Engaging Meaningful Learning Design Principles in a Gamified Desktop VFE for Geoscience Education

The Rockbridge Memorial State Park Experience

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Extended Reality | extended reality technology | geology education | iterative design | Meaningful Learning | virtual field experience

Geoscience higher education is increasingly adopting extended reality (XR) experiences, notably virtual field trips, to overcome challenges in integrating fieldwork into courses. However, emphasizing XR technology highlights shortcomings in physical field trip experiences for meaningful learning, raising concerns about student access. A prototype desktop virtual field experience was developed using the Meaningful

Online Learning (MOL) framework to address these issues. The design was tested in a large introductory geology course using a case study approach. Subsequent feedback informed improvements, and the design was re-tested for the same course in a subsequent semester. Results illustrate the importance of involving students in defining meaningful learning in an experience and hold implications for using the MOL framework early in the design process.

Introduction

In geosciences and other STEM-based disciplines, there is a need to explore education through place-based interactions in the field. Field-based education positively impacts students' learning while providing environments which foster autonomy and competence (Fedesco et al., 2020). Within geosciences, practitioners and educators have long considered field education a fundamental curriculum component (Mogk & Goodwin, 2012). However, increasing class sizes, reduced financial support, legal liabilities, and accessibility concerns pose growing challenges (Jones & Washko, 2022). To address these field-related hurdles, extended reality (XR) technologies -inclusive of virtual reality, augmented reality, and mixed reality- offer ways to replicate the physical world in digital space – the virtual field trip (VFT) and virtual field experience (VFE). These experiences utilize various media (text, audio, video, images, etc.) to present guided learning materials which mimic in-person trips. VFTs often provide tour-based opportunities which passively guide students through learning materials, while VFEs offer guided instruction and open-ended exploration like real-world fieldwork (Speir et al., 2022). For this study, we focus on using a VFE, but much of the research into these types of learning tools focuses on VFTs.

The promise of XR technology for serving as a viable alternative to in-person field trips focuses on the affordances of the technology, such as immersion and interactivity, to enhance the feeling of being in the physical space (Klippel et al., 2019; Tuthill & Klemm, 2002). Despite the degree of immersion, interactivity, and novel engagement in developing these experiences, findings indicate replicating in-person field trips and experiences may be less pedagogically sound for attaining higher-order learning (Dolphin et al., 2019). The reason replicating in-person field trips and experiences through XR may be less pedagogically structured is the in-person trips place less emphasis on establishing relationships between concepts and more focus on recognition and identification (Argylian et al., 2024). This notion of getting students out in the field is an idea we similarly experienced in reviewing our field trip experience. In looking at our field trip design, participation was based on showing up and filling in worksheets rather than meaningfully connecting the experience to materials learned within the course. We believe there is promise in engaging higher-order learning by adopting a fieldwork approach (Huysken et al., 2016), where students are challenged with connecting foundational knowledge to actions taken within a physical space.

Adopting a fieldwork approach prompted a focus on the meaningful design of virtual experiences from both instructional and learning perspectives. In two recent studies comparing VFTs that use VR headsets to desktop computer VFTs and in-person field trips, students perceived learning more from the virtualized experiences (Zhao et al., 2020) and demonstrated higher learning gains (Ruberto et al., 2023). The results of these studies underscore the significant role the design of virtualized experiences plays in student learning, even when the learning design mirrors that of an in-person field trip. The success in comparing the two VFTs further provides opportunities to address challenges faced by students' access to technology. While XR technology has become more ubiquitous, students still may not have access to it, and not all technology supports disabilities (Ziker et al., 2021).

To investigate how VFEs can be meaningfully crafted using instructional design principles to promote higher-order learning, we conducted a case study focused on creating and improving an asynchronous VFE that replicated an in-person field trip experience. The VFE was modeled on an existing in-person field trip catering to an undergraduate curriculum in geological sciences. Specifically, the reasoning behind developing this VFE in geology pertains to ongoing limitations and challenges (e.g., accessibility, inclement weather, and the COVID-19 pandemic) impacting the in-person experience for enrolled students. This investigation addresses how VFEs can be meaningful and student-centered in the design of the experience, emphasizing two primary factors: 1) defining what meaningful learning represents in the context of VFE and 2) understanding student-centered approaches for asynchronous learning from a technological perspective. This work culminated in a web-based VFE, a type of VR that works through a browser on a desktop computer called web-VR, designed as an asynchronous experience in geology post-secondary education. Several meaningful learning principles guided the design, centering on the Meaningful Learning Framework (MOL; Dabbagh et al., 2019). Analyzing student feedback against the original design revealed distinctions between features students found meaningful. Specifically, this study aims to identify the VFE features students perceive as meaningful for their learning by deciphering the variations in intent and interpretation of these experiences between designers and students.

Literature

Virtual field trips and experiences have grown in popularity among the research community, especially those trying to justify using XR technology to engage students in STEM-based disciplines, specifically within Web-VR. Issues regarding availability and access to XR technology vary from learner to learner (McEldoon, 2023). Another consideration in justifying XR technology to engage students is relying on technology alone to elicit engagement. Meaningful learning design should drive how technology facilitates engagement and the construction of knowledge.

