Immersive Place-based Learning – An Extended Research Framework

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Abstract

At Kelvar 2019, we introduced a research framework for immersive virtual field trips (iVFTs) as a key element of immersive place-based learning. Organizing our research in this framework has been highly successful. We will be documenting outcomes of our research guided by this approach here, both as a conceptual extension of the original framework and through discussing three new studies that complement our existing empirical studies aimed at providing an evidence-based basis for assessing immersive learning. We believe in and strongly argue for the necessity of such a framework as we witness for the first time in the history of immersive technologies opportunities for comprehensive studies of immersive place-based learning, given the accessibility of the technology and the growing need for an evidence-based foundation. In detail, to assess the value of immersive experiences for learning, we argue for the necessity to compare them to traditional media such as desktop environments; correspondingly, we extended the framework to include non-sensing media. We conducted several new studies (both submitted and still unpublished work) that fill in gaps such as comparing desktop versus immersive VFTs, comparing Oculus GO versus Quest, and we describe our first experiences with moving immersive learning into the category of advanced iVFTs using both simulations and gamification as potential advantages of immersive technologies. We critically reflect on the results and lay out an agenda for future research on immersive place-based learning.

Index Terms: Human-centered computing—User studies; Human-centered computing—Virtual reality; Human-centered computing—Empirical studies in HCI;

1 Introduction

Immersive place-based learning, realized through immersive virtual field trips (iVFTs), is a prime example of the potential of immersive technologies to transform education [26,29,35]. This is true for the earth sciences where any kind of field work and field site experiences are intimately linked to how disciplines such as geology understand themselves. Field work in geology is tied to defining the very nature of the discipline, from critical discoveries (e.g., geologic time scales [32]) to the firm belief that field work is essential for educating the next generation of geologists, calling field camps—field work—a rite of passage. The importance of field experiences in earth sciences has numerous advocates [15], yet only sparse empirical evidence exists that supports its effectiveness [5]. Experiences in the field are equally important for the humanities and disciplines like global health where students immerse in different cultures. This includes experiencing profound and often challenging differences of how other societies work, teaching students cultural humility, adaptability, and essential problem-solving skills [39].

Place-based learning, through physical but also virtual immersion, occurs in environmental education where learners focus on understanding issues within a local community before addressing more complex global issues [28]. This learning approach combines the practices found in problem-based learning and experiential learning to nurture a sense of place that generates an authentic learning experience, something valued across disciplines from the social to the physical sciences. Placing learners into the real-world with a specific problem that is relevant to a location provides a more direct connection of key learning points that learners can understand and has the potential to foster a deeper engagement [31]. Place-based learning can be used to scaffold other learning approaches such as discovery-based learning, which is founded in a constructivist approach where the act of discovery in problem-solving is guided by a teacher through steps of scaffolded instruction [28]. The blending of place-based and discovery-based learning approaches in immersive virtual environments allows for the “perceptual blending of the real and the virtual world with its place-based authenticity” to enable a better learning experience ([11], p. 2).

Despite the excitement for immersive technologies as a potentially paradigm-shifting medium for place-based education, it is important to stress the need for serious empirical evaluations as there is still a substantial gap in our knowledge [26]. We are lacking design guidelines for creating optimal educational content [12] as well as pedagogies for this new medium [6]. Furthermore, we are finding that central topics such as immersion and presence are both confusing and have resulted in contradictory empirical data [24,21]. We strongly believe that with the increased availability and accessibility of immersive technologies, it is imperative to organize studies into frameworks to systematically address pertinent research questions.

The remainder of this paper is structured as follows: We first discuss an extension of our earlier framework to reflect on new insights into the evaluation of immersive place-based learning experiences. We then discuss new studies complementing our existing portfolio of evidence-based evaluations in environmental settings and discuss emerging research and how it would fit into our framework. We conclude with a critical reflection and perspective on future work.

