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Research Framework for Immersive Virtual Field Trips

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ABSTRACT

Virtual field trips have been thought of and implemented for several decades. For the most part, these field trips were delivered through desktop computers and often as interactive but strictly two-dimensional experiences. The advent of immersive technologies for both creating content and experiencing places in three dimensions provides ample opportunities to move beyond the restrictions of two dimensional media. We propose here a framework we developed to assess immersive learning experiences, specifically *immersive virtual field trips* (iVFTs). We detail the foundations and provide insights into associated empirical evaluations.

Keywords: immersive learning, virtual field trips, research framework.

Index Terms: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

INTRODUCTION

Virtual field trips have been thought of and implemented for several decades [1]. For the most part, these field trips were delivered through desktop computers and often as interactive but strictly two-dimensional experiences [2]. The advent of immersive technologies for both creating content and experiencing places in three dimensions provides ample opportunities to move beyond the restrictions of two dimensional media [3]. Everyone is now in the position to capture a place on earth through a 360° camera or by utilizing effective photogrammetric methods and in turn create immersive place-based learning experiences.

While the methods for capturing three-dimensional or better 360° information are improving dynamically, they also offer conceptual stability. 360° cameras and techniques such as structure from motion (SfM) are established and might become more user friendly or provide higher resolutions but the results they deliver remain the same: 360° images and 3D models. In contrast, we find dynamic developments in the area of xR (mixed and virtual reality) that allow us to access immersive content, this is true for the high-end spectrum of consumer grade immersive technologies such as computer-based head-mounted systems as well as the most dynamic end of the spectrum, that is, mobile xR solutions.

All these opportunity-opening developments make the most important contribution of academia to the field of xR challenging: providing empirical evaluations of immersive learning [4, 5]. In response to this challenge we propose here a framework we developed to assess immersive learning experiences, specifically *immersive virtual field trips* (iVFTs). Some aspects of this framework are specific to field trips while others are universal for immersive learning experiences.

We describe our approach starting with a brief discussion of some core concepts essential to place-based learning, discuss two conceptual tools, a continuum and a taxonomy, that ultimately allow for structuring our studies at the meta-level. We will reference a number of our own empirical studies that are starting to populate the framework, and discuss future work directions and research.

CORE CONCEPTS – A SELECTION

There are several concepts/themes relevant for our research on immersive virtual field trips. Two of the most prominent ones are *place* and *scale*. *Place* as it allows for a framing of immersive virtual field trips in discussions such as place-based learning; *scale* as a critical topic in environmental education that could particularly benefit from immersive learning experiences but has so far not received sufficient attention. We briefly review both here.

Place is central to theories in all environmental sciences such as geography, geosciences, landscape architecture, environmental psychology, or environmental education [6]. This multi- and often transdisciplinary approach to place has contributed to a rich corpus of literature including a plethora of both qualitative and to a lesser extent quantitative approaches to assess the importance of place on learning [3]. Place is notoriously difficult to define but the most commonly accepted definition is that place is a location with meaning [6]. This definition holds for both the humanities and physical sciences.

The role that immersive technologies play in place-based education is an open question. It is intimately linked to endeavors to create realistic experiences of places in virtual environments aiming at high levels of display and interaction fidelity. With the advent of immersive technologies such as 360° cameras and platforms such as ThingLink™ or RoundMe™, the foundations exist to collect media and create scaffolds for place-based education without the requirement of physically visiting a place. It is without question that low-tech/low-cost approaches such as those based on 360° imagery fall short of actual place experiences as they only offer limited interactivity. And, even high-tech solutions will not be able to cater to all senses that scholars

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in place-based disciplines consider important such as smell or touch (but see [7]).

However, immersive technologies also offer access to a place not available through experiencing physical reality. The quality of going beyond reality [8] is a key advantage of virtual environments. In the case of experiencing a place, this could be achieved through providing experiences at a different time such as the past or the future, or, as we will discuss in the next section, through changing the scale of an embodied experience.

Scale. We find, again, numerous definitions and taxonomies across disciplines that aim at theorizing *scale*. Lam and Quattrochi [9] offer the following definitions: *Cartographic scale* is the relationship between the distance on a map to the corresponding distance on the surface of the earth. *Geographic scale* refers to the spatial extent of a phenomenon or a study. *Operational scale* corresponds to the level at which relevant processes operate. Scale can also refer to measurement or the level of resolution, such that large-scale studies incorporate coarse resolution while small-scale studies are based upon fine resolution. Montello [10] suggests that scale is a psychological concept that comes into play when people experience a place. He defines scale as the projective size of the place relative to the human body. In other words, place is a scale-dependent environment in which people perceive relations between objects by relating the projective size of that environment to their body and actions (e.g., looking, walking).