Defining Meaningful Learning

Exploration of meaningful learning and related concepts, such as engagement, in educational technology research poses challenges for designing virtual learning experiences. These challenges arise from diverse perspectives and theoretical approaches which contribute to defining and explaining meaningful learning. For example, Petersen et al. (2020) associate meaningful learning in a VFT with the student's purposeful effort to integrate information with pre-existing knowledge. However, many researchers attribute meaningful learning to the interaction with the virtual learning experience, demonstrated through performance or positive comments (Kundu, 2016). This lack of a standardized definition leads to variations in learning designs, which are challenging to compare. Such comparisons are further complicated when the nature of the technology is considered, such as when XR is experienced through VR headsets, which allow for embodied movement of the user's head and hands (Markowitz et al., 2018). These complications warrant additional considerations in the design of learning beyond a web-based experience.

Building on meaningful learning, Jonassen (2007) observed such learning cannot always be prescribed by an instructor or designer, leaving it open-ended for individual students. The idea of meaningful learning as part of the learning experience stems from students' questions about why specific activities are essential and how they connect to real-world contexts (Karunanayaka, 2023). Meaningful learning should be authentic, purposeful, and intentional in the eyes of the learner, where the content and context enable a simultaneous understanding of prerequisite knowledge for intended higher-order thinking (Jonassen, 2007). Thus, grounding meaningful learning in the natural human experience provides a framework which addresses interpreting and predicting how students would engage with the learning environment and manipulate its objects (Jonassen & Strobel, 2006).

When contemplating meaningful learning as both a goal and a guide to instructional design, additional importance is attributed to the role of the instructor, implementation, and, ultimately, the level of guidance provided (Merrill, 2002). Despite VFTs often being designed without the necessity of a live instructor, the decisions influencing the design and implementation of such a learning tool are crucial for ensuring meaningful learning. For example, an instructor must efficiently design and develop such an experience or gain access to an existing XR technology for implementation to maintain focus toward meaningful learning. However, this must not be done not in isolation of the learner, who must make the active connection from new content to their existing cognitive structure through prior experiences, feelings, and interactions with other students (Vargas-Hernández & Vargas-González, 2022).

One way to address the consideration of meaningful learning within a VFE, particularly a web-based version, is to incorporate frameworks from online learning. In this case, we look to the MOL framework by Dabbagh et al. (2019) to consider the needs of students when technology is involved. The MOL framework was established with the consideration of learning technology in mind, which led us to select it over other frameworks. In particular, the MOL framework allows designers to consider the asynchronous nature of a VFE while still addressing aspects of social activity within learning. Specifically, MOL presents a design framework incorporating five principles derived from Jonassen and Merrill's work. These principles (i.e., active, constructive, cooperative, authentic, and intentional) enable the embedding of technical capabilities into the learning design by considering the student's perspective (see Table 1).

Table 1

MOL Framework principles and definitions summarized (Dabbagh et al., 2019, pgs. 9-10)

Principle	Summarized Definition
Active (Manipulative/Observant)	Students are active participants in learning. They can manipulate objects to develop new knowledge.
Constructive (Articulative/Reflective)	Students consider the choices they make and the actions they take. They make a conscious effort to explain what has been done or observed.
Intentional (Goal-Directed/Regulatory)	Students have a goal to work towards, whether it is provided to them or self-established.
Authentic (Complex/Contextual)	Students are situated in real-world experiences and content, allowing them to transfer knowledge to concrete situations.
Cooperative (Collaborative/Conversational)	Students can co-construct knowledge through interaction with others. They can engage others or be engaged by others to form new ideas.

To use the framework, designers and instructors consider each part of a learning experience (e.g., activities, assessments, technology features, etc.) and align them to MOL principles. This alignment enables designers and instructors to see where a design may be stronger or weaker before implementing it with students in a classroom setting. The framework incorporates the perspectives of human learning experience as interpreted by Jonnassen (2007). When considering the nature of XR technology with a framework like MOL, aspects of presence (i.e., the feeling of being in a simulated space) and embodied interaction could extend our understanding of meaningful learning. While our scope in this study is on Web-VR, where presence and embodied interaction are limited, some frameworks embed such embodied experiences as part of the online learning experience (Dunlap et al., 2016).

Virtual Field Trips for Learning

XR technology for VFTs and experiences incorporates decisions focused on learning design. Specifically, these designs aim to improve engagement and learning outcomes, though few consider the design aspects that make learning meaningful. Virtual field trips often rely on several factors to engage students, some of which have been connected to increased learning (Fauville et al., 2020; Markowitz et al., 2018). In their review of immersive VFTs, Faulville et al. (2020) indicated factors which could connect with environmental literacy development, such as pedagogic agents to guide students, embodied experiences to learn the perspective of others or objects, and direct experience in performing an action like cutting a tree. These factors engage students in different ways, but most have gone unexplored from a learning framework perspective that could explain how different activities elicit different learning outcomes.

Beyond activities and intentional pedagogic factors, XR technology affords different sensory experiences, which could impact learning (Markowitz et al., 2018). Affordances of XR technology provide capabilities which can extend the content from an experience directly to the user by directly situating them and enabling multiple perspectives (Dede, 2009).

Materials and Methods

Within the first year of development, we explored various methods to efficiently create a VFE which would be meaningful in its design and easy to develop and implement. Our solution was a gamified VFE for geology higher education, which utilized pre-existing tools to reduce the time invested in development. Using a combination of Articulate's Storyline 360, Sketchfab, and Thinglink, we created a desktop VFE comprising multiple media types related to Rockbridge Memorial State Park. Articulate Storyline 360 provides an interface to develop interactive web-based learning content that can be integrated into different learning management systems using the Sharable Content Object Reference Model (SCORM). Sketchfab is an online service which allows users to upload and share 3D models. Thinglink is an online service that develops 360° immersive learning experiences using hotspots. 360° images with narrated recordings were combined to create a navigable space. Students can drag the mouse to look around, interact with points of interest, and gather information about the geologic context of the area. To advance through the VFE, students could use the navigation arrows to follow a semi-linear path or access sites with the navigation menu.