2 Revision of Immersive Learning Framework

In our [18] paper, we introduced a framework for immersive virtual field trips as a critical component of immersive place-based learning. In a nutshell, the framework consists of two conceptual constructs, the first is a taxonomy for iVFTs, originally introduced in [17]; the second is SENSATIUM, the SENsing-ScaAlibility Trade-off contInuUM. There was no need to revise the taxonomy but we extended SENSATIUM (see Figure 1) after reflecting on creating a comprehensive evidence-based approach for immersive learning assessments. The iVFT taxonomy has three components that have guided our design of iVFTs and their evaluation. As a reminder, basic VFTs replicate the actual physical reality of a site. Users are confined to the same physical constraints experienced during an actual field trip (AFT). Plus VFTs offer perspectives and information that cannot be provided in the normal confines of physical reality. Yet, they still consist of recordings/replications of the actual physi-
3 RESEARCH FRAMEWORK AND EMPIRICAL EVALUATION

Since 2017, we conducted a large number of empirical evaluations of immersive experiences for place-based education. We have run over a dozen studies focusing on largely geoscience education but also expanding into biology and energy education. We will not go into all the details here, but we will contextualize our new experiments with the overall approach of this research and present new empirical evidence we have added to the framework since March 2019.

To contextualize the empirical results, we briefly discuss the design of immersive place-based learning experiences. Our experiences are cutting across several workflows that allow for creating immersive experiences for place-based learning. We use a combination of methods ranging from basic technologies such as 360° photography (using a high-end camera, Panono, with 36 individual lenses), to creating models of physical sites using structure-from-motion, and on to modeling physical environments from scratch using digital elevation models in combination with assets such as trees, shrubs, or water features. The latter, as we will detail below, is the most labor-intensive approach that allows for realizing both interactivity and simulations (see Section 3.3). Figure 2 provides examples of 360° photography, 3D models derived via structure-from-motion, and a designed 3D environment.

Using this combination of approaches to create immersive experiences for place-based education, we systematically evaluate which features of immersive experiences interacting with different sensing/interaction opportunities influence user engagement, sense of presence, and different performance measures. Figure 3 provides an overview of the different studies we have conducted since 2017 and where they are located within our framework. New studies are highlighted in bold and will be discussed in more detail below.

3.1 Desktop versus iVFT

There are numerous studies addressing the question of how much immersion is necessary and desirable, trying to quantify the hypothesized effects that higher levels of immersion provide, for example, on the sense of presence, learning, or user engagement [4, 27]. Immersion in these studies and in this article is defined as referring to the system characteristics [36]. [37] was one of the first to propose a connection between immersion, the resulting sense of presence, and performance improvements. This direct connection later has been criticized by [2] and replaced by a more intricate model of different aspects of immersion affecting different output measures. Empirical studies have been largely supportive of increased levels of immersion but not without controversy. In a recent article, [22] found that moving from a desktop to an immersive headset improved memorization. In contrast, [25] found that higher levels of immersion led to an increase in the sense of presence while at the same time lowering learning performance. Other studies such as [30] found that increased immersion has an effect on feelings of team membership, but only if enjoyment is taken into account. The bottom line is that increasing immersion, for example, by moving from a desktop screen to a head-mounted display, as appealing as it seems, does not automatically affect output measures such as learning, even though enjoyment, sense of presence, and feelings of awe might be increased. A direct connection between subjective experiences
and objective performance measures is, however, something that has been proven to be flawed—in multiple studies and disciplines [2, 24]. This aspect deserves to be reflected in SENSATUM and we included non-sensing digital environments such as traditional desktops that are deprived of advanced, natural interaction opportunities (see Figure 1). We also designed a study that we briefly discuss here (see [43] for more details). Although a pilot, the results are a reminder and call to critically explore the promises of immersive learning experiences and not follow plausible yet non-evidence-based assumptions and propositions.

In Fall 2019, we divided an introductory geoscience lab section into three groups with the first group attending an actual field trip to the Salona Formation (AFT; N = 26) in Central Pennsylvania. The second and third groups, respectively, experienced a 20-minute VFT to the same site on either desktop (dVFT; N = 13) or through an HTC Vive Pro headset (iVFT; N = 13). In the dVFT, students sat in front of a desktop screen, and used keyboard and mouse to look around and interact with the virtual content. In the iVFT, the experience was the same except the students wore an HTC Vive Pro headset, stood in the center of the tracking area, and used a hand-held controller to interact with the environment. The virtual field site was composed of 12 discrete locations rendered as high-resolution 360° images in which students had access to the environment at both normal eye and 27-foot high levels (adapted from [42]). Students could select information icons stitched onto the 360° image for supplementary information about the Salona Formation. The 360° image along with each piece of additional information was associated with a short audio narration pre-recorded by the course instructor that guided students through ongoing observations.