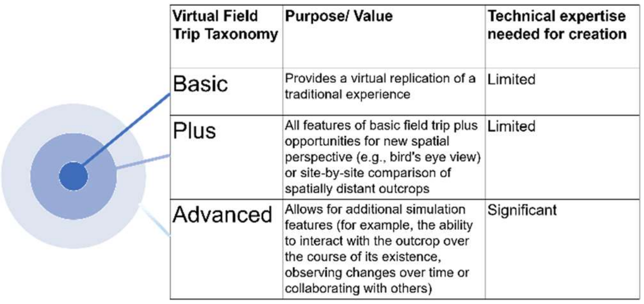
Experiencing a place at different scales and thereby changing one's perspectives is essential for all observational sciences, which essentially all environmental sciences are. Within immersive experiences, we can systematically address, for example, how users access a place at different scales. To foster learning, we can provide a scaffold to understand relational aspects of entities in the environment at different geographic scales in ways not possible through experiences at ground level alone. Figure 1 shows an example of parts of 360° images either taken at ground level or at a height of 27 feet using a particularly large tripod. The aspect that obviously changes is that of the spatial extent (geographic scale) that is accessible to a user through his or her egocentric perspective. What this means though is that a user has access to a larger number of entities and their relations through direct observation and embodied interaction. This embodied experience and the potential to offload information into the environment have long been deemed critical for the efficient processing of information by the human cognitive system [11, 12]. Storing information is seen as expensive while reading information directly from the environment is comparatively cheap [13, 14]. Through increasing the geographic scale that is directly accessible to a human user as an embodied experience allows for providing an efficient way to offload the understanding and storing of relational information into the environment. This aspect of immersive experiences has not received sufficient attention in educational settings.

TWO CONCEPTUAL TOOLS

In this section be briefly describe two conceptual tools that we have established to guide our research, a virtual field trip taxonomy and SENSATIUM, the **SEN**sing-**S**c**A**lability **T**rade-off cont**I**nu**UM**.

Figure 1: 360 image at ground level (left) and elevated level (right). The 27'perspective increases the geographic scale of a single viewpoint allowing for reading off information from the environment.

The virtual field trip taxonomy. In response to possibilities arising from immersive experiences and associated technologies to create them, we developed a simple taxonomy distinguishing three general kinds of iVFTs ([15]; see Figure 2). The distinctions made are important as they reflect fundamentally different aspects of virtual reality and how immersive experiences may facilitate learning. In a nutshell: *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 are still recordings/replications of the actual physical reality. These advancements may include a bird's eye perspective using images from large tripods or drones (see Figure 1), a comparison of outcrops side-by-side of physically distant field sites, or the possibility to reduce the scale of a 3D model to allow for embodied measurements that would otherwise be challenging. *Advanced VFTs* require the generation of models and simulations that can be manipulated to create immersive experiences. Instead of recording reality, advanced VFTs create access to otherwise inaccessible physical reality, such as geological past or future, underground, or a simulation that shows the genesis (or competing hypotheses of it) of a formation. Advanced VFTs also allow for collaboration in immersive experiences.



Virtual Field Trip Taxonomy	Purpose/ Value	Technical expertise needed for creation
Basic	Provides a virtual replication of a traditional experience	Limited
Plus	All features of basic field trip plus opportunities for new spatial perspective (e.g., bird's eye view) or site-by-site comparison of spatially distant outcrops	Limited
Advanced	Allows for additional simulation features (for example, the ability to interact with the outcrop over the course of its existence, observing changes over time or collaborating with others)	Significant

Figure 2: Taxonomy of immersive virtual field trips (iVFTs) from basic, to plus, to advanced [15].