Each 360° image was embedded with text excerpts, videos, 3D models, and images to align content with the narrative story of the in-person field trip. The VFE allowed for additional insights and observations regarding the geologic framework of the area that cannot be incorporated during in-person field instruction. The formative and summative assessments were included as knowledge checks and the final quiz. Incorporating gamified elements, such as collecting geologic 'time gems' to unlock a secret challenge, provided an activity which engaged a higher-order understanding of the timing of major geologic events in forming the state park. The resulting VFE was embedded into the Canvas learning management system using a SCORM file to enable activity scoring within the experience to update the gradebook automatically.

Aligning Design with Meaningful Learning Principles

The design of any technological experience should be thoughtfully considered to engage the end-user meaningfully from both an instructional and the students' standpoint. In our implementation, we combined three learning principles: Merrill's First Principles for Instruction (Merrill, 2002), Gagne's Nine Events (Gagne, 1985), and MOL (Dabbagh et al., 2019; see Figure 1). Ultimately, we used the MOL framework to address the unique interactions and types of activities within the VFE while still considering the underlying principles put forth by Merrill and Gagne (Table 2). Our design emphasized activating existing knowledge as a foundation for new knowledge throughout the experience (Merrill, 2002). In other words, we aimed to blend the experience through direct representations of the principles for an expanded look at the MOL framework.

Figure 1

Rockbridge Memorial State Park VFE V1.0, Quest menu interface

Table 2

Summary of MOL principles aligned with the VFE design features

MOL Principle	Alignment in Design
Active	• Collectible items such as fossils and gems are used for the higher-order assessment. • Students could navigate which areas they wished to complete first by selecting the Non-Linear or Linear guidance options.
Constructive	• Knowledge Checks allowed students to test and retest their knowledge in different areas within the VFE. • Acting as co-designers, students could reflect on what was meaningful about the VFE experience.

Intentional	• Learning objectives are focused on declarative and conceptual knowledge with clear instructions and labels. • Students could pursue the two optional badges, resulting in-VFE points for a higher score.
Authentic	• 360° interactive environment is an authentic replication of the in-person VFE. • Narration replicated the same explanations as the in-person field trip, including ambient noise from the park.
Cooperative	• Opportunities for learners to provide feedback engage the student as co-designer.

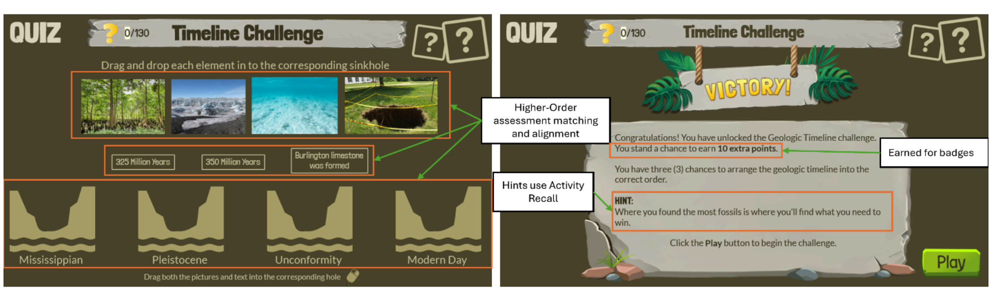
Adopting an Instructional Systems Development (ISD) approach first, our design connected the in-person field trip to a higher-order objective tested through a geologic timeline assessment (Figure 2) and a final quiz. We created the following learning objectives to be used in both the in-person field trip and the VFE:

1. Communicate what a fossil is and its importance to the formation of the Burlington Limestone.
2. Relate the underlying geology to the observed topographic features today.
3. Higher-order objective: Evaluate the major geologic events involved in the formation of Rockbridge Memorial State Park and arrange them chronologically.

Students navigate multiple locations within the state park, using the physical location as part of the scaffolding. With each location, we considered the components necessary to convey knowledge from the trip to support our higher-order objective. This included providing clear objectives of what should be learned through this experience (Gagne, 1985) and a means for students to know upfront what the material was before being assessed (Merrill, 2002). All of these were presented within the 360° environments that situated the learning in the VFE to align with the in-person trip (Dabbagh et al., 2019).

Figure 2

Unlocking the Secret Timeline Challenge higher-order assessment



It is worth noting students gain foundational knowledge about geologic periods throughout the first part of the semester, and this prior knowledge is activated during the VFE. We implemented the Wetzels et al. (2011) Perspective Taking technique to adapt prior knowledge activation. Perspective Taking is a top-down-oriented strategy to support students with prior knowledge which aligns with a given perspective. In our VFE, students approach the content from the perspective of a 'Geologists' Assistant' and attempt to level up from Junior to Senior Assistant by fulfilling various tasks. This perspective contextualized what prior information was expected from the VFE experience. The top-down approach with Perspective Taking enabled us to implement higher-order thinking in the final summative quiz using the geologic timeline.

Following the First Principles of Instruction (Merrill, 2002), we aimed to use the learning medium to incorporate the strategy of tell, ask, show, and do. In our VFE, students receive instructions on navigating the experience at the entrance to the park. Students are encouraged to actively explore various media, assessments, and gamified content as they progress through the different areas. Formative assessment occurs through knowledge checks, which offer immediate feedback to students (Figure 3). The knowledge checks throughout the VFE align with the content in each location. These assessments can be taken several times to improve understanding and prepare for the summative assessment after the entire experience.

