

Improving Technology- Enhanced Immersive Learning with Design-Based Implementation Research

Eileen McGivney, Harvard Graduate School of Education, eileen_mcgivney@g.harvard.edu

Abstract: While research on learning with immersive virtual reality (VR) to date has primarily focused on technology-focused or media comparison experiments, the field of learning sciences increasingly calls for research that accounts for classroom constraints to better translate findings to practice and instructional design. This paper describes the benefit of design-based implementation research (DBIR) as a method for studying immersive learning technologies and a work-in-progress study of VR that employed DBIR to illustrate its application. The process surfaced learning outcomes and instructional methods that would have been difficult to find in a lab experiment, including the benefit of knowledge-building discourse for students' development of curious dispositions about scientists' work.

Introduction

The field of learning sciences increasingly recognizes the value of research accounting for implementation in education systems to better impact policy and practice and advance our understanding of learning. For example, McKenney (2018) invited more research focused on collaboration between research and practice, attending to issues of implementation to better impact learning at scale. Learning scientists have pointed to design-based implementation research (DBIR) as a fruitful method to advance research and practice (Yoon & van Aalst, 2017). Such methods may be particularly useful for technology-enabled interventions with transformative aims to be effective and usable in education systems at scale (Fishman et al., 2004).

Despite this call for research that centers collaboration and implementation, learning with immersive virtual reality (VR) is most often studied in laboratory experiments leading with questions about the technology rather than problems of educational practice. Reviews point to the prevalence of hardware-focused (Jensen & Konradsen, 2018) or media-comparison studies (Mayer et al., 2022), comparing VR to another device or value added by a specific feature. Many of these studies are conducted in laboratory experiments, and those conducted in classrooms are often in response to a brief experience (Markowitz et al., 2018) or unrelated to the curriculum (Petersen et al., 2022). Much research on VR has been conducted with state-of-the-art technologies to understand people's behavior in these environments, not as learning tools (Bailenson, 2018; Slater & Sanchez-Vives, 2016). While this research points to important issues of VR learning design to account for issues like cognitive load and avatar choices, their translation into classroom practice is a challenge. Questions that remain include the impact of the technology as its novelty wanes, appropriate instructional designs incorporating VR in lessons, assessing learning outcomes beyond content knowledge gains, and navigating constraints such as limited internet connectivity, time, and space. DBIR offers a useful framework to study learning with VR in authentic contexts and can be implemented systematically, what can be referred to as "state of the actual" (Southgate, 2020) or "state of practice" research (McKenney, 2018). This paper describes DBIR as a research method, its applicability for improving research on VR in authentic educational environments, and describes a study that is currently in progress to illustrate the benefits of conducting DBIR on technology-enhanced immersive learning.

Theoretical Background

DBIR has four guiding principles, described in Table 1 (Fishman et al., 2013; Research + Practice Collaboratory, n.d.). These principles describe a collaborative research process to address problems of practice, design studies around classroom constraints, iterate implementation of interventions, and build capacity. In VR research, such approaches have not yet been widely used to study its impact on learning: most studies identify technology-focused research questions rather than problems of practice and focus on isolating causality with controlled experiments outside of classrooms. Using DBIR can benefit the study of immersive learning technologies by focusing on instructional designs that illuminate effective implementation and provide a better understanding of their impact on student learning in an authentic context.

A DBIR study of learning with VR

To illustrate the applicability of DBIR to VR learning research, this paper describes a work-in-progress study of VR field trips in two high school engineering classes and preliminary findings about students' learning that guided implementation. The study was conducted in 2021-22 at an urban public charter high school in the greater Boston area serving primarily low-income and minority students. Participants were 30 (5 female) 11th and 12th grade

students from two engineering classes. 28 students were second-generation American, and one first-generation, primarily from Latin American and Caribbean countries.