SENSATIUM. The second conceptual tool we developed is termed SENSATIUM, the **SEN**sing-**S**c**A**lability **T**rade-off cont**I**nu**UM** (see Figure 3). SENSATIUM reflects the sensing capabilities and resulting interaction opportunities of different xR systems and, importantly, associated costs: Greater sensing can be useful for creating more enriching experiences, producing a finer classification of different learner types, and understanding how and what types of interactions best facilitate learning. Yet, greater sensing comes at a cost that reduces scalability (i.e., accessible to fewer learners or requiring substantial investments). Using SENSATIUM allows us to assess how much we gain by adding a more comprehensive portfolio of sensors to immersive learning environments and describes what opportunities for advanced interactivity and adaptation are possible at which point in the continuum. In a nutshell, on the low end of the sensing side of the continuum we have xR systems such as the Oculus GO. These are stand-alone headsets at the entry level (about USD200). They offer limited interactivity and limited capabilities for sensing human behavior, both actual and virtual. They allow for tracking rotational head movements but not translation. One step up are systems like the HTC Vive which allow for room scale tracking of (physical) learner movements. Additionally, the standard Vive allows for both head and controller tracking to record advanced interactions and body movements. On the high end of the datafication of learner behavior are systems like the Vive supplemented by both body trackers and eye tracking. The basic version of body tracking requires Vive body trackers to be fixed to the feet, torso, and upper arms of a user. This combination allows for a sophisticated recording of user interaction and behavior in an immersive learning environment. New systems such as the Oculus Quest (standalone mobile headset) will allow for inside-out tracking. This will effectively move mobile systems closer to the HTC Vive along the SENSATIUM. There are numerous opportunities to expand sensing on the right end of the spectrum that we are aware of but that are beyond the scope of this paper.

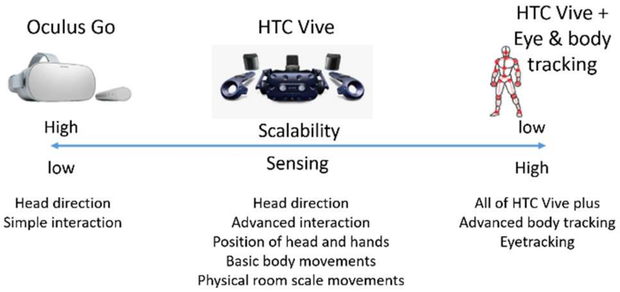


Figure 3: SENSATIUM, the SENsing-ScAlability Trade-off contInuUM.

THE IMMERSIVE VIRTUAL FIELD TRIP - EXAMPLE

We are developing a repository of field trips focusing first on Pennsylvania (for the purpose of easy access to empirical, comparative evaluations) while working on expanding our portfolio. We briefly describe here the general materials used in the first iVFT, which we have and are continuously improving for continuous empirical evaluations.

We used a combination of high resolution 360° images and 3D models using structure-from-motion methods to capture the field sites digitally. The Unity3D game engine in combination with the HTC Vive or more recently Oculus GO is delivering the actual immersive, interactive experience. One of the main developments we added to the original virtual field trip are 360° images not only at ground-level but also at the height of 27‘. We have been experimenting with this approach we call *pseudo-aerial* for some time [16] and the effect often is critical to understanding an environment. The elevated perspective increases the geographic scale visible from a single point of view (see Figure 1). This elevated perspective can reveal, for example, spatial patterns otherwise not visible. While not the same as drone images, the tripod used to create these images still offers a substantial change in perspective and can be used without legal issues and in areas restricted for drone flight.

In addition to the 360° images, we enhanced students' access to essential details of the outcrop through high-resolution DSLR images as well as additional information usually found in the field manual through interactive markers embedded in the 360° images. Students access this information using a controller and clicking a marker. Figure 5 exemplifies such additional information: a red box (marker) embedded into a 360° image. Upon selecting the marker, students received a high resolution image taken with a DSLR camera (Nikon D7200, not shown) as well as a chart explaining (or reminding) students of different depositional environments.

Figure 4: Example of combining different resolutions and integrating interactive content. A red marker in a 360° image (left) indicates the availability of additional information.

While 360° images are an efficient way to create immersive experiences and allow for some interactivity, many aspects of why field trips are used in earth science education require advanced interactivity offered only through 3D models. To allow students to perform the same activities virtually that they would perform during an actual field trip, we used structure from motion [17] for parts of the outcrop and created a 3D model. Figure 5 (top left) provides some details. The exercise that students perform at the actual outcrop is measuring the thickness of layers along a section of the outcrop (location 6, see Figure 6). Students were able to change the ruler length and place the ruler onto the outcrop surface to measure thickness of rock layers mimicking measuring activities at the physical site (Figure 5, top right). A data board, which displayed the set of measured widths, allowed students to review, organize and edit the data they collected (Figure 6, bottom). The thickness data along with a screenshot of the outcrop model were sent to students after the experiment such that they could complete the official lab assignment, that is, to create a stratigraphic map.

