Learning with a Desktop Virtual Reality Field Trip in Public Outreach Settings

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Program Abstract

This study investigated how the VR experience (immersion and presence) and design features (narrative, guidance, and feedback) were related to participants' engagement and perceptions of learning with a desktop Virtual Reality field trip in three public outreach settings. Results highlight the importance of presence and the design features for engagement and perceived learning.

Proceedings Abstract

This study investigated how the VR experience (immersion and presence) and design features (narrative, guidance, and feedback) were related to participants' engagement and perceptions of learning with a desktop Virtual Reality field trip (dVFT) in public outreach settings as used by environmental education centers. Data was collected from 139 participants at three different types of public outreach settings. The results found that immersion, presence, engagement, learning about local environment, VR design features, and affective learning were perceived favorably by the majority of the study's participants. Design features, engagement, learning about the local environment, and affective learning were significantly lower for young participants (≤ 18 years old) compared to adults. EE center festival participants had higher favorable mean responses for each subscale followed by Web location participants, followed by Homework Club participants. Results from the path analysis highlighted the importance of presence and the design features for engagement and perceived learning. Our findings support that learning about one's local environment with a dVFT can have a positive impact on engagement and learning, particularly in public outreach learning environments.

1. Introduction

Desktop VR field trips (dVFTs) hold much potential to have a positive impact on engagement and learning in outreach activities for environmental education (EE) centers. Public outreach is an important component of the missions of most EE centers. Center activities are generally designed to engage a wide range of audiences that includes the general public and school-age children on environmental topics, an important component of STEM education. EE center outreach activities can take a variety of forms that include programs or festivals at a nature center, public talks, after-school homework or nature clubs, and school presentations in addition to providing dVFT experiences or Web-based learning resources and activities for home computer access.

Engagement is critical to learning in informal STEM education [1]. During informal STEM education, learners are engaged by experiences that offer interactivity [1-4], and visitors often seek out interactive activities at informal STEM education centers [5]. According to *Learning Science in Informal Environments* [1], a goal of the informal STEM education field is to introduce new media technologies (e.g., Virtual Reality) into STEM learning environments to enhance and modernize the quality of the visitor experience, and also to improve learning outcomes.

A virtual reality (VR) field trip presents several characteristics of great appeal to learners and can be an enhancement to an EE center's outreach programs or for informal home learning. Features such as active control of the user experience, realistic representation of natural settings, and real-world situations may increase engagement and learning [6]. A VR field trip experience can also provide a sense of presence and immersion of being at specific geographic locations that may be inaccessible in time or dangerous [7]. In a dVFT environment, authentic imagery and other media content can be incorporated to provide learners with a highly immersive learning experience. Since VR technology allows for such supports in an immersive environment, it can be designed to provide improved access to environmental and STEM-related content for those who are physically unable to visit an outdoor location due to mobility disabilities or transportation issues [6]. In addition, Leung et al. [8] found that virtual immersion in the natural world was sufficient to enhance a sense of connection to nature, including for individuals with a low affinity to nature.

VR field trips can offer a sense of agency through their ability to change one's perspective of the environment in any direction within the 360º media with little physical effort (Klippel et al., 2020). Some dVFTs may be designed to be very structured and include multimodal media to describe specific features across a sequence of locations. Other dVFTs may be more exploratory, offering users the capability to view the virtual environment at their own pace [10, 11].

The majority of published studies pertaining to VR field trips have occurred in formal learning environments, including university settings (e.g., [10-12]), middle and high school classrooms (e.g., [13-15]), and elementary school settings (e.g., [16- 18]). Many of these studies used headset VR during implementation. In formal learning environments, the use of dVFTs were found to increase student participation in classes [19] and enhance learner perceptions of science course work content understandings [20]. Zhao et al. [11] found that both desktop VR and headset VR field trips had more positive learning effects than a traditional field trip, and although students reported higher motivation and being more present in the headset VR group, they did not learn more compared to those in the desktop VR group.

There is limited research that has investigated VR field trips and related VR experiences for public outreach. Markowitz et al. [21] conducted a headset VR study at a film festival in which participants had an underwater experience to learn about ocean acidification. They reported that total physical movement was a predictor of inquisitiveness. Bibic et al. [22] developed a VR game that engaged the public with learning about biochemistry and shifted participants' perceptions about spider venoms using VR headsets and Android devices in a Cardboard visor. Kersting et al. [23] reported that a headset VR tour facilitated the visualization of abstract astronomy concepts among participants at a science festival and promoted a sense of immersion, but that sense of immersion did not seem realistic to about half of the participants. Renne et al. [24] found that in community workshops, headset VR proved effective in increasing participants' understanding of sea level rise related to transportation planning, and the experience motivated them to become more engaged on the topic. Huang et al. [25] investigated the effects of a headset VR nature trail tour on participants' science learning, self-efficacy, cognitive load, perceived enjoyment, and perceived usefulness, as compared to actual walking tours. They found that the VR experience was effective in improving participants' science learning and their self-efficacy perceptions. The participants found the VR tour to be as enjoyable as the walking tours and expressed that it did not pose an unnecessary cognitive load during the learning process.

Each of the published VR studies that have been conducted in public outreach settings have used headset VR experiences. While headset VR experiences likely provide a more immersive user experience than a desktop VR experience, most EE centers and informal learning environments (e.g., at home and at public libraries) do not have headset VR equipment. Hence, dVFTs can provide more accessibility to learners of all ages for public outreach learning. Thus, this study investigated the implementation of a dVFT for an EE center to utilize for public outreach. Specifically, we examined levels of immersion, presence, engagement, perceptions of learning about the local environment, and affective learning. In addition, we were interested in users' perceptions of the dVFT's design features. We also investigated how the VR experience of immersion, presence, and the design features were related to engagement and learning.

2. Related Background

2.1 Engagement

Engagement can be defined as one's focus, participation, and persistence within a task and can therefore be related to adaptive or self-regulated learning [26-30]. Engagement has been discussed in the literature as behavioral, cognitive, affective, and agentic. Behavioral engagement refers to active participation in a learning experience; cognitive engagement concerns the learning processes and understandings during a learning experience; and affective engagement involves emotional experiences that occur during an experience [27]. Agentic engagement refers to one's active behaviors during an experience [31, 32]. When thoughtfully designed, a dVFT experience can provide learners with the ability to select a task sequence and thus promote learner autonomy in the experience [33].