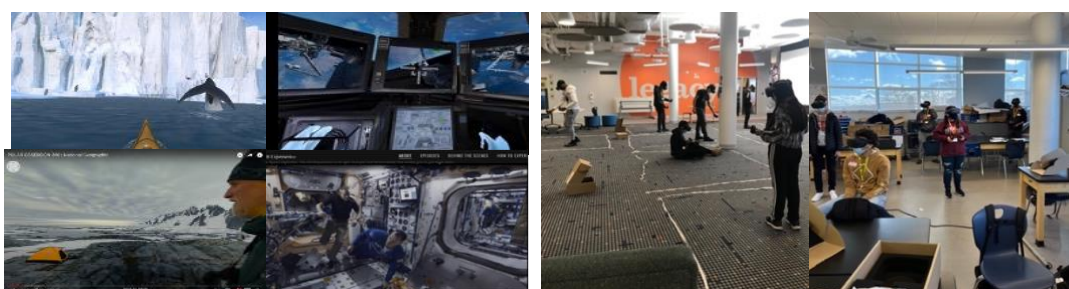
Table 1: DBIR Principles and Applicability for Immersive Learning Technology Research

| <i>DBIR Principle</i> | Description | Benefit for immersive learning technologies | Differences from typical VR learning research |
|---|---|---|--|
| <i>Deciding on a focus for joint work</i> | Teams form around a focus on persistent problems of practice from multiple stakeholders' perspectives. | Immersive learning interventions are developed within a curricular framework to address the needs of educators, making them more usable and useful in classrooms. | Focus on meaningful learning experiences rather than features of the technology. |
| <i>Organizing the design process</i> | To improve practice, teams commit to iterative, collaborative design. | Research findings include optimal instructional designs for immersive technologies by iterating their implementation, making the interventions more effective and scalable. | Research design adapts to the constraints of schools and classrooms, resulting in interventions in addition to evidence on learning with VR. |
| <i>Doing research in DBIR</i> | As a strategy for promoting quality in the research and development process, teams develop theory related to both classroom learning and implementation through systematic inquiry. | Research attends to questions of implementation, individual learning, and opens areas of inquiry valuable for classrooms including group dynamics and collaborative learning. | Research informs design but does not drive it. Findings provide thick description and insight into mechanisms in authentic environments. |
| <i>Developing capacity for continuous improvement</i> | Design-based implementation research is concerned with developing capacity for sustaining change in systems. | Educators and students get sustained exposure to technologies and develop modes of implementation. | Control of the technology given to educators and students. |

The VR field trips addressed a challenge identified by the teacher and aligned to NGSS engineering standards: students struggle to identify and articulate problems engineering could solve in open-ended tasks. By exploring virtual environments and observing scientists working in extreme conditions, students could practice problem-finding and improve their ability to write problem statements, the first step in engineering design. The primary research questions were how the VR experiences engendered students' sense of agency (control over their learning) and presence (feeling of "being there" in the environment), and how their problem statements varied over time or by type of VR used. Students used Quest headsets over 4 lessons, two with 360-degree videos (filmed footage of the environment and people), and two interactive graphical applications (videogame-like environments to move and interact with objects). Two lessons were on Antarctica and two the International Space Station (ISS). Figure 1 depicts the VR applications and implementation. Students took a pre-survey one month before the first lesson and post-surveys after each VR application (measuring sense of agency, presence, and intrinsic motivation), and 8 students were interviewed. To assess learning, students wrote engineering problem statements about the VR experience. Class discussions and field notes were recorded.

Lessons used a "plan, act, reflect" experiential learning model (Dede et al., 2017): students completed a pre-work activity, used the VR application, then participated in written reflections or discussions before writing problem statements. We iterated the lesson plan after the first lesson was rushed and students struggled to make meaning of what they had seen and learned. Figure 2 illustrates how students largely did not write statements (e.g. "I don't know"), wrote about problems with the technology (e.g. vision difficulties), or wrote what the narrator had told them about the environment (e.g. climate change is impacting Antarctica). To address this, lessons 2-4 spread activities across multiple lessons and added small group discussions to scaffold student meaning-making before the assessment. Figure 2 illustrates how these discussions shifted the focus of students' problem statements: in lessons 2 and 3 they focused on problems the people face (e.g. difficulties working on

Figure 1 Left: VR Applications (Clockwise from top left: National Geographic Explore, Mission:ISS, Space Explorers, Polar Obsession). Right: Students using interactive environment (left) and immersive video (right)



the ISS) which had been the focus of the discussions. Following lesson 4 many students wrote technology-focused statements, likely because the teacher also led a concluding discussion to reflect on the four VR experiences.