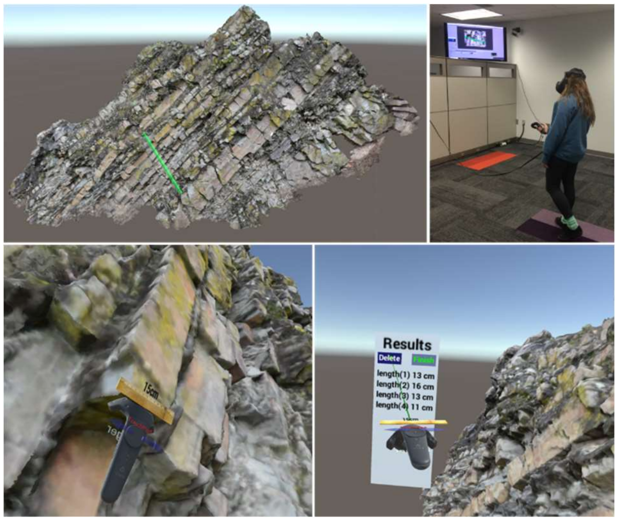


Figure 5: Shown is an example of a 3D model created for parts of the Reedsville/Bald Eagle formation. Top left shows the outcrop model with an indication of which part students were ask to measure. Bottom left shows a close up of the outcrop model with the ruler tool used on top of a HTC Vive controller. Bottom right shows the virtual board on which the measurements are recorded and that students can use to delete measurement. Top right shows a student performing the measurement.

Figure 6 provides an overview of the field site in form of an aerial image summarizing the discussion above. The numbers indicate locations at which we took high-resolution 360° images. Locations indicated by yellow numbers allow users to experience the outcrop from an elevated perspective (27'), locations with a white circle offered audio information, and the blue arrow shows the location at which students measured the stratigraphy by accessing a 3D model created using structure from motion (see also Figure 5).

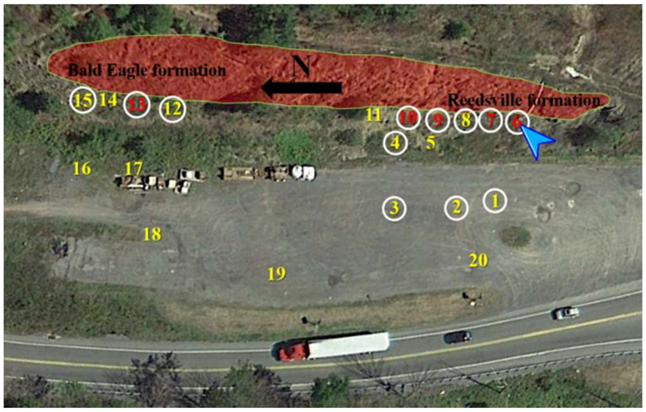


Figure 6: Aerial image of the actual field site. There are 20 locations accessible through high-resolution 360° imagery on the ground plus 15 elevated 360° images taken at the height of 27 feet using a megamast (yellow numbers). Audio scripts were attached to 12 locations (white circles). Location 6 is the entry to a 3D model of the outcrop used for measuring the stratigraphy (blue arrow). (Source: Google Maps)

All this information was integrated into a Unity project. To allow for basic navigation between locations we placed arrows on the ground that participants selected with their controllers. Arrows were only available in a meaningful, predefined sequence mimicking the storyline of the actual field site visit. In a free exploration phase at the end, all arrows would be activated (to neighboring locations). The opportunity to access the elevated perspective as well as returning to the ground were indicated through red circles (something we may make subtler in the future).

RESEARCH FRAMEWORK AND EMPIRICAL SPIN-OFFS

We synthesized the theoretical discussions above into a series of empirical evaluations of the effectiveness of immersive learning experiences, three consecutive semesters with nearly 150 participants (for an overview, see Figure 7). We are continuing to develop virtual field trips and constantly improving them and, for the most part, evaluate them holistically or evaluate aspects of them as part of an actual lab assignment aiming for ecological validity. Additionally, we have singled out central aspects of immersive learning experiences and channeled them into more controlled experiments. We have started to evaluate these aspects (e.g., locomotion, scale) and their effects on spatial learning and are in the process of extending this line of basic research into more advanced concepts such as system thinking [18], psychological distance [19], and Bloom's taxonomy [20], which is a framework used to categorize learning and educational goals.