According to the Science Learning Activation Theory [27], an activated science or environmental learner is captivated by natural and physical phenomena. Such a learner may have an emotional and cognitive connection to environmental topics and learning tasks, which acts as an internal drive for participation. Additionally, positive emotions toward science or the environment, inquiry, and knowledge comprehension are also important and have been linked to engagement in science learning [34].

2.2 Immersion and Presence

A significant portion of VR research has concentrated on designing elements that create immersion and presence [35] in VR environments. Immersion refers to the sensory fidelity provided by a VR system and the user's experience of it [36]. VR technology achieves this by replacing real sensory input with digital sensory input, such as audio and imagery [37]. Spatial immersion occurs when a user finds the simulated world perceptually convincing and feels as if they are actually present in it [7]. Presence is the user's perceptual response to a VR system, where they react to the environment as if it were authentic and has a "sense of being there" [38]. The experience of presence may affect situational interest levels in a VR environment when one encounters realistic and novel environmental experiences [38]. Furthermore, models of presence formation suggest that the ability to interact with the space within a mediated environment contributes to spatial presence [39], and previous research indicates that the level of interactivity provided by a VR interface can influence presence experiences [40].

2.3 Place-based Education

Our VR field trip was designed using the principles of place-based education [41, 42] which focuses on engaging students with their local environment. This approach to environmental learning is rooted in the idea that learning is a cultural process, influenced by local and historical contexts [43, 44]. By connecting learners to their immediate surroundings, place-based education provides meaningful and relatable experiences that help foster a sense of connection to a particular location [41, 42, 45]. This approach has been shown to be effective in improving students' environmental attitudes, values, and knowledge [41, 46, 47], as well as promoting environmental stewardship and positive behavior [42, 48-50].

3. The Desktop VR Field Trip

The dVFT, *The Lehigh Gap Story*, was developed in Unity through an iterative design and development process (see [6]) and was designed for adolescents and adults to learn about the environmental changes that have taken place in the Lehigh River watershed in Pennsylvania over the past two centuries due to the operation of a zinc smelting plant in Palmerton, PA. The plant, which began operating in the 1890s, caused a once-green mountain ridge to become barren due to the emissions of sulfur dioxide and heavy metals [51]. These emissions led to local acid rain and widespread environmental damage. After the plant closed in 1980, the U.S. Environmental Protection Agency (EPA) initiated a large-scale revegetation project, which has successfully revitalized much of the area with warm-season grasses that trap heavy metals in the soil. Today, the site is home to a wildlife refuge and nature center used for education, research, and recreation. The dVFT provides an interactive experience that tells this story of pollution and restoration. Both local geographic factors and industrial smelting led to the locus of pollution and environmental degradation at the Lehigh Gap.

The VR field trip landing screen presents two distinct experiences to select from: Story Mode and Exploration Mode. In Exploration Mode, a trail pathway map allows an independent tour of the area by choosing photospheres (i.e., 360º photos) enriched with ambient audio of natural sounds, 2D media, and 3D assets throughout the refuge area. In Story Mode, the avatar bird, Brownie, guides the user through a sequence of seven photospheres using audio narration, subtitles, and related historic photos. The first photosphere has a short play-through tutorial sequence for users to familiarize with the dVFT interactivity and locate the interface elements (UI). As soon as the tutorial is completed, the bird avatar prompts users to "talk to Brownie" by pressing the "T" on the keyboard or using the cursor to click Brownie, who will start narrating the story of the Lehigh Gap area (Figure 1a). *The Lehigh Gap Story* features collapsible (i.e., non-persistent) UI on each corner of the screen for support on-demand, including the game controls panel, help cards, and a progression checklist. The checklist must be completed (in any order) before Brownie invites the users to proceed to the next photosphere by interacting with a green arrow (Figure 1b). This design provides for navigational agency for the user to freely explore the virtual environment within each photosphere at their own pace.

----------------------------------INSERT FIGURE 1 ABOUT HERE --------------------------------

Each photosphere focuses on a specific topic. In the second photosphere, the geology of the area is highlighted, and users are able to manipulate virtual rock pieces of anthracite, quartzite, and sphalerite that are relevant the Lehigh Gap story (Figure 2a). This provides the users with a three dimensional level of interactivity within the dVFT. Users also learn about the importance of zinc for making products such as batteries. The third and fourth photospheres focus on historical canal and railway transportation routes for bringing coal and zinc through the Lehigh Gap and also for transporting coal to areas further south in the watershed for other manufacturing processes. Within each photosphere, there are interpretive signs in which the user can click on a magnifier icon to enlarge text or images (Figure 2b). The fifth and sixth photospheres focus on the New Jersey Zinc Company and the establishment of the town of Palmerton, PA. Users learn about the zinc smelting process to produce zinc ingots and other zinc-based products. Next, learners view an acid rain animation to learn how the smelting process from the plant denuded the mountain (Figure 3). The final photosphere focuses on the establishment of the area as an EPA Superfund site for remediating the contamination, the testing of mixtures of warm-season grasses to restore the ecological health of the mountain, and the success of establishing diverse habitats that can be observed today.

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The design principles for our project draw from the research literature on designing learning for informal science education environments and the affordances that VR can provide:

1. Provide a strong narrative. A VR learning experience designed for public outreach requires strong narrative elements to generate interest or enjoyment for environmental learning [52]. In the dVFT, Brownie (she/her/it) drives the narrative by telling an emotive story about her ancestors. Her story focuses on how the environmental changes at the Lehigh Gap affected their natural habitat.
2. Provide supportive guidance and feedback. Guidance using methods such as advice, feedback, prompts, and scaffolding can help facilitate deeper understanding and learning [53, 54]. Support is also enhanced by different forms of engaging feedback [55]. In the dVFT, Brownie provides guidance on how to complete the checklist tasks in each photosphere. Feedback is also given when the checklist tasks are completed and the learner is to move forward on the trail to the next photosphere.

4. Research Questions

The main purpose of this study was to investigate how the VR experience (immersion and presence) and design features (narrative, guidance, and feedback) were related to participants' engagement and perceptions of learning with a dVFT in public outreach settings used by EE centers. As previously noted, most EE centers and home learning environments do not have headset VR equipment. While dVFT experiences may not be as immersive as headset VR experiences, we sought to examine if a dVFT would provide a level of immersion and presence that would lead to engagement and learning. Since public outreach activities involve a wide range of audiences, we were also interested in differences between adults and youth, as well as female and male learners. In addition, since there are many types of public outreach settings that EE centers are involved with, we were interested in examining participants' experiences across different settings.