Figure 3

Knowledge Check (Left), Feedback Screen (Right)

In addition to an ISD perspective, we considered the learner's role in creating meaningful learning, as argued by Jonassen (2007). Delving into human learning, we explored Gagne's (1985) nine events occurring within the design of our VFE to enable the conditions for learning. For example, events like *Gain Attention* and *Inform Learners of Objectives* are embedded in the VFE, where students access instructions and objectives visually through the interface and 360° images. In alignment with Gagne's Present the Content event, relevant content was curated for each location and reinforced through knowledge checks and gamified activities.

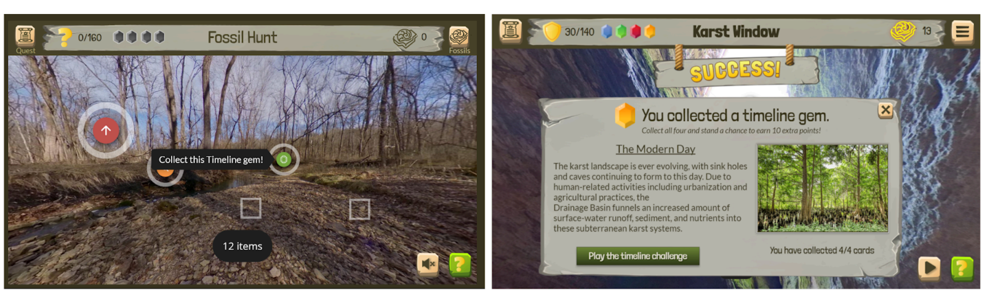
Using the MOL framework, we focused on meaningful learning within an online asynchronous setting (Dabbagh et al., 2019). While VFTs have increasingly incorporated synchronous sessions (Wallgrün et al., 2019), most XR experiences in web-VR remain independent learning experiences. In our VFE, we explored features to motivate and engage through the framework's five components. Utilizing a gamified activity, we concentrated on item collection (e.g., fossils and gems) to provide relevant tasks associated with the in-person field trip activity of fossil hunting (Figure 4). We focused on developing an activity to further engage through points and badges, connecting those with extra credit potential (DeMers, 2023), including the gamified activity aligned with the time spent fossil hunting during the in-person field trip at the park. While the 360° images offered an authentic context for each site visited during the field trip, the scenario-based activity of collecting gems following the specific geologic timeline allowed for constructive and reflective knowledge development at a higher-order level. As a motivational aspect, students could earn in-VFE bonus points for fully exploring and completing the gamified scenarios.

Through these game elements, we explore the application of Lepper's Instructional Design Principles for Intrinsic Motivation. Giving the learners a sense of control over the environment allows them to make decisions independently of outside influences. Participation in the gamified activities was not mandatory for the learners to complete the VFE. However, the activities were designed to generate curiosity and motivate learners to achieve in-VFE goals, allowing for the integration of "purpose, focus, and measurable outcomes" (Kapp, 2012, p. 28). Visual feedback was integrated into the user interface to indicate progress towards goal completion, providing incentives and feedback to the learner. The authentic context and environment also stress the utilitarianism of the learning activity (Lepper, 1988).

Finally, to align with the MOL framework's cooperative principle, we focused on the intersection of the in-person field trip with the VFE experience. Students who completed the VFE before the in-person field trip were afforded opportunities to reflect on their results and discuss with their field trip instructor. Conversely, students who completed the in-person field trip first could use the insight their field trip instructor provided to aid in completing the assessments and gamified activities within the VFE. This cooperative aspect of the MOL framework is further discussed below.

Figure 4

Collecting a gem in the 360° image (Left), Four gems are collected to access the higher-order assessment (Right)



In addressing the principle above, we recognized the overlap in our approach to designing a meaningful VFE. This overlap suggests that when testing, students will articulate their individual learning preferences and experiences, indicating that the MOL framework may be the most suitable tool for examining the learning experience.

Case Method

Each semester, large introductory geology courses at the University of the Midwest conduct a local field trip experience to enhance course content. The field trip, generally held as an in-person activity, is conducted during the regularly scheduled laboratory session. Guided by the course's graduate teaching assistants, students tour the local Rockbridge Memorial State Park to connect overarching principles in landscape formation. Highlights of this field trip include discussing the formation of a large, natural rock bridge, cave exploration, and hunting for fossils on the riverbanks. Students complete a worksheet during the field trip based on the information provided by their graduate teaching assistant.

Over two consecutive semesters in the same course, depending on circumstance, we presented our prototype VFE of the field trip either before or after the in-person field trip. We gathered student feedback to update further and retest the VFE experience—the nature of the input transitioned to accommodate how students interacted with the various media. In addition to technical issues, students provided insights into the nature of the pedagogical experience and what they felt would improve their experience further. For example, the first iteration of the VFE included a self-exploration option called the Walkabout. The Walkabout simulated an open-world environment where students could explore the terrain freely without guidance. After feedback on the first iteration, we removed this feature and shifted our focus to a more guided experience while maintaining the ability to explore.

Students were required to complete both the in-person field trip and the VFE, except in cases where inclement weather resulted in the cancellation of the in-person trip. As we focused on getting the students into the experience, we allowed faculty to indicate the order in which students participated in the VFE and in-person trip as long as one group would use the VFE first. The other group would use the in-person trip first. In iteration one, the first group was able to complete the in-person trip and then the VFE, but the second group could only complete the VFE due to inclement weather. In our second iteration, the instructor had the first group complete the VFE and attend the in-person trip. The second group participated at the in-person trip and then completed the VFE.