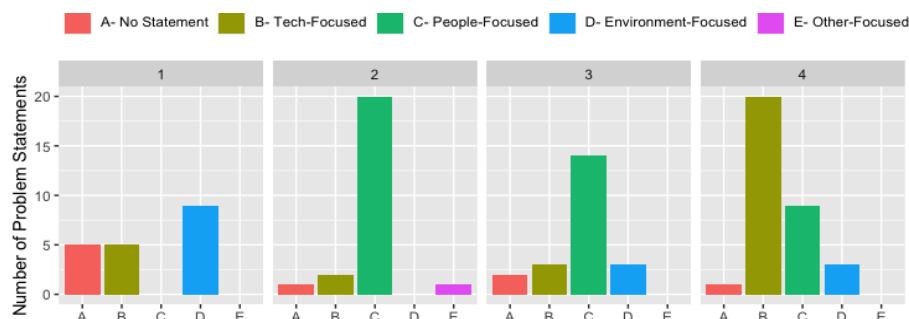
Deciding on a focus for joint work

The focus of the lessons and the research design were developed collaboratively by the author and the educator through their shared interest and multiyear partnership. This required designing a series of lessons that addressed the problem of practice the teacher faced (supporting students in writing problem statements) and the research questions that interested the researcher (how interactivity and embodiment in VR affect student experience and learning). The collaboration around dual goals led to several decisions that differed from controlled experiment designs, especially the need for all lessons to be experienced equally and for each VR application to provide a meaningful learning experience. Rather than restrict experiences of a control group, we varied the order in which they used immersive video or interactive applications, allowing for comparisons in response to varied interactivity and addressing space constraints, as only half of students in a class period needed space to move in VR (see Figure 1). To ensure VR was used in a meaningful way we used high-quality 360-videos rather than isolating interactivity in VR by giving some students a recording of an interactive application (e.g. Johnson-Glenberg et al., 2021). The result was the development of meaningful learning experiences with two different types of media, as well as a holistic understanding of students' resultant learning and subjective experiences.

Organizing an iterative, collaborative design process

Implementing the lessons required flexibility from the teacher and researcher to make changes to the lesson plan and timing, rather than adhering to an inflexible controlled design. The most significant iteration came after lesson 1, when we saw in practice how the lesson did not address students' need for more time and discourse to make sense of the VR experiences. We observed that students were eager to discuss what they saw and did in VR with their peers, but written reflections did not capitalize on this enthusiasm. When given the opportunity to participate in a facilitated small group discussion, they articulated more problems related to the scientists who work in these environments. The result was lessons that maximized learning and were practical for classroom implementation. This also revealed how the discussions can make concepts more salient for students, as the varied focus from lessons 2 and 3 (challenges facing scientists) to the final discussion (reflecting on VR) revealed.

Figure 2 *Content of students' problem statements by lesson*



Doing research in DBIR

The iterative design process highlighted benefits for research on VR to understand group dynamics and assessment. The study intended to use students' problem statements to assess learning outcomes. However, after recognizing students' struggles to write the statements, using small group discussions as reflective activities provided a rich source of data on how students learned with the VR in ways not demonstrated on the assessment. While this analysis is ongoing, preliminary findings suggest students developed curious dispositions about what it means to do science and be a scientist. This suggests learning with VR is better understood as a collaborative exercise in meaning-making aligned with a knowledge-building framework (Scardamalia & Bereiter, 2005), than an individual endeavor. The compromises made by being flexible and suiting the intervention to learning rather than maintaining a controlled experiment therefore provided fruitful insights about how VR field trips can engender a rich learning experience, particularly when peer collaboration is engaged.