This study was guided by the following research questions:

RQ#1. For the perceptions that participants experienced with the dVFT (the VR *design features*; *immersion*; *presence*; *engagement*; *learning outcomes about the local environment*; and *affective learning* outcomes), was there a significant difference across the subgroups of *age* (≤ 18 years old or young vs. adults), *gender* (male vs. female), and/or *public outreach settings* (Web, EE Center Migration Festival, Homework Club)?

RQ#2. How well do VR design features and VR experience predict participants' *engagement* and *learning* in a dVFT environment? Specifically,

2a. How well do participants' perceptions of *design features*, *immersion* and *presence* predict their *engagement* in the dVFT they experienced?

2b. How well do participants' perceptions of *design features*, *immersion*, *presence*, and *engagement* predict (1) their perceived *learning about the local environment* and (2) their *affective learning* with the desktop VR experience?

5. Methodology

5.1 Participants

This study was implemented in three different public outreach settings. In August 2022, the dVFT was placed on a public website hosted on our institution's server that could be accessed through the EE center's website. The website included passive consent materials to participate in the study. That is, users of the dVFT could opt in to complete a Qualtrics Web survey that was linked to the green arrow at the end of the last photosphere in Story Mode. Information about the dVFT was shared by the dissemination channels of the EE center. Data collection was open for three months. The second public outreach setting included participants who attended a seasonal festival at the EE center. The third outreach setting took place with an urban middle school's after-school homework club located approximately 20 miles (32 km) south of the EE center.

In total, the outreach yielded 150 responses. Eleven responses were removed from the data set due to missing items or spurious responses (zigzag or straight line patterns, for example). The final data set resulted in 139 valid responses and included 58 responses from the Web, 37 participants from the EE Center Festival, and 44 participants from the homework club that consisted of 35 middle school students and 9 college-age tutors. The total sample included 76 (54.68%) women, 56 (40.29%) men, 2 (1.43%) who self-identified as non-binary, and 5 (3.59%) who preferred not to answer or respond to the gender demographic item. Ethnicity responses included 86 White or Caucasian, 27 Hispanic or Latino, 13 Asian, 8 Black or African American, 5 Middle Eastern or North African, 2 some other race, ethnicity, or origin, and 8 who preferred not to answer this question. Participants were able to select multiple ethnicities for this demographic item. Age range responses included 27 (19.42%) under 13 years old, 31 (22.30%) 13 – 18 years old, 25 (17.99%) 19 – 24 years old, 18 (13.04%) 25 – 40 years old, 17 (12.95%) 41 – 55 years old, 14 (10.07%) 55 – 70 years old, 6 (4.32%) over 70 years old, and 1 (0.72%) who did not respond to this item.

5.2 Instrumentation

The survey included 24 Likert scale items that were scored with a five-point scale of 1 (Strongly Disagree) to 5 (Strongly Agree). The survey subscales included *Engagement* (7 items), *Presence* (3 items), *Immersion* (3 items), *VR design features* (2 items), *Learning about the local environment* (5 items), and *Affective learning* (4 items). The *Engagement* subscale items measured a respondent's self-reported cognitive, behavioral, and affective engagement during a science learning opportunity and were modified from Chung et al. [56] for the dVFT context. The original measure was designed specifically for science learning activities in informal science centers. *Presence*, *Immersion*, and *Affective learning* subscale items originated from the Perceptions of Learning with VR Games survey [33] and were modified for the dVFT context. Appendix A includes the survey items. Subscale reliabilities (Cronbach's alpha) from this study were uniformly high; 0.815 for *Engagement*, 0.812 for *Presence*, 0.842 for *Immersion*, 0.773 for *VR design features*, 0.832 for *Learning about the local environment*, and 0.767 for *Affective learning*.

5.3 Data Analysis

To address research question 1, for each factor (*age*, *gender*, *setting*), we ran a separate one-way multivariate analysis of variance (MANOVA) in SPSS to compare a set of means across the subgroups. The skewness and kurtosis values were expected to fall within the recommended range of -2 to +2 [57] (see Table 1). Next, we checked the assumption of homogeneity of covariance matrices (as part of the MANOVA output), expecting Box's test to be non-significant. If the assumption was met, Wilks' lambda would be examined to test the overall null hypothesis of no significant mean difference across the groups. If the assumption was violated with a significant Box's test ($p < .05$), given the unequal sample sizes across the subgroups for *age*, *gender*, and *settings*, Pillai's trace would be reported as a more robust test along with Wilk's lambda [58].

After we had significant multivariate tests for *age* and *settings*, we examined univariate F-tests. For outcome variables with significant univariate F test between the two age groups (young and adult), $p \leq .05$, their group means would suffice to identify the group with a higher mean on each dependent variable. For the three outreach settings (Web, EE Center Festival, and

Homework Club), when the outcome variables had significant univariate *F* test, we examined *post hoc* comparisons of means using Tukey's HSD.

To investigate research question 2, a single path analysis was conducted in Mplus version 8.8 [59] to address RQ #2a and 2b regarding the relationship among the perceptions that participants had with the dVFT. We started with the model including (1) three exogenous variables (predictors; *presence, immersion, design feature*) predicting three endogenous variables (*engagement*, *learning about the local environment*, and *affective learning*); and (2) *engagement* predicting *learning about the local environment* and *affective learning*.

Moreover, we requested estimates for indirect effects from three exogenous variables to the two *learning* outcomes via *engagement*. Namely, the variable *engagement* was tested as a mediator for the relationship between the three predictors and the two perceived learning outcomes. The requests for indirect effects do not modify the path model specification or coefficients. The indirect effects were tested using the bootstrap approach (using 1000 draws) to get bias-corrected confidence limits and standard errors [60].

The observed variables in path models are assumed to be measured without error, which is possibly a strict assumption for measurement. However, path modeling allows us to incorporate the potential correlation between errors (residuals) of the two perceived learning outcomes; their correlation would have been ignored in two separate regression analyses. Given our limited sample size in this study, we did not include the group variables *age*, *gender*, or *settings* as potential covariates or moderators.