The VFE was accessed through the Canvas learning management system (LMS), allowing faculty to track completion within the Canvas LMS gradebook, with some faculty members also electing to provide bonus points to encourage student participation. After completing the VFE, students could consent to participate in the study and complete a qualitative survey. The survey collected basic demographic information (e.g., age and grade level) and an open-ended question asking for feedback to improve the VFE. In our presentation about participating, we emphasized the importance of the open-ended question, noting that feedback would improve the VFE for the upcoming semesters.

Demographics

We collected 91 responses from our first iteration (Spring 2022) of the VFE and 96 consented responses from our second iteration (Fall 2022). In our first iteration, the class consisted of 68 freshmen, 13 sophomores, seven juniors, and three seniors. The class average age was 19.07. For the second iteration, we similarly had more early-grade college students with 61 freshmen, 22 sophomores, eight juniors, and five seniors with a class average age of 18.95. No students repeated the course, keeping both iteration samples separate.

Analysis

Using a deductive content analysis (Krippendorff, 2018), we initially coded the data from each semester iteration for responses related to the features of the VFE, including positive and negative alignments, with the analysis of the first iteration informing updates for the second iteration. Subsequently, we compared the resulting categories from both iterations using the MOL framework to identify any underlying patterns related to our design of meaningful learning. The coding process underwent two rounds of refinement (Saldaña, 2016). The first round of coding focused on grouping comment segments using the VFE feature. The second round refined the alignment of the groups to form categories. Final categories were formed based on the percentage of codes. Two coders examined and coded the data separately, followed by a singular collaborative consensus coding session with a third researcher to address any differences in interpretations (Williams & Moser, 2019). Cohen-Kappa indicated a moderate to strong agreement between the two coders for the final categories (k = 0.841).

Results

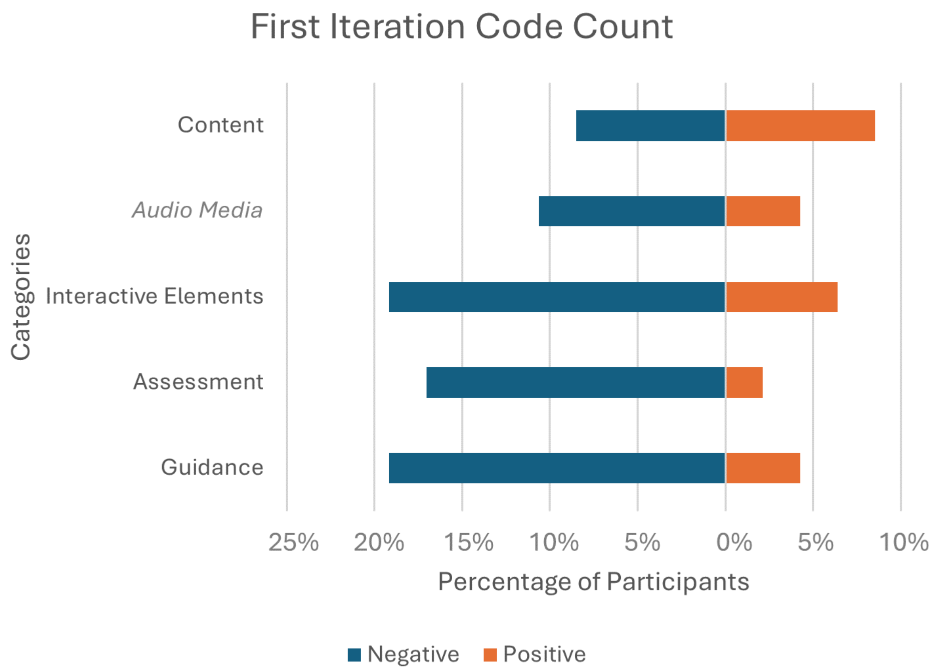
The results of our investigation presented several suggested changes students perceived would improve the learning experience. Based on participant surveys, we coded responses into four primary categories: content, interactive elements, assessments, and guidance. Given the research approach, we present the initial and second iteration results.

First Iteration

In the first iteration, reception towards the VFE was optimistic overall towards the experience but indicated several challenges focused on improving technical and content issues. Students were enthusiastic about participating in the activity, reflected by a 92% response rate to the open-ended feedback question. 46% of the feedback could be coded into the following categories: content, audio media (a subcategory of content), interactive elements, assessments, and guidance (Figure 5). We parsed the codes within each category as positively or negatively aligned, where positive included aspects that were liked without any suggested changes and negative as suggestions for improvements or issues.

Figure 5

Code count by the percentage of participants parsed by positive and negative alignment



Note. Audio Media is a subcategory of Content. Due to the comparatively large percentage of codes relating to the audio content, we included the subcategory here as a separate focus.

The content category elicited both positive and negative reactions to the multimedia approach. Students desired more diverse content related to the state park experience while still appreciating it as an asynchronous learning opportunity. Support for this category was evident in comments like, "I don't like how the website did not save your work and let you come back to it." Regarding content, some students mentioned it was "going too fast" and "very redundant and boring." However, these criticisms were balanced by positive remarks, with the same two students also stating, "It is fine the way it is!" and "...it was educational." Students also wished for more content about collected items and related media to connect with their prior knowledge.