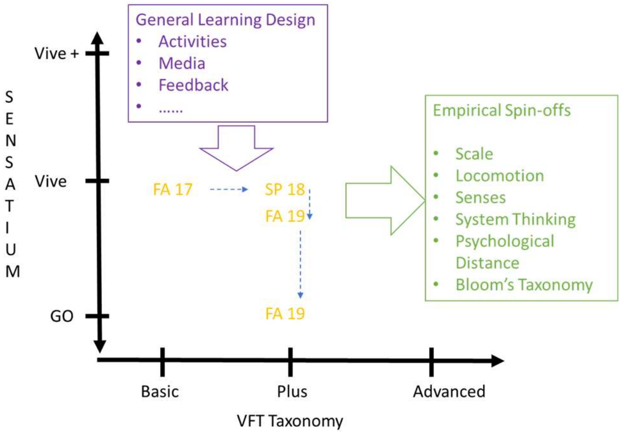


Figure 7: Research Framework - Overview

First: We started with evaluating a basic iVFT (see Section 3) against an actual field trip with overwhelming success for the iVFT (Fall 2017, Figure 7). Details can be found in [15]. We saw significantly higher appreciation of the iVFT, enjoyment, learning experience, and lab grades, compared to the actual field trip. We did not expect results to be overwhelmingly positive and as this is not a controlled experiment but a real world assessment, there may be factors outside our control at work (distractions during actual field trips, weather, etc.)

Second: To corroborate our findings and advance the science behind iVFTs, we moved the basic iVFT into the realm of a plus iVFT by adding a perspective to the iVFT not possible in the real world (see Figures 1, 2, 7). We used a megamast to take 360° images at the height of 27‘. This allowed students to access the field site at an increased geographic scale. We also advanced the evaluation framework and collected more open ended responses to obtain more detailed feedback for future developments. There was additionally the real world challenge of a discipline that firmly believes in the value of actual field trip experiences. The effect was that all students were required to participate in the actual field trip per request of the instructor. This added the possibility though to add an assessment of how well iVFTs can prepare for actual field site visits. In a nutshell, we found that our main results were confirmed and that students were overwhelmingly positive in favor of virtual field trips including how well they prepare for actual field site visits. Lab grades were assessed for all students after the actual field trip and we did not find significant differences this time (paper in prep).

Third example: We stayed in the realm of plus iVFT but we moved along SENSATIUM towards high scalability. Additionally, we made changes to the learning design and included questionnaires into the experience. In a nutshell, in order to deliver immersive learning experiences to a larger audience, we re-developed the iVFT for mobile devices, specifically for the Oculus GO. We resolved challenges stemming from reduced degrees of freedom and interactivity (e.g., measuring the stratigraphy). In return, we were able to deliver the iVFT to groups of students at the same time. The analysis is ongoing but our first results indicate a surprising success of the mobile iVFT.

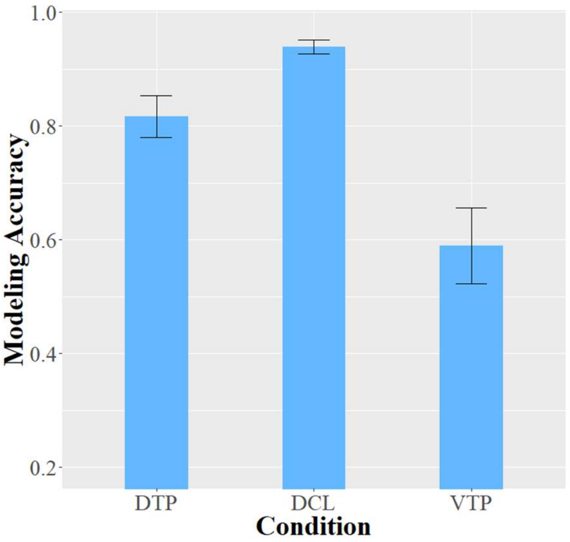


Figure 8: Participants' modeling accuracy of a model-building task after an immersive experience: (right) varied across desktop teleportation (DTP), desktop continuous locomotion (DCL) and Vive teleportation (VTP) conditions. Error bars represent ± 1 standard error of the mean.

Empirical spin-offs. In addition to the more holistic assessment of iVFTs, we are also addressing basic research questions associated with immersive learning experiences, particularly those related to place-based learning experiences such as field trips. We have implemented several of them, others are in planning.

Locomotion. It is without a doubt that physical activities such as walking allow for developing an understanding of a place. This is a challenge for immersive experiences as in almost all cases the actual size of a field site exceeds the space available for an immersive experience. For devices such as the Oculus GO with only 3 degrees of freedom the limit is actually a single point of view. While there are creative solutions for locomotion in virtual environments [21] and, for example, teleportation allows people to a) navigate efficiently and b) avoid motion-sickness, we do not know what their effect on spatial learning is. A literature review and a pilot study [22] conducted in our lab show that teleportation and associated lack of optical flow pose challenges to immersive learning reflected in relatively low modeling accuracy of participants (see Figure 8).