Students in the dVFT and iVFT groups were tested on a set of multiple-choice questions embedded in the experience and answered self-report questions including VR features, usability, and sense of presence (self-location: [40]) after the virtual experience. In addition, students in all three groups were asked self-report and open-ended questions about their motivation (field trip enjoyment) and learning experience (perceived learning effectiveness; [23]). To examine whether the immersive setup was an effective medium to generate positive learning experiences compared to a traditional desktop learning practice, we examined differences in media factors and learning outcomes between dVFT and iVFT groups using independent two-sample t-tests. The learning experience of VFTs in contrast to an AFT experience were examined through the one-way analysis of variance (ANOVA). Bayesian analyses were conducted to boost statistical power for non-significant results [42]. The estimated Bayes Factor is a statistical index that quantifies the evidence for a hypothesis. We reported BF10's below to indicate the Bayes Factor supporting the alternative hypothesis over the null hypothesis. If BF10 is larger than .33 but smaller than 1, there will be anecdotal evidence in favor of the null hypothesis (i.e., the values of the target variable were similar between groups). If BF10 is larger than 1 but smaller than 3, there will be anecdotal evidence in favor of the alternative hypothesis (according to [11]).

Our t-test results indicate that students reported being more present and show higher motivation to learn in the iVFT group compared to the dVFT students (self-location: iVFT: M = 3.86, SD = .75; dVFT: M = 2.99, SD = 1.07; t(214) = 2.4, p = .026, d = .94; field trip enjoyment: iVFT: M = 4.62, SD = .51; dVFT: M = 4.08, SD = .73; t(214) = 2.18, p = .04, d = .86); but students in the iVFT group did not learn more compared to those in the dVFT group (in-VFT test score: iVFT: M = 4.69, SD = .85; dVFT: M = 4.92, SD = .86; t(240) = -.09, p = .50, d = -.27, BF10 = .43; perceived learning effectiveness: iVFT: M = 4.03, SD = .81; dVFT: M = 3.95, SD = .87; t(239) = .23, p = .82, d = 10, BF10 = .46). Our one-way ANOVA results indicate that, across both VFT groups, students reported higher scores for learning experience than the AFT group (perceived learning effectiveness: AFT: M = 3.45, SD = .86; F(2, 49) = 2.64, p = .08, η² = .10; BF10 = 1.08). These findings show a positive learning effect of VFTs (both iVFT and dVFT) compared to traditional field trips (AFT), suggesting that place-based learning can be effectively delivered through digital media. However, a standard desktop screen with a mouse and keyboard seems to be sufficient to fulfill the needs for learning geologic concepts and principles even though motivation and sense of presence were significantly lower. More details on this study can be found in [43].

### 3.2 Oculus Go versus Quest

Our first investigations of using the Oculus Quest versus the Oculus Go explored the very critical aspect of scalability of immersive experiences in the classroom. In contrast to Oculus Go that offers 3DOF orientation tracking, the Oculus Quest is a full 6DOF headset with inside-out tracking, allowing a high-performance wireless room-scale experience [9], moving it closer to an HTC Vive (see Figure 1). The ultimate goal of this research is to examine whether the added features of the Quest—6DOF headset with inside-out tracking, higher display resolution (2880x1600 vs. 2560x1440), and more natural object-interaction capabilities—add any more educational value to iVFT experiences than more basic VR headsets (e.g., Samsung Gear VR or Oculus Go).

One of the immersive learning experiences we recently created was designed for a large, introductory biology class at the 200 level at the authors’ university. The immersive experience was designed to be short (5 min) and integrated into the students’ regular lab sessions as a preparation for an actual field trip, a set up we found to be a successful application of immersive learning experiences [19].