A subcategory concerning content was audio media, and students predominantly highlighted contextual issues and glitches. One significant glitch mentioned by many students was the audio overlapping, as there was no option to pause, skip, or scrub through the various audio segments. Another set of comments focused on restrictions during audio playback, with students noting that they could not look around while audio clips played. One learner expressed this limitation: "When audio from one of the clickable modules is playing, you can't interact with other things or look around while it's playing." With audio being a primary means to provide information, similar to the in-person experience, these points highlighted the desire for more control and capabilities to connect the material to the experience.

One interesting point was expressing a desire to explore rather than interact with click-based activities. This desire for exploration, however, aligns with a suggestion for fewer collecting activities, as one learner remarked, "Feels like it has a lot of needless repetition in looking for fossils." Such comments revolved around gamified interactivity, where collecting fossils and gems was crucial to earning badges. The nature of item collection was also questioned, with a student noting the illogical placement of gems in the sky for an activity focused on examining rock structures on the ground. Despite gems being used to encourage looking around the 360° images, keeping interactive content closer to where students allocate their attention may prove more effective in maintaining engagement. There was an expressed desire for diverse ways to explore each 360° area, with a learner stating, "The only thing I would want is more mobility, that [is] similar to Google Map[s]." This reference to an existing familiarity of user interface, which affords specific interaction, presents an interesting movement away from the confusion expressed when moving between more than one embedded application.

Formative assessment feedback played a crucial role for students who found locating knowledge checks difficult or struggled with recalling where answers could be found. A student emphasized the helpfulness of hints in completing tasks and addressing knowledge checks, with feedback such as "...possibly include hints to find certain things." Another notable aspect regarding knowledge checks and the final quiz was the desire to retake them for improved understanding. One student viewed knowledge checks as a useful self-paced learning tool to prepare for the final quiz, while another highlighted the difficulty in retaking assessments. This disparity indicates the importance of feedback for performance and clear instructions on engaging with assessment materials.

The final category centered on the guidance provided throughout the VFE. This category primarily included comments about improving instructions and directions for navigation, with one learner stating, "I was confused with the directions." The learner comments highlighted the clarity in navigation directions, identification arrows corresponding to specific locations, and responsiveness of interactions. While some students mentioned the VFE "was quite responsive," others reported loading issues and confusion regarding navigation. One specific suggestion involved introducing color coding for different areas, with a learner proposing, "I think that the arrows within an area or category should be a different color than arrows that go back to previous areas." The comments and suggestions regarding the delivery and nature of instructions for navigating the VFE were valuable for proposed updates.

These suggested improvements and comments gathered from our cursory analysis above were used to inform updates to the VFE between data collection sessions over the summer semester. In version 1.2, we made several updates that corresponded with the resulting code categories from our analysis:

- Activity
    - removed ThingLink slides and Walkabout
    - simplified Gem Cards for Timeline Challenge
    - attached a cheat sheet in Resources, including the Gem Cards
    - moved and consolidated content from Fossil Hunt to Cave
    - reduced collectibles at the Creek and Fossil Hunt
- Assessment
    - replaced fill-in-the-blank knowledge check question
    - knowledge check feedback includes the correct answer

    - retry both the knowledge check and final quiz
    - final quiz added to the main menu
- Guidance
    - changed icons on the audio play/pause button
    - moved map access to the lower left-hand corner with a new icon
    - changed the options menu to the fossil menu
    - added skip, replay, and a seek bar for user control
    - simplified the mission tasks
    - simplified and shortened the orientation

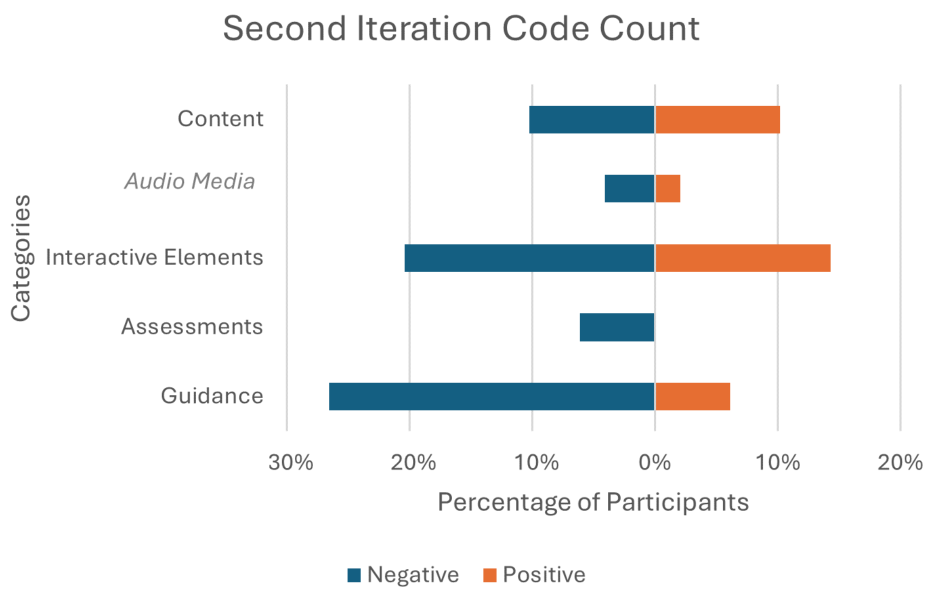
Though some results indicated student preferences for changes, we kept some critical features due to time constraints or supporting evidence that such features should be included, for example, those noted in Huysken et al. (2016). The features we maintained would be retested in the second iteration to determine their contribution to the student's interpretation of meaningful learning.