6. Results

The descriptive statistics for the six continuous measures (*engagement*, *presence*, *immersion*, *VR design features*, *learning about local environment*, and *affective learning*) are summarized in Table 1. All the continuous variables had negative skewness and kurtosis between 0.0 and -0.83. We viewed favorable responses for each subscale to have an average item mean of 4.0 (reflecting 'agree' on the 5-point Likert scale). The results support that, overall, the participants reported favorable perceptions of each subscale measure. Table 2 displays the descriptive statistics by *age* group, *gender* group, and location (outreach *settings*).

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6.1 One-way MANOVA for RQ #1

The assumption of equal covariance matrices was met for *age* group with a non-significant Box's test (p = .136), but the assumption was not met with significant Box's tests for both gender (p = .003) and locations (p = .005).

For the age group (58 participants ≤ 18 years old vs. 80 adults; one not reporting), the multivariate test was statistically significant, Wilks' Λ = .87, $F(6, 131) = 3.23$, p = .005, the effect size index *partial* η^2 = .13 (see Table 3). Univariate F tests showed that the young participants (≤ 18 years old) had significantly lower means than the adults on four of the six measures: *design features* (p = .005), *engagement* (p < .001), *learning about the local environment* (p = .005), *affective learning* (p = .008). The two age groups had no significant mean difference in *presence* and *immersion*, both p > .05 (see Table 4).

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For gender (56 male vs. 76 female participants), the multivariate test of the *gender* group difference in the set of outcome measures was statistically non-significant, Wilks' Λ = .94, Pillai's trace = .06, $F(6, 125) = 1.41$, p = .217, partial η^2= .06 (see Table 3). However, some univariate tests were significant, including *immersion* (p = .029, partial η^2= .04), *design features* (p = .041, partial η^2= .03), and *learning about the local environment* (p = .028, partial η^2= .03).

The univariate test for *presence* was marginally significant (p = .066, partial η^2= .03). The inconsistency between multivariate and univariate significance tests could be due to low power (i.e., N is too small; Tabachnick & Fidell, 2001). The female participants consistently had higher means for these outcome measures than male participants (see Tables 2 and 5).

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For public outreach setting, 58 participants for the Web, 37 for the EE Center Festival, and 44 for the Homework Club), the multivariate test was statistically significant, Wilks' Λ = .84, Pillai's trace = .16, $F_{(12, 262)}$ = 1.95, p = .029, partial η^2 = .08 (see Table 3). Univariate F tests were significant on five of the six measures: *presence* (p = .039, partial η^2 = .05), *design features* (p = .007, partial η^2 = .07), *engagement* (p = .003, partial η^2 = .08), *learning about the local environment* (p = .001, partial η^2 = .10), and *affective learning* (p < .001, partial η^2 = .10). The *setting* groups had no significant mean difference only in immersion, p = .105 (see Table 6). *Post hoc* mean comparison using Tukey's HSD revealed that the EE Center Festival participants had a significantly higher mean than the Homework Club participants in *design feature* (p = .005), *engagement* (p = .003), *learning about the local environment* (p < .001), and *affective learning* (p = .001). Web participants had a significantly higher mean than the Homework Club participants in *engagement* (p = .022) and *affective learning* (p = .008). For the outcome *presence*, the Homework Club participants had marginally significantly lower means than the other two settings, both with p < .10 (see Table 7). In addition, for each subscale, EE Center Festival participants consistently had higher favorable mean responses followed by Web location participants, followed by Homework Club participants who had the lowest mean subscale values for each construct (see Table 2).

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6.2 Path Analysis for RQ #2

Path analysis was conducted in Mplus for the 139 participants (no missing data from the online survey) to examine the relationship between (1) three exogenous variables (predictors; *Presence, Immersion, Design Features*) and three endogenous variables (*engagement*, *learning about the local environment*, and *affective learning*); and (2) *engagement* and the two types of learning (*learning about the local environment* and *affective learning*). Indirect effects from three exogenous variables to the two learning outcomes via *engagement* were tested with 1,000 bootstrap draws requested and completed. This path model was *just* identified and thus had zero degrees of freedom, yielding non-informative model fit statistics.

The variance explained for each endogenous variable was 49 percent (49%; $R^2 = .49$) for *engagement*, 66% for *learning about the local environment* ($R^2 = .66$), and 74% for *affective learning* ($R^2 = .74$). All the path coefficients were positive and significant (see Table 8 and Figure 4) with the following two *exceptions*: (1) *Immersion* was not significantly predicting any of three endogenous variables, and (2) *Engagement* was not significantly predicting *learning about the local environment* ($p > .05$). Specifically, with each one-point increase in *presence,* the predicted increase would be 0.83 points for *engagement* ($\beta = 0.44$ for the standardized path coefficient), 0.28 points for *learning about the local environment* ($\beta = 0.23$), and 0.18 points for *affective learning* ($\beta = 0.17$), $p < .05$. Similarly, with each one-point increase in *design feature,* the predicted increase would be 1.34 points for *engagement* ($\beta = 0.44$), 0.98 points for *learning about the local environment* ($\beta = 0.50$), and 0.51 points for *affective learning* ($\beta = 0.30$), $p < .001$. However, with each one-point increase in *immersion,* the predicted *engagement* would *decrease* by 0.23 points ($\beta = -0.10$), increase by 0.13 points for *learning about the local environment* ($\beta = 0.09$), and increase by 0.07 points for *affective learning* ($\beta = 0.06$), all being non-significant with $p > .05$. Further, with each one-point increase in *engagement,* the predicted increase would be 0.07 points for *learning about the local environment*, $p = .188$, and 0.26 points for *affective learning*, $p < .001$.

Two indirect effects, tested using bootstrapped standard errors, were significant for *affective learning* via *engagement*, starting from *presence* (B = 0.22, β = 0.21, $p = 0.001$) and from *design feature* (B = 0.35, β = 0.20, $p < .001$). The other four indirect effects (from *Immersion* to *affective learning,* as well as the three for *learning about the local environment*) were non-significant, $p > 0.05$ (see Table 8).

