. https://doi.org/10.1007/s10758-014-9241-5

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, *8*(1), 1–32. https://doi.org/10.1007/s40692-020-00169-2

Jensen, H., Pyle, A., Zosh, J. M., Ebrahim, H. B., Scherman, A. Z., Reunamo, J., & Hamre, B. K. (2019). *Play facilitation: The science behind the art of engaging young children* [White Paper]. The LEGO Foundation.

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*(4), 1515–1529. https://doi.org/10.1007/s10639-017-9676-0

Johnson-Glenberg, M. C. (2018). Immersive VR and Education: Embodied Design Principles That Include Gesture and Hand Controls. *Frontiers in Robotics and AI*, *5*. https://www.frontiersin.org/articles/10.3389/frobt.2018.00081

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation* (1st edition). Cambridge University Press.

Lepper, M. R., & Henderlong, J. (2000). Turning "play" into "work" and "work" into "play": 25 Years of research on intrinsic versus extrinsic motivation. In C. Sansone & J. M. Harackiewicz (Eds.), *Intrinsic and Extrinsic Motivation* (pp. 257–307). Academic Press. https://doi.org/10.1016/B978-012619070-0/50032-5

Lucas, B., Hanson, J., Claxton, G., Royal Academy of Engineering (Great Britain), & Standing Committee for Education and Training. (2014). *Thinking like an engineer: Implications for the education system : a report for the Royal Academy of Engineering Standing Committee for Education and Training*.

Makransky, G., & Petersen, G. B. (2021). The Cognitive Affective Model of Immersive Learning (CAMIL): A Theoretical Research-Based Model of Learning in Immersive Virtual Reality. *Educational Psychology Review*. https://doi.org/10.1007/s10648-020-09586-2

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, *60*, 225–236. https://doi.org/10.1016/j.learninstruc.2017.12.007

Mardell, B., Lynneth Solis, S., & Bray, O. (2019). The state of play in school: Defining and promoting playful learning in formal education settings. *International Journal of Play*, *8*(3), 232–236. https://doi.org/10.1080/21594937.2019.1684157

Mayer, R. E., Makransky, G., & Parong, J. (2022). The Promise and Pitfalls of Learning in Immersive Virtual Reality. *International Journal of Human–Computer Interaction*, 1–10. https://doi.org/10.1080/10447318.2022.2108563

McGivney, E. (2021). Immersive Media in Remote Schooling: “I Was Surprised at How Engaged I Was.” *7th International Conference of the Immersive Learning Research Network*, 120–122.

McGivney, E. (2023). Improving Technology- Enhanced Immersive Learning with Design-Based Implementation Research. *17th International Conference of the Learning Sciences Proceedings*, 1030–1033.

McGivney, E., Tribe, C., & Feng, T. (2022). Remote Learning with Virtual Reality Technologies: Student Mastery, Community and Agency. *Educational Innovations and Emerging Technology*, *2*(1), 56–73.

Nelson, B., Ketelhut, D. J., Clarke, J., Bowman, C., & Dede, C. (2005). Design-Based Research Strategies for Developing a Scientific Inquiry Curriculum in a Multi-User Virtual Environment. *Educational Technology*, *45*(1), 21–28.

NGSS. (n.d.). *HS.Engineering Design*. Retrieved April 29, 2021, from https://www.nextgenscience.org/topic-arrangement/hsengineering-design

Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, *110*(6), 785–797. https://doi.org/10.1037/edu0000241

Piaget, J. (1962). *Piaget, Jean. Play, Dreams, and Imitation in Childhood*. W. W. Norton & Company. https://onlinelibrary.wiley.com/doi/abs/10.1002/1520-6807%28196604%293%3A2%3C189%3A%3AAID-PITS2310030222%3E3.0.CO%3B2-Z

Pimentel, D., Fauville, G., Frazier, K., McGivney, E., Rosas, S., & Woolsey, E. (2022). *An Introduction to Learning in the Metaverse*. Meridian Treehouse.

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2014). *Playful Learning: An Integrated Design Framework* (White Paper # 02/2014). Playful Learning Institute.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Rogoff, B., & Lave, J. (Eds.). (1984). *Everyday cognition: Its development in social context*. Harvard University Press.

Southgate, E. (2020). *Virtual Reality in Curriculum and Pedagogy: Evidence from Secondary Classrooms*. Routledge. https://doi.org/10.4324/9780429291982

Squire, K. D. (2005). Resuscitating Research in Educational Technology: Using Game-Based Learning Research as a Lens for Looking at Design-Based Research. *Educational Technology*, *45*(1), 8–14.

Wu, B., Yu, X., & Gu, X. (2020). Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis. *British Journal of Educational Technology*, *51*(6), 1991–2005. https://doi.org/10.1111/bjet.13023

About the Author:

Eileen McGivney, PhD is an Assistant Professor at Northeastern University’s College of Arts, Media and Design. She studies how people learn with immersive technologies like virtual reality.