Scale (geographic scale). A critical part in the overall research framework, we are hypothesizing scale as a major potential advantage of immersive learning experiences. Humans are bound to a ground perspective in the physical world (for the most part); immersive experiences are free from such constraints. While tools such as Google Earth, maps, or images are available to support the contextualization (spatial scaffolding) of individual locations, they lack the embodied aspect that immersive experiences afford. We approach scale questions in two ways in our research, first as part of the holistic iVFT experience, second, as a basic research question that requires a constrained experimental setup. For the first, we singled out a measure, the spatial situation model, which is part of a widely used presence questionnaire [23]. We administerd this questionnaire in the basic iVFT, plus iVFT, as well as in the actual field trip (see Figures 7 & 9). We found that there is a significant overall increase in users self-assessed understanding of the lay-out of the site. Spatial situation models are an essential component in evaluating media effectiveness and for place-based learning they are a potential indicator of how well media supports spatial scaffolding. Encouraged by these results, we are also running controlled experiments on the effects of increased geographic scale on spatial knowledge acquisition. We created an artificial maze that allows for controlling every aspect in the environment such as how many landmarks are visible from each perspective. Data collection is ongoing.

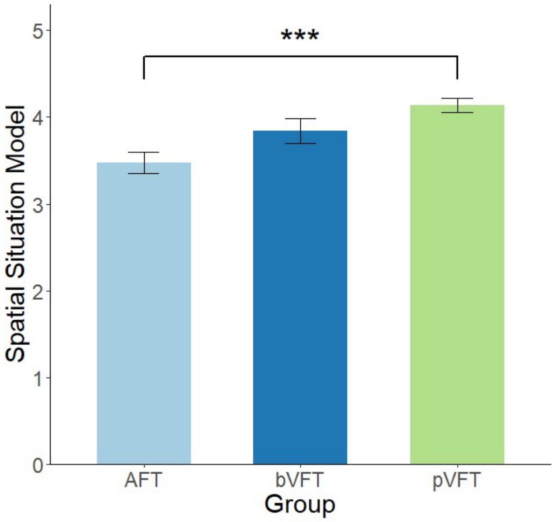


Figure 9: Spatial situation model (SSM) scores varied across actual field trip (AFT), basic virtual field trip (bVFT), and plus virtual field trip (pVFT) groups. Error bars represent ± 1 standard error of the mean.

CONCLUSIONS AND OUTLOOK

In this article, we discussed an evolving research framework for the empirical evaluation and advancement of immersive learning experiences, specifically immersive virtual field trips. Field trips, as one aspect of place-based learning, are multi-faceted learning experiences. They are embedded in a specific curriculum and often last an hour or longer. While they come in various forms, the one we are focusing on for now are those embedded into lab exercises, that is, field trips possible within a 90-120 min teaching period (in contrast to week long experiences overseas). While there is literature on field trips and limited discussion of immersive virtual field trips, there is a noticeable gap of research frameworks for immersive virtual field trips (and maybe even for immersive learning) [24].

Our approach aims at designing a research framework that ultimately will allow us to establish a science of immersive virtual field trips with an in-depth understanding of what different elements of this framework contribute to learning experience and learning success. With the proposed framework, we aim to systematically examine the different elements that contribute to learning performance and experience while trying to separate general learning design characteristics from those specific to the medium of immersive experiences.

In our opinion, this is only possible by discussing conceptual frameworks that allow for a conceptualization of both the technology and the experience in a domain-independent approach (see VFT taxonomy and SENSATIUM). Critical for fully understanding immersive learning of place-based content is to extract specific qualities that immersive media afford in contrast to traditional learning environments as well as the real world. This allows for addressing challenges (e.g., locomotion restrictions) as well as opportunities (e.g., increase of geographic scale).

Our plans for the future are to flesh out this framework with a number of different approaches that are critical for learning in general (e.g., Bloom's taxonomy) and earth sciences in particular (e.g., system thinking). For example, using the opportunities that arise due to using drones for creating 360° images that capture entire landscapes relevant for understanding processes at a specific location (e.g., wetlands), we are designing experiments that test specifically which aspects of Bloom's taxonomy are facilitated by increasing the geographic scale of human embodied experiences.

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