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7. Discussion

An important goal of public outreach is to develop learning experiences that are engaging for a wide range of audiences. This is a prominent design challenge for VR field trip developers who seek to develop learning activities for a wide age range of people that would include adolescents and senior citizens who may engage with a dVFT in different settings. Throughout our iterative design and development process, we engaged a wide range of age groups to use the prototype and pilot-test versions of *The Lehigh Gap Story*. Early in the development process, participants reported that interactivity was important, since they enjoyed having tasks to complete in each photosphere. In each photosphere, participants complete a series of tasks before moving on to the next photosphere. The user has the autonomy to select the order in which they wished to complete these tasks. We believe that this autonomy likely contributed to the participants' engagement of the dVFT experience.

The findings from the path analysis support the notion that both *design features* (narrative, guidance, and feedback) and *presence* in a dVFT are important for participants' engagement and learning. Given the favorable levels of engagement and perceived learning that the participants experienced, the indirect path results support that a combination of the design features (narrative, guidance, and feedback) and the VR affordance of presence may have led to users' engagement that influenced affective learning. In the dVFT, the feeling of presence was achieved through thoughtful design of including high-quality, visually rich natural settings in the photospheres with authentic natural audio sounds. Such designs with VR technology can produce psychological presence, with presence often presumed to then augment related media effects [61]. If the dVFT experience perceptually situated a user within the narrative, that user may then be more cognitively, emotionally, and behaviorally engaged within the narrative or events conveyed [40]. One hundred twenty-one participants (87.05%) responded that they enjoyed the storyline. *The Lehigh Gap Story* was narrated by Brownie, a bird avatar who shares an emotional story about the destruction of her ancestors' habitat. Emotionally appealing storylines can serve to motivate and engage a person and lead to increased learning [62]. It is conceivable that Brownie's story hooked the users' attention at the beginning of the dVFT experience. The storyline may also have served to stimulate other design characteristics of the dVFT experience, such as curiosity, interactivity, and autonomous control.

When designing VR field trips for public outreach, a challenge is to optimally design interactive experiences that focus on learning without cognitively overwhelming the user with other elements that may distract learners from a learning focus. Careful attention during the iterative design and development of the dVFT was placed on ensuring that the narrative story and the interactive elements in the experience did not demand a high cognitive load on the user. Too much interactivity may affect users' cognitive load during the experience and impact learning [63]. In previous implementation studies with middle school and college students using learning games in formal learning environments, the combination of storylines and interactivity was found to either decrease or have no effect on learning and have mixed effects on motivation and engagement [64]. Our findings may have differed from these past studies due our public outreach context. Learners in formal school environments may often focus on extrinsic motivation for task completions compared to public outreach settings in which people seek intrinsically rewarding experiences. That said, not all participants were completely engaged throughout the entire dVFT experience. The type of interactivity in the dVFT might account for the lower levels of engagement with youth contrasted to adults. Compared to dynamic video games that youth tend to play, the interactivity features in the dVFT are not as dynamic. The most dynamic feature was the ability to manipulate the rocks on the trail by rotating and zooming. While the historical signs within the photospheres had images and text that could be magnified, users had to read the text on these signs. There was not an option for this text to be read aloud to the users. This may have affected the engagement of some of the participants, especially youth who may be reluctant readers or English language learners.

The levels of immersion, presence, engagement, perceptions of learning about the local environment, and affective learning across all participants and settings were viewed favorably. The average item means of each subscale was greater than 4.0. However, for each subscale, participants at the EE Center Festival had higher valued responses compared to the Homework Club participants. Age and geographical proximity to the EE center may have been factors that may explain this outcome. Univariate *F* tests showed that the young participants ($\leq$ 18 years old) had significantly lower means than the adults did on four of the six measures: design features, engagement, learning about the local environment, and affective learning (p = 0.008). The Homework Club participants included the highest percentage of youth participants in the three outreach settings. In addition, the Homework Club participants lived in geographical distant areas from the EE center, which may have resulted in a weaker sense of place or connection to the EE center compared to those who were physically present at the EE Center Festival.

The results from the path analysis found that immersion was not statistically related to engagement, perceptions of learning about the local environment, and affective learning in public outreach settings. This was surprising, given the fact that presence was statistically related to engagement, perceptions of learning about the local environment, and affective learning. Immersion (the ability to move and interact within the technology-mediated environment) and presence (the sense of being there) are two features that are closely linked [65]. Immersion can be subjective and difficult to precisely quantify, and results have been mixed on its effects on learning [66]. Perhaps in the dVFT environment, the visual and auditory stimuli promoted a more heightened sense of presence compared to a sense of immersion. A follow-up study using a more immersive headset VR field trip experience of *The Lehigh Gap Story* and comparing the results to the dVFT findings might address this finding.

A limitation of this study is that we did not explicitly measure participants' perceptions of the place-based local context of the dVFT. The local context may have been an important component of the dVFT and may have had an indirect effect that led to the perceived learning and engagement of the participants. Local and regional learning can support learners' agency in public outreach learning contexts by providing experiences regarding authentic environmental issues. VR field trip designers can incorporate features such as avatars and storylines to achieve an emotional connection between users and place [67]. In addition, *The Lehigh Gap Story* included high-fidelity, photo-realistic imagery and realistic ambient sound, coupled with navigational agency, for the users to freely explore the virtual environment at their own pace. These visual and auditory components likely contributed to the high levels of presence and immersion that the users experienced and may have contributed to keeping the users engaged and on task, which may have led to their perceived learning. However, only 56.1% of the sample found the things that they learned in the dVFT to be relevant to their daily lives. It is likely that some of the study participants have not actually visited the nature center to hike on the trails on the revegetated mountain and thus did not have a personal connection to this area.

There are other factors that may have contributed to our findings. First, this study only included three types of public outreach settings. There are many different types of public outreach events that STEM and environmental education centers conduct (e.g.s., community groups, school outreach programs, local festivals). Future studies may examine differences among these settings. Second, it is possible that many participants had a favorable bias towards engaging with the dVFT. Those who attended the seasonal festival at the nature center may have been intrinsically motivated to learn more about an environmental site that they were visiting for a public outreach event. Third, the dVFT itself may have provided a novelty effect for the participants due to the dVR technology experience.