The VR application consisted of a 360° image based tour through different locations at the Millbrook Marsh Nature Center. This iVFT was fully automated with pre-recorded audio commentary by the instructor. The application started with an overview map of the site and participants then could start the tour using gaze control. Participants could look around freely in each 360° image but otherwise the tour did not include any further interactions. Participants did not have to use a controller for the experience. The tour included two embedded videos demonstrating activities the students would have to perform during the AFT.

We had a total of 210 participants (control group; N = 114, Oculus Go; N = 57, (Oculus Quest; N=39) out of the 400 total enrolled. Students who consented to the iVFT experience were randomly assigned to the Quest or Go experience with the control group being a different lab section. After the iVFT, students filled out a survey concerning their overall experience of the VR tour. In the second and third groups, respectively, experienced a 20-minute VFT on the actual field trip (approximately one week after their VR tour experience) and filled out another survey with self-report questions regarding their AFT learning experience, enjoyment, and spatial situation model, as well as a multiple-answer question asking for choosing at most two from a list of information sources that best prepared them for the AFT.

Students in the control group did not use the iVFT. They participated in the actual field trip only and received a survey afterwards (with most questions identical to those of the iVFT students for comparing different experiences). To evaluate the effects of different VR headsets (Quest vs. Go) in the context of place-based learning in biology as well as the educational value that iVFTs may add to the AFT, we examined the main effects of Quest, Go, and control groups on the learning experience and field trip enjoyment, using one-way ANOVAs. There were no significant main effects (learning experience: Quest: M = 4.01, SD = .77; Go: M = 3.84, SD = .8; control group: M = 3.84, SD = .89, F(2, 207) = 0.65, p = .53, η² = .006; field trip enjoyment: Quest: M = 3.91, SD = .85; Go: M = 3.68, SD = 0.86; control group: M = 3.73, SD = 1.01, F(2, 207) = 0.79, p = .46, η² = .007). Our results suggest a minimal, non-significant advantage of VR headsets and no substantial differences between the two headsets. However, with regard to the information sources

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that best prepared students for the field trip, all groups felt direct communication with the professor was important (control: 78.9%, Go: 47.4%, and Quest: 61.5%). Yet in the iVFT the iVFT experience rated their experience as being the most informative. More students across both iVFT groups felt the virtual experience was an important information source over other options (Go: 84.2%, Quest: 71.8%). This finding indicates that, although there was no significant difference comparing perceived learning effectiveness between the two iVFT groups and the control group, the virtual field trip is highly valued as an authentic preparation for the actual field site visit. These results are consistent with previous findings [19].

A possible concern about the effect of different VR headsets is that the non-significant effect of Quest vs. Go might be due to the almost identical virtual experience. Students in both iVFT groups were seated in swivel chairs and experienced an automated tour without holding controllers and using only 3DOF head tracking, even for the Quest. The lack of interactions with the virtual field site (not utilizing the 6DOF tracking) prevented users from benefiting from the more advanced features of the Quest, leaving display quality as the main difference.

In response to this concern, we tailored a geoscience iVFT that has been used as the immersive intervention across multiple VFT studies [16–19] to fit the specific affordance of the Oculus Quest for a room-scale experience in Fall 2019. This iVFT leads students to the Reedsville and Bald Eagle formations accessible through an outcrop about 12 miles from State College, PA. Similar to the setup for the HTC Vive, students using the Quest stood in the center of the tracking area and held one Oculus touch controller to experience the iVFT. Their immersive learning experience was compared to that of students viewing the same iVFT through the Oculus Go in Fall 2018. Instead of allowing students to move around freely, Go users were seated in swivel chairs allowing them to turn their heads and bodies to perceive vestibular feedback. The students’ iVFT experience was assessed in terms of sense of presence, simulator sickness [14], field trip enjoyment, and perceived learning effectiveness. Independent t-tests were conducted to evaluate the effects of Quest vs. Go on geology field learning. We did not find a statistical significant difference between Quest (N = 26) and Go (N = 19) (self-location: Quest: M = 3.59, SD = .79; Go: M = 3.11, SD = 1.09; t(31.1) = 1.66, p = .11, d = .53; simulator sickness: Quest: M = 2.05, SD = .73; Go: M = 1.86, SD = .57; t(42.8) = .96, p = .34, d = .28; field trip enjoyment: Quest: M = 3.96, SD = .82; Go: M = 3.79, SD = 1.13; t(31.2) = .56, p = .58, d = .18; perceived learning effectiveness: Quest: M = 3.5, SD = .95; Go: M = 3.47, SD = 1.02; t(37.2) = .09, p = .93, d = .03), so we cannot conclude the Oculus Quest experience led to a better learning experience here.