Developing capacity for continuous improvement

Conducting DBIR in classrooms required giving control of the technology to the teacher and students. While its novelty waned as students used the technology over time, their mastery increased. With each lesson, the students

more easily set up and put away the equipment, navigated to the applications, and operated the controllers. In interviews and discussions, they shared critiques for how VR experiences could be improved. The teacher gained an understanding of VR's affordances and applications that would be valuable in his classroom. This points to the ways doing research in classrooms with teachers and students can help build their capacity to improve the implementation of emerging technology in education.

Discussion

While this study illustrates the benefits of using DBIR for studies of learning with VR, it also has several limitations. Future research should investigate longer-term implementations with multiple iteration cycles and capacity building such as training teachers to create and school-wide integration. The flexible and iterative process provided holistic description of student learning with immersive technology, but limits claims about causality and generalizability to other media or populations. However, collaborating with an educator to use VR to tackle a persistent problem of practice and answer the author's research questions about how young people learn with VR over time led to a set of lessons using VR field trips that are meaningful and feasible in classrooms, as well as research findings that would have been difficult to uncover in a more controlled experiment. Pivoting from individual written work to knowledge-building discourse revealed students' curious dispositions about what it means to do science, a learning outcome not captured on the individual assessments. The iterative collaboration also helped highlight the ways VR field trips need to be scaffolded to support student learning.

References

- Bailenson, J. (2018). *Experience on Demand: What Virtual Reality Is, How It Works, and What It Can Do*. W. W. Norton & Company.
- Dede, C., Jacobson, J., & Richards, J. (2017). Chapter 1: Introduction: Virtual, Augmented, and Mixed Realities in Education. In D. Liu, C. Dede, H.-M. Huang, & J. Richards (Eds.), *Virtual, Augmented, and Mixed Realities in Education*. Springer Nature.
- Fishman, B., Marx, R. W., Blumenfeld, P., Krajcik, J., & Soloway, E. (2004). Creating a Framework for Research on Systemic Technology Innovations. *Journal of the Learning Sciences*, 13(1), 43–76.
- Fishman, B., Penuel, W., Allen, A.-R., Cheng, B. H., & Sabelli, N. (2013). Design-Based Implementation Research: An Emerging Model for Transforming the Relationship of Research and Practice. *National Society for the Study of Education*, 112(2), 136–156.
- 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.
- Johnson-Glenberg, M. C., Bartolomea, H., & Kalina, E. (2021). Platform is not destiny: Embodied learning effects comparing 2D desktop to 3D virtual reality STEM experiences. *Journal of Computer Assisted Learning*, 37(5), 1263–1284.
- Markowitz, D. M., Laha, R., Perone, B. P., Pea, R. D., & Bailenson, J. N. (2018). Immersive Virtual Reality Field Trips Facilitate Learning About Climate Change. *Frontiers in Psychology*, 9.
- 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.
- McKenney, S. (2018). How Can the Learning Sciences (Better) Impact Policy and Practice? *Journal of the Learning Sciences*, 27(1), 1–7.
- Petersen, G. B., Petkakakis, G., & Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. *Computers & Education*, 179, 104429.
- Research + Practice Collaboratory. (n.d.). *DBIR*. LearnDBIR. Retrieved October 26, 2022, from <http://learndbir.org/principles>
- Scardamalia, M., & Bereiter, C. (2005). Knowledge Building: Theory, Pedagogy, and Technology. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (1st ed., pp. 97–116). Cambridge University Press.
- Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing Our Lives with Immersive Virtual Reality. *Frontiers in Robotics and AI*, 3. <https://doi.org/10.3389/frobt.2016.00074>
- Southgate, E. (2020). *Virtual Reality in Curriculum and Pedagogy: Evidence from Secondary Classrooms*. Routledge.
- Yoon, S. A., & van Aalst, J. (2017). A Note From the Incoming Editors. *Journal of the Learning Sciences*, 26(1), 7–9.