8. Conclusion and Implications for Science Teacher Educators

In this study, we found that immersion, presence, engagement, learning about local environment, VR design features, and affective learning were perceived favorably by the majority of the study's participants. The results for young participants (≤ 18 years old) were significantly lower than those for adults on four of the six measures: design features, engagement, learning about the local environment, affective learning. The two age groups had no significant mean difference in presence and immersion. With regards to gender, the female participants consistently had higher means for the outcome measures than male participants, but statistical differences were inclusive based on the multivariate and univariate significance tests results, which may have been due to low power. For public outreach settings, EE Center Festival participants consistently had higher favorable mean responses for each subscale, followed by Web location participants, followed by Homework Club participants, who had the lowest mean subscale values for each construct. The setting groups had no significant mean difference only in immersion. Results from the path analysis highlighted the importance of presence and the design features (narrative, guidance, and feedback) for engagement and perceived learning. Immersion did not significantly predict either engagement or learning.

Our findings support that learning about one's local environment with a dVFT can have a positive impact on engagement and learning, particularly in public outreach learning environments. Attention to design features that include a narrative storyline and guidance and feedback during the dVFT experience should be considered for use in public outreach settings. Since most STEM and environmental education centers do not have headset VR equipment, dVFTs placed on a public website that can be accessed on a computer screen provide for greater access to engaging learning experiences for different types of outreach settings, thus providing equity for novel VR learning experiences.

Many institutions are located in or near watersheds that have past and/or current environmental issues. Understanding and addressing environmental issues is important for promoting environmental literacy and for preparing science teachers. Thus, *Watershed Explorers* has broad appeal to science teacher educators living in other geographical locations.

Many areas have non-formal environmental education or STEM-related centers that look to partner with higher education faculty to promote environmental and watershed literacy to the public. These centers are an invaluable resource that can provide science teacher educators with environmental content expertise, rich visual imagery, and other resources that could be used to enhance the development of a personalized DGLE. The *Watershed Explorers* DGLE was created through a collaborative partnership between faculty at our institution and our EE partners. This collaboration resulted in a superior learning experience that would likely have not been as successful with our inservice and preservice science teachers had either partner developed the DGLE on their own.

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Appendix A. Survey Measure Items

Engagement subscale items:
I felt excited when I used the VR field trip.
My mind was elsewhere when I used the VR field trip. (reverse code)
I was focused on the VR field trip most of the time.
I felt bored when I used the VR field trip. (reverse code)
Time went by quickly when I used the VR field trip.
I was doing other things when I used the VR field trip. (reverse code)
When I used the VR field trip, I talked to others about things not related to the VR field trip. (reverse code)

Presence subscale items:
I had a sense of "being there" when using the VR field trip.
I was able to concentrate easily when using the VR field trip.
I felt present in the VR field trip.

Immersion subscale items:
The VR field trip had a realistic-looking environment.
My seeing and hearing senses were fully used during the VR field trip.
I felt immersed when using the VR field trip.

VR design features subscale items:
I enjoyed the storyline of the VR field trip.
I enjoyed receiving guidance and feedback during the VR field trip.

Perceptions of learning about one's local environment subscale items:
I learned about my local environment with the VR field trip.
I learned about local history while using the VR field trip.
I learned about local environmental issues when using the VR field trip.
The "real-life" context of the VR field trip made learning about the local environment interesting.
The things I learned while using the VR field trip were relevant to my daily life.

Affective learning subscale items:
Using this VR field trip was a rewarding experience.
Using this VR field trip was a worthwhile experience.
This VR field trip did not hold my attention. (reverse code)
I would describe this VR field trip as very interesting.

Table 1
Descriptive Statistics for the Outcome Variables

	Min	Max	Mean (SD)	Skewness (S.E.)	Kurtosis (S.E.)
Presence	5	15	12.12 (2.27)	-0.63 (0.21)	0.24 (0.41)
Immersion	6	15	12.73 (2.00)	-0.83 (0.21)	0.90 (0.41)
Design Feature	5	10	8.55 (1.39)	-0.63 (0.21)	-0.49 (0.41)
Engagement	17	35	28.9 (4.29)	-0.54 (0.21)	-0.05 (0.41)
Learning local environment	14	25	21.5 (2.73)	-0.51 (0.21)	-0.5 (0.41)
Affective Learning	11	20	16.94 (2.41)	-0.41 (0.21)	-0.57 (0.41)
Valid N (listwise)	139				

Note: Number of items in each subscale: Presence (3), Immersion (3), Design Features (2), Engagement (7), Learning local environment (5), and Affective learning (4).

Table 2

Descriptive Statistics for the Outcome Variables by Age Group, Gender, and Location

Outcome Variables	Age		Gender		Location	
	Group	Mean (SD)	Group	Mean (SD)	Group	Mean (SD)
Presence	Young	11.76 (2.37)	Male	11.75 (2.47)	HW Club	11.41 (2.59)
	Adults	12.35 (2.17)	Female	12.49 (2.09)	Web (online)	12.40 (2.01)
					EE Fest	12.54 (2.12)
Immersion	Young	12.59 (2.08)	Male	12.30 (2.04)	HW Club	12.30 (2.18)
	Adults	12.81 (1.95)	Female	13.08 (1.97)	Web (online)	12.74 (1.98)
					EE Fest	13.24 (1.72)
Design Features	Young	8.16 (1.50)	Male	8.25 (1.30)	HW Club	8.11 (1.56)
	Adults	8.83 (1.25)	Female	8.75 (1.42)	Web (online)	8.55 (1.29)
					EE Fest	9.08 (1.19)
Engagement	Young	27.34 (4.22)	Male	28.38 (4.34)	HW Club	27.16 (4.42)
	Adults	29.95 (3.99)	Female	29.24 (4.26)	Web (online)	29.38 (4.14)
					EE Fest	30.22 (3.75)
Learning Local Environment	Young	20.72 (2.88)	Male	20.91 (2.71)	HW Club	20.52 (3.10)
	Adults	22.04 (2.50)	Female	21.97 (2.71)	Web (online)	21.47 (2.51)
					EE Fest	22.73 (2.10)
Affective Learning	Young	16.28 (2.52)	Male	16.68 (2.56)	HW Club	15.86 (2.60)
	Adults	17.38 (2.23)	Female	17.09 (2.34)	Web (online)	17.26 (2.25)
					EE Fest	17.70 (2.01)

Note. Age = 18 years old or younger versus Older than 18 years. Gender = Male versus Female. HW = Homework. EE = Environmental education.