Second Iteration

The second iteration proved optimistic and elicited more detailed comments focused on improvement. Students had a 72% response rate to our qualitative question, with 45% of comments coded based on content, audio media (a subcategory of content), interactive elements, assessment, and guidance (Figure 6). Audio media and assessment received far fewer comments than our first iteration. Overall, students in the second iteration were more critical and took an active role in their comments to suggest improvements. As such, we reserved expanding connections with the literature till the discussion.

Figure 6

Code count by the percentage of participants parsed by positive and negative alignment



Content remained a central category in the second iteration. However, there was a notable difference in the desire for information inaccessible during the in-person field trip. One student commented, "I would say that it needs a little bit more camera freedom and ability to roam and see from a bird's eye perspective," while another student similarly suggested, "My only suggestion would be to include the park in different seasons so one can compare and contrast the environment in different seasons." These comments elaborated more on how expanding the content could be implemented within the VFE. One noteworthy point came as a direct result of our updates. In removing the areas hosted through Thinglink, one learner commented they wanted "access to more area[s] of the park." Overall, comments concerning content balanced positive and negative, as demonstrated by the statements: "I liked that there was a variety of audio and video clips, as well as text," and "...more explanation on the things that you are finding." This shift in focus toward content suggests the balance of multimedia improved in the second iteration.

Regarding interactive elements, students commented on the ease of navigation between sites and expressed a desire for increased interactivity. After reducing the number of items to collect, the gamified fossil and gem-hunting activities were viewed more positively; as one student noted, "the scavenger hunt aspect was very fun." In examining the comments about navigation, one student made a unique distinction, stating: "The navigation was fine, just turning the camera was a little glitchy." This distinction suggests looking around the individual areas was viewed differently from navigating between areas. Similarly, one student added, "Instead of clicking and sliding the screen, I think it would be easier to have an arrow to click that rotates the screen to the next side." This suggestion proposed maintaining consistent navigation using arrow buttons throughout the entire experience. These suggestions distinguished the two types of navigation connected with comments in the final category.

The final guidance category focused on similar issues with navigating the VFE the first iteration experienced, yet most comments were on instructional guidance. Students noted, "It was fun to look around, [but] the objective wasn't too clear" and "At some parts, it was a bit unclear on what to do next." This distinction suggests revisions to the mission tasks may need to be more concise, leaving out potentially important information for each area's tasks. Similarly, introducing colored arrows to inform navigation proved confusing to one student, "I was also unsure of when I had completed the activity, and so I did the final quiz without fully exploring I think." The emphasis on the nature of guidance indicated a need for more detailed and area-specific indicators of what to do and how to carry out the activities.

The second iteration additionally focused on the placement and nature of labels, buttons, and consistent information as part of the experience. The location of essential guiding information was important, as one student indicated, "Make the items you can click on more clear." In addition to suggestions, some students pointed out technical issues, such as "sometimes the knowledge checks would not appear at the bottom because the audio progress bar was in the way." Students quickly recognized the importance of a navigable interface, content presentation, and clear guidance in shaping their learning experience.

Discussion

Our qualitative analysis of student feedback informed the implementation choices we made in our design. The feedback enabled us to enhance meaningful learning in an asynchronous VFE experience. Our understanding of meaningful learning often relies on current instructional experiences to define the boundaries of a learner's experience. Translating a physical activity to a desktop experience posed a challenge for our VFE. While VFTs and VFEs using VR headsets can offer embodied interactions, they only sometimes meaningfully engage in learning with proper activity. The iterative design of our VFE, combined with the opportunity to participate in the in-person field experience (in most cases), enabled students to derive aspects meaningful enough to provide informed feedback.

Considering the responses, we acknowledge the expectations of our students were most likely high, given prior exposure to online learning and various interactive learning tools that provide high degrees of engagement. These high expectations influenced the nature of the responses we received, but the feedback across both semesters embraced a genuine interest in developing the VFE. The feedback from each iteration often pointed out technical issues common in early application versions. Students noted technical challenges like lag, screen freezing, and application closing but attributed them to individual computer issues. Despite technical challenges, feedback supported the effectiveness of the design of the VFE. Including students in the refining process proved successful, though more iterations will be needed to address all the suggestions.

Examining how meaningful design is represented within a desktop VFE involves navigating aspects of ISD and the MOL framework. The refined categories from each iteration aligned initially with the MOL framework, encompassing five categories: active, constructive, intentional, authentic, and cooperative (to an extent). An additional review of the experience through the MOL perspective allows us to compare the two iterations across these five aspects of meaningful learning. Overall, the evolution of the VFE, guided by initial feedback, yielded refined responses that homed in on specific attributes associated with meaningful learning.

Active and Constructive

A key distinction in the literature between a field trip and a field experience revolves around the learner's actions (Jones & Washko, 2022). Involving students in actions which lead to learning is widely recognized as one of the most effective ways to engage students meaningfully. Nevertheless, the results from each iteration revealed that engaging in actions solely for the sake of it, as seen in activities like fossil collecting, may be less meaningful. Reducing the amount of collection required corresponded to fewer comments regarding redundancy. This distinction highlights a known design challenge in interactive learning media—task-irrelevant cognitive load (Skulmowski & Xu, 2022). Understanding the minimal amount of interactivity, content, and even immersion (Bowman & McMahan, 2007), Cummings and Bailenson (2016) align with Dabbagh et al. (2019) on the point that activity by itself is not meaningful if it does not engage a conscious amount of thinking about the objective of the task. By reducing repetitive content and task-irrelevant cognitive load, feedback focused less on redundancy issues and more on their active learning experiences.