3.3 Advanced virtual field trips

For the last project we will discuss a work-in-progress that serves as an advanced form of a virtual field trip: a serious game called CZ Investigator [34] was designed to inform and educate the general public about the concept of the Critical Zone (CZ). To revisit our definition of an advanced VFT, it requires the generation of models and simulations that can be manipulated to provide experiences not otherwise known as a model of reality [8]. The use of a model of the actual environment in VR enables more direct comparisons to be made between our cases using basic and plus VFTs. We discuss the details of the game elements used to form the advanced VFT.

The game uses a VR headset to promote immersion and natural interaction with the environment [7]. The game environment is based on the actual Shale Hills Critical Zone Observatory (CZO) in Pennsylvania, with a 2–4-meter accuracy in topography, and elements of vegetation and natural resources found in the actual site, otherwise known as a model of reality [8]. The agent informs the player of a logging company planning to deforest parts of the Shale Hills, and that the newspaper will write an article on how this decision will influence the CZ of this area with the player as the lead investigative journalist. Throughout the interaction with the agent, the player is provided a basic definition of what a CZ is, and asked to go to the Shale Hills to experience and explore the different components of the CZ, and can ask for more information by selecting prompted conversation statements. While at the CZ, the player investigates and gathers evidence on how the CZ can be affected by the logging project. Guiding the serious game experience and design are the learning objectives: 1) understanding what a CZ is (based on a concrete experience in addition to abstract conceptualization) and 2) exploring the effect of natural and human processes on the comprising components of a CZ.

In the second scene, the player is transported to the Shale Hills CZ area. As each component of the CZ is designed to be a separate mission step, the player only focuses on the hydrosphere in this first working-version of the game. The player is introduced to another agent, a CZ expert who communicates through emails received on a tablet, which provides more specific instructions in the Shale Hills area along with feedback when a task is complete. The player explores and investigates the hydrosphere component of the CZ, by experiencing (based on the learning cycle of Kolb [20]) the effects of natural (e.g. rain) and human (e.g. deforestation) processes on the flow and storage of water in the CZ. With respect to the natural processes, the player can manipulate environmental variables (i.e. rain) to see how it affects the flow and storage of water in measurement wells (Fig. 5(a)) and a weir (Fig. 5(b)). For human actions on the CZ, the player experiences the effect of deforestation on the flow and storage of water by cutting down one acre of trees to observe the impact on the infiltration of water (leading to potential hydrological natural hazards such as flood).

As part of this work-in-progress, we conducted an informal pilot
We argue that it is essential to set up research frameworks to systematically address opportunities and challenges of immersive virtual learning environments. Given the possibilities that arise from immersive technologies becoming a medium of mass communication, we will go into the VFT. It will require additional studies and careful discussions to identify the advantages of immersive experiences compared to traditional desktop experiences are not increased. There are several reasons to rationally explain this, for one, we, as users, are conditioned to work on desktop computers and while they may not be ideal, we are accustomed to them. That familiarity can play a large role from a design perspective and considering the nature of the content a learner will experience. For experiences like a virtual field trip that largely relies on 360° images rather and a full 3D model (except for when interactions with the environment are required), it may not be completely necessary to use full immersion. For instance, outcrops are usually linear, so we may actually not lie in immediate learning gains but closer to what is found with traditional fieldwork, a longer term engagement and interest that a student might develop. For this, however, we need longitudinal studies that are still rare, not just in studies of immersive experiences but technology and learning as a whole [10].

ACKNOWLEDGMENTS

This work is supported through a Penn State Strategic Planning award. We thank Peter La Femina for his collaboration. Dr. Klippel would like to acknowledge funding through the National Science Foundation grants #1617396 and #1526520.