Table 3

One-way MANOVA Conducted Separately by Age, Gender, and Location

		Value	*F*	df		*p*	Partial Eta Squared
				Hypothesis	Error		
Age	Wilks' Lambda	.87	3.23	6	131	.005	.13
Gender	Pillai's Trace	.06	1.41	6	125	.217	.06
	Wilks' Lambda	.94					
Location	Pillai's Trace	.16	1.95	12	262	.029	.08
	Wilks' Lambda	.84					

Note. Age = 18 years old or younger versus Older than 18 years. Gender = Male versus Female.

Table 4
Follow-up Univariate F tests for Each Subscale by Age

	Dependent Variable	Type III Sum of Squares	df	Mean Square	*F*	*p* value	Partial Eta Squared
Age	Presence	11.76	1	11.76	2.31	.131	0.02
	Immersion	1.72	1	1.72	0.43	.514	0.00
	Design Features	15.09	1	15.09	8.17	.0005	0.06
	Engagement	228.20	1	228.20	13.68	<.001	0.09
	Learning Local Environment	58	1	58.00	8.18	.005	0.06
	Affective Learning	40.62	1	40.62	7.32	.008	0.05
Error	Presence	692.82	136	5.09			
	Immersion	546.26	136	4.02			
	Design Features	251.15	136	1.85			
	Engagement	2268.90	136	16.68			
	Learning Local Environment	964.47	136	7.09			
	Affective Learning	754.34	136	5.55			

Note. Age = 18 years old or younger versus Older than 18 years.

Table 5
Follow-up Univariate F tests for Each Subscale by Gender (Male vs. Female)

	Dependent Variable	Type III Sum of Squares	df	Mean Square	*F*	*p* value	Partial Eta Squared
Gender	Presence	17.51	1	17.51	3.43	.066	.03
	Immersion	19.38	1	19.38	4.85	.029	.04
	Design Features	8.06	1	8.06	4.28	.041	.03
	Engagement	23.95	1	23.95	1.30	.257	.01
	Learning Local Environment	36.43	1	36.43	4.95	.028	.04
	Affective Learning	5.51	1	5.51	.93	.337	.01
Error	Presence	663.49	130	5.10			
	Immersion	519.37	130	4.00			
	Design Features	244.75	130	1.88			
	Engagement	2396.86	130	18.44			
	Learning Local Environment	956.50	130	7.36			
	Affective Learning	770.57	130	5.93			

Table 6
Follow-up Univariate F tests for Each Subscale by Public Outreach Setting

	Dependent Variable	Type III Sum of Squares	df	Mean Square	*F*	*p* value	Partial Eta Squared
Location	Presence	33.22	2	16.61	3.32	.039	.05
	Immersion	18.06	2	9.03	2.30	.105	.03
	Design Features	18.81	2	9.41	5.13	.007	.07
	Engagement	210.78	2	105.39	6.17	.003	.08
	Learning Local Environment	98.04	2	49.02	7.16	.001	.10
	Affective Learning	78.39	2	39.19	7.34	<.001	.10
Error	Presence	679.70	136	5.00			
	Immersion	535.09	136	3.93			
	Design Features	249.53	136	1.83			
	Engagement	2323.81	136	17.09			
	Learning Local Environment	930.71	136	6.84			
	Affective Learning	726.03	136	5.34			

Table 7
Post Hoc Mean Comparison Results Using Tukey's HSD

Dependent Variable	(I) Location	(J) Location	(I-J) Mean Difference	S.E.	*p* value	95% C.I. Bounds	
						Lower	Upper
Immersion	EE Fest	HW Club	0.95	.44	.085	-0.1	2
Presence	Web	HW Club	0.99	.45	.073	-0.07	2.05
	HW Club	EE Fest	-1.13	.50	.064	-2.31	0.05
Design Features	EE Fest	HW Club	0.97	.30	.005	0.25	1.68
Engagement	Web	HW Club	2.22	.83	.022	0.26	4.18
	EE Fest	HW Club	3.06	.92	.003	0.87	5.24
Learning Local Environment	EE Fest	Web	1.26	.55	.06	-0.04	2.57
	EE Fest	HW Club	2.21	.58	<.001	0.82	3.59
Affective Learning	Web	HW Club	1.39	.46	.008	0.30	2.49
	EE Fest	HW Club	1.84	.52	.001	0.62	3.06

Note. The error term is Mean Square(Error) = 5.338. Multiple mean comparisons have been reduced to (marginally) significant pairs, $p < .10$. HW = Homework. EE = Environmental education.

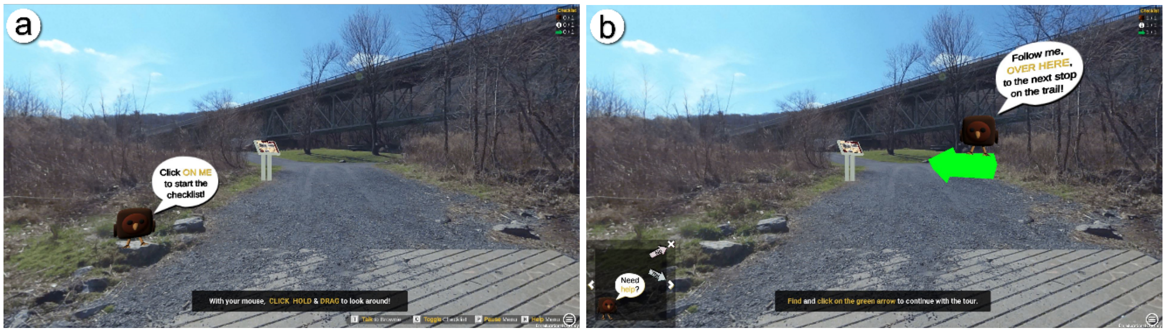
Table 8

Path Model Results with Bootstrapped Bias-Corrected 95% Confidence Interval

	Estimate (B)	S.E.	2-tailed *p*-value	Lower 2.5%	Upper 2.5%	Standardized Estimate (β)
Engagement						
Presence	0.83	.20	< .001	0.42	1.21	0.44
Immersion	-0.23	.25	.369	-0.69	0.32	-0.11
Design features	1.34	.25	< .001	0.83	1.80	0.44
Learning Local Environment						
Presence	0.28	.11	.008	0.07	0.48	0.23
Immersion	0.13	.12	.294	-0.11	0.35	0.09
Design features	0.98	.15	< .001	0.66	1.24	0.50
Engagement	0.07	.06	.188	-0.02	0.21	0.12
Affective Learning						
Presence	0.18	.09	.034	0.01	0.36	0.17
Immersion	0.08	.09	.398	-0.09	0.26	0.06
Design features	0.51	.12	< .001	0.26	0.73	0.30
Engagement	0.26	.03	< .001	0.20	0.33	0.47
Indirect Effect via **Engagement**						
Presence to Ln_Envir	0.06	.05	.259	0.00	0.19	0.05
Immersion to Ln_Envir	-0.02	.03	.562	-0.08	0.02	-0.01
Design features to Ln_Envir	0.10	.08	.228	-0.01	0.30	0.05
Presence to Ln_Affec	0.22	.06	< .001	0.12	0.34	0.21
Immersion to Ln_Affec	-0.06	.07	.382	-0.17	0.08	-0.05
Design features to Ln_Affec	0.35	.09	< .001	0.23	0.54	0.20