Through the second iteration, the gamified activity proved highly engaging for the students. From a games-based learning perspective, games provide meaningful ways to connect students with complex knowledge, usually through clear goals and core loop structures (Macklin & Sharp, 2016). The focus on collecting in the gamified activity enabled students to connect information across the park's areas to the geologic timeline. When not faced with technical issues, this gamified activity was an aspect students wanted to be expanded, with one student stating, "[the VFE] should be more like a game where you answer questions the guide asks often." As an activity within our MOL framework to address both the active and constructive categories, gamification proved valuable in engaging students. However, as noted earlier, it only worked if the value aligned with the purpose of the VFE.

Intentional and Authentic

Support for using field trips and their virtual counterparts lies in the situated and place-based learning they offer (Klippel et al., 2019). When examining the VFE, contextualizing movement and action of real-world tasks encounter challenges in translation. XR technology simulates real-world walking and lifting but may fail to deliver authentic field experiences. However, clear instructions aligning with a situated space can enhance intentional and authentic attributes of meaningful learning. This concept stems from students relating concepts-in-use to past experiences to derive meaning from activities that do not entirely mimic real-life tasks (Jonassen, 2007).

Our VFE's learning objectives focused on declarative and conceptual knowledge, where clear instructions and labels could provide students with a unique experience not possible in an in-person field trip. Despite guidance challenges in the second iteration, there was a notable desire for more authentic representations, from wanting a bird's eye view to seeing areas across different seasons. Time traveling through multimedia was also noted to authentically engage students with geologic timeline content. These suggestions align with the virtual field trip taxonomy where additional information not possible in the physical location is considered a plus or advanced type of VFT (Klippel et al., 2019). While plus or advanced types of suggestions may require significantly more skill to create, the question remains if they would allow for meaningful connection of concepts to achieve the objectives versus simply having a novel experience, which is generally educational.

Of particular interest was the number of comments referring to instructions and aspects of the interface of the VFE. In the first iteration, changes between different software introduced new interfaces, leading to confusion among the learners. However, removing the additional software led to more scrutiny of the interface with the VFE. The consideration of user interface towards a meaningful experience in learning is helpful. The cognitive effort to learn and remember a new interface presents additional challenges to students, which may detract from the intended learning process (Guney, 2019). Nevertheless, students also wanted more control over the various multimedia within the VFE experience, adding a need for further agency provided through the interface. These two interface aspects offer insights into the complexity of adding interactivity through multimedia to a web-VR experience.

Cooperative

The final attribute of the MOL framework pertains to incorporating social activity. The VFE design aimed to remain asynchronous without an option for social learning. The in-person field trip allowed active discussion with classmates and graduate teaching assistants. However, students wanted to embrace the shared experience during the in-person field trip by walking through the VFE as a class in the same physical space. Feedback from the second iteration supports the idea students find meaning in shared experiences. Without an authentic shared virtual experience, our approach to VFE design provided a way for students to feel involved in the design process through feedback. The concept of a user-involved view presents opportunities for feedback, which contributes to the genuineness of the VFE (Marti & Bannon, 2009). This perspective of engaging the student directly as a co-designer in future iterations, instead of direct social activity, builds further on how we bring students into the design process.

Conclusion

The Rockbridge Memorial State Park VFE presents a designer's interpretation of meaningful learning towards an asynchronous virtualized field trip experience. The focus on meaningful learning stemmed from the notion that accessible and easily implementable solutions would be valuable in large-scale classes where XR technology is scarce. From an instructional systems design perspective, role-playing in the experience proved successful, though not without nuanced issues in usability and guidance. Including students as part of the refining process proved successful, though more iterations will be needed to address how the tool can meet a greater variety of learner needs.

Regarding frameworks that guide an understanding of meaningful learning design, the MOL framework proved valuable in identifying how specific features of our VFE were meaningful or not to students. Limitations in our short study focus on the nature of student feedback. Students in both semesters were very excited to provide feedback based on their individual experiences to assist in improving the design. The opportunity to provide feedback led to an overall positive outlook toward the VFE. Our analysis categories showed improvement between the two iterations. We did not offer follow-up questions for students to clarify statements and comments, leading to a singular question informing our analyses. However, the number of participants in the study who provided a viable response was sufficient for the conclusion.

While directly including students in the initial design process proved helpful in turning students into co-designers, logistical challenges prevented us from exploring this direction. Much of our feedback was on clarity of direction based on preferences for other popular tools. This consideration of building on commercially available tools may reduce confusion and allow for more focus on learning without the added cognitive load of learning a new interface. Though our study had limitations, the instructional perspective on designing these experiences contributes to the broader discourse on using XR technologies compared to more accessible desktop computer VR, such as web-VR.

Our experience designing and testing the VFE through meaningful learning focused on web-VR capabilities. Other XR technologies with added immersive and interactive capabilities may provide additional considerations for how activities and, ultimately, guidance should be provided to students. Much of our feedback was on clarity of directions based on preferences for other tools. From a practitioner perspective, when designing and implementing such a VFE, we found the MOL framework helpful in identifying which features would be meaningful for learners. The backward design process noted by Huysken et al. (2016) was necessary for placing the higher-order objectives at the forefront of the design' which also helped us establish how we needed to incorporate more social learning with an asynchronous experience – student feedback. Regarding our implementation, we also found that piloting the experience with actual students to garner feedback to inform the final design was insightful and robust in aligning with our use of the MOL framework. Learners like to be engaged in the co-design process.

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