Notes. Ln_Envir = Learning Local Environment; Ln_Affec = Affective Learning.

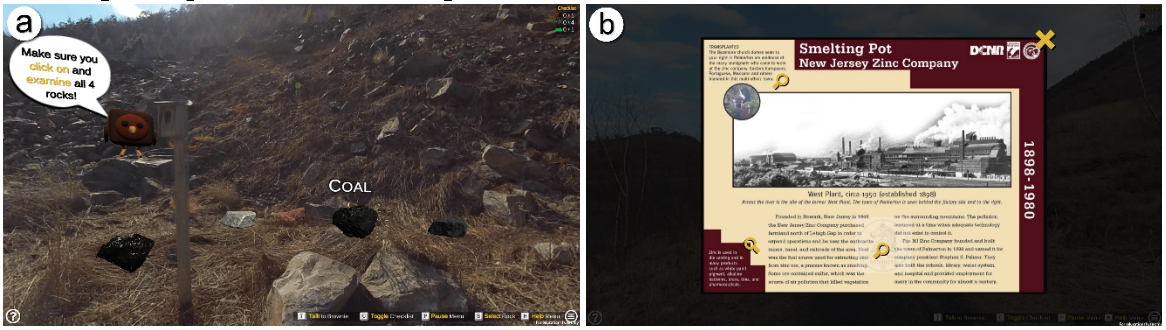
Figure 1.
Lehigh Gap Story photosphere features.



Note. Notice the two instances of non-persistent UI on the bottom corners of the screen. Figure 1a shows the user experience when they first enter a photosphere. Figure 1b shows a completed checklist and prompts the player to move to a new photosphere.

Figure 2.

Interactive photosphere element examples.

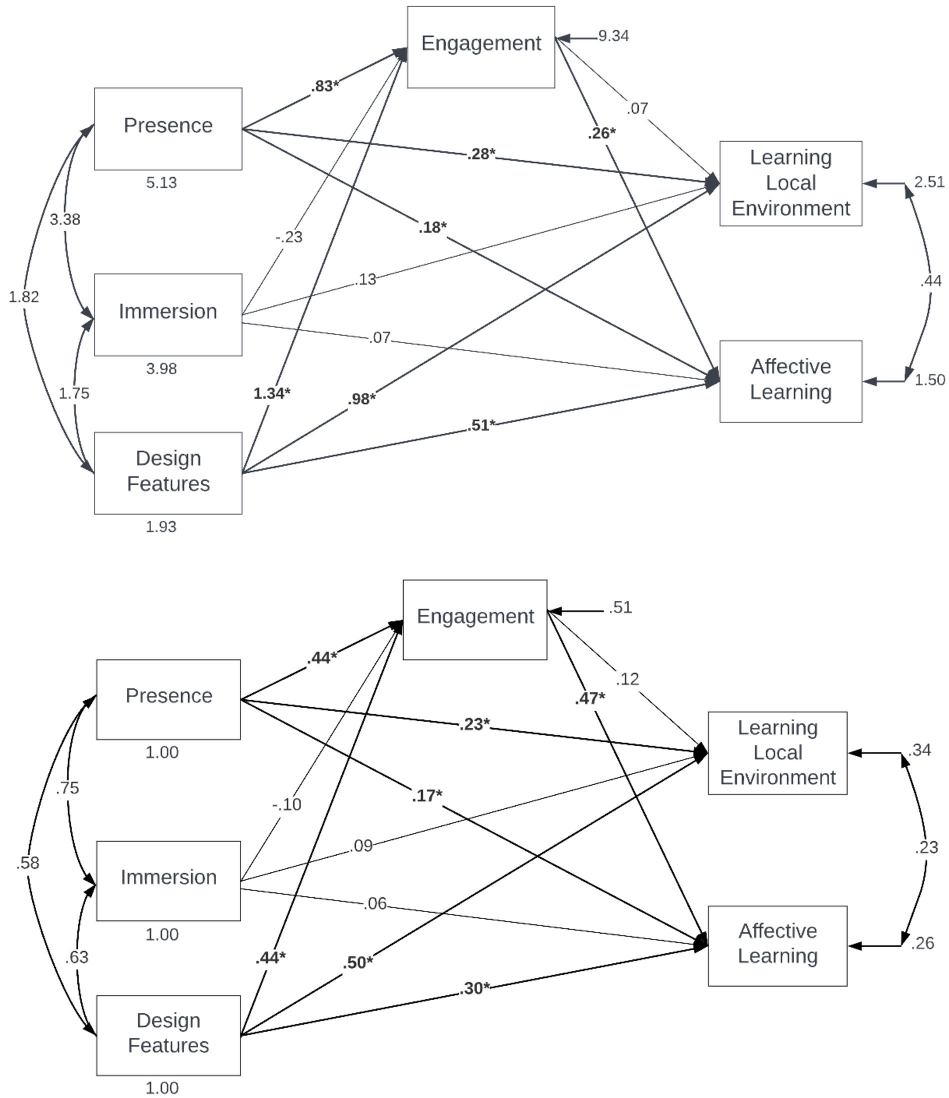


Note. Figure 2a shows avatar Brownie prompting the user to examine the four rocks in the photosphere. Figure 2b shows an interpretive sign. Magnifier icons can be clicked to enlarge the text and image.

Figure 3.
Acid rain animation.

Figure 4

Path Model with Unstandardized (Top) and Standardized (Bottom) Output



Note. * $p < .05$.