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Using Simulated Real-world Terrain in VR to Study Outdoor AR Topographic Map Interfaces

H. Furuya, Z. Choudhary, JJ. DeGuzman, M. Gottsacker, G. Bruder, G. Welch

University of Central Florida, USA

Abstract

Augmented reality (AR) technology enables advanced integration of spatial information useful in a variety of important domains, including for reading topographic maps in the field. It is also important to understand how this technology may potentially affect spatial learning ability. In this paper, we demonstrate the use of virtual reality (VR) to conduct a human-subject study investigating the impacts of different simulated AR topographic map interface designs on spatial learning outcomes. Our results show that interfaces that encourage engagement with the interface instead of with the map and the environment result in fast task completion times but poor spatial learning. We also found participant preference for a novel interface design that assists users with map orientation without explicitly guiding the user through the task.

CCS Concepts

• ***Human-centered computing*** → ***User studies; Virtual reality;***

1. Introduction

Augmented reality interfaces are a critical part of the technological vision of the future for numerous domains that rely on spatial visualization and understanding in the outdoors, including hiking, Earth sciences, search and rescue, defense, and many others [Azu99, AZD*12, LAATD19]. In these domains a commonly used tool is the topographic map, a two-dimensional (2D) depiction using elevation contour lines to represent the shape of three-dimensional (3D) terrain [NWA*15], [RCKM07]. Given the well-known difficulty in learning to read topographic maps [WF11, CRL*08], a growing body of research has emerged on how augmented reality (AR) and virtual reality (VR) can be used to make using topographic maps easier [BRC*16, CCAC*17].

One significant question facing interfaces meant to support real-world spatial tasks is whether their use degrades spatial learning and memory. For the most studied type of such tasks, navigation and wayfinding, a prior work has established that ubiquitous technologies such as GPS guidance adversely affect spatial learning abilities such as mental rotation and perspective taking abilities [CMF*21, DB20, LSL22, RCRSC19]. Much research has been dedicated toward explaining the mechanism for this undesired side-effect, leading to the development of frameworks that address the importance of locomotion and exploration in spatial learning and navigation [CW13, PBNE21, RCRSC19].

But what about tasks that use topographic maps, many of which are not navigational or locomotive in nature? A search and rescue helicopter pilot may use a topographic map to assess the viability of a landing area before making a rescue attempt and a skier may use one to decide whether a particular slope is an avalanche risk before skiing, for example, all without being required or able to explore and navigate through the environment in question a priori [WF11]. Furthermore, navigational tasks such as driving and walking directions are typically two-dimensional tasks, whereas the topographic maps are designed for the three-dimensional. Research is necessary to understand whether these fundamental differences change the key outcome, that task assistance interfaces thwart spatial learning. Researching the effects of AR topographic map interfaces meant for real-world outdoor use can be challenging, however, without assuming significant costs. For example, how might one conduct human subjects research on how AR interfaces impact spatial learning outcomes over a diverse range of terrain types? It is frequently not feasible to receive participants in the mountains to conduct controlled user studies, as evidenced by prior studies that did just that [ATN*18]. We thus arrived to the following two research questions:

- **RQ1**: How might we feasibly test prototype AR topographic map interfaces?
- **RQ2**: Does reducing spatial task engagement using AR topographic map interfaces reduce spatial learning outcomes?

In this work, we describe the implementation of a VR testbed for simulating real-world terrain, simulating prototype AR topographic map interfaces, and administering a virtual scavenger hunt and pointing test to evaluate the performance of different AR topographic map interface designs. We used this testbed to conduct a between-subjects experiment (N=37) in which we assessed the effects of 3 AR topographic map interface designs on participants' ability to learn the configuration of landmarks in a simulated real-world landscape. Our results show that the topographic map interface designed to explicitly guide participants through the spatial task exercise resulted in significantly lower task completion time but also significantly lower spatial memory assessment results. Our experiment also yielded participant preference for a topographic map interface designed to assist with map orientation without providing explicit task guidance.

The contributions of this work are as follows:

- **C1** Use of a simulated real-world terrain to employ a VR scavenger hunt and pointing test to assess the performance of simulated AR topographic map interfaces.
- **C2** Demonstration that interfaces that minimize engagement lead to reduced spatial learning.

The remainder of this paper is organized as follows: Concepts and prior work that form the background for this paper in Section 2, the hardware setup, simulated environment, and tasks used in our experiment in Section 3, the AR topographic map interface designs used in Section 4, the experimental design in Section 5, our results in Section 6, the discussion of these results in Section 7, and the conclusion in Section 8.

2. Related Work

2.1. Topographic Maps in AR and VR

Topographic map reading is known to be a difficult task [RCKM07], thus great care has been taken to understand how spatial skills are composed and acquired [KMC*09]. Numerous techniques have been evaluated to assist in reading topographic maps, such as relief shading [PLS75], shearing animations on digital devices [WJID15], augmented reality instruction [CPC18], sandboxes augmented with projection displays [JKV*19, MRW*20, RSD18], and 3D visualization [CCAC*17, RCKM07]. There is scarce evidence of many of these techniques actually being used in the field, and many experts persist in the use of classic 2D topographic maps over 3D representations [WF11]. This work aims to expand prior efforts in utilizing AR and VR for topographic map education and learning towards outdoor use by assessing the spatial learning effects of topographic map interfaces designed for tasks in real-world scale environments.

2.2. Usage of Virtual Environments to Simulate AR Interfaces

Using virtual environments, such as in VR, confers several benefits, such as more control over the environment, reduction of registration errors, and simulation of systems that are not actually available to the experimenters [RWBH09]. For systems that are designed to be used outdoors, it is frequently impossible to control important aspects of experimental conditions, such as weather, leading to confounding effects that are difficult to account for [LA08]. In the case of AR interfaces for outdoor use in domains relevant to topographic maps, such as geology [AZD*12], terrestrial exploration [ATN*18], and search and rescue [LAATD19], significant effort is required to solve technical and engineering challenges before any interface research can be conducted. Thus, recent work in related domains, such as outdoor AR navigation interfaces, has turned to VR simulation to study questions related to AR systems [ZSCRB23]. For these reasons, we chose to simulate real-world terrain to investigate the effects of simulated AR topographic map interfaces on spatial learning outcomes.

2.3. Effects of Technological Aids on Spatial Learning

The rapid rise of navigation aid systems like GPS has thus motivated research exploring the potential negative effects of technological aids on spatial and navigational abilities [GBT15, Mon09]. Such studies associate GPS use with worse mental rotation and perspective taking skills [RCRSC19] and orientation skills [IK05]. Partial active engagement with the environment can lead to worse learning of the environment in driving scenarios, as well [BLP08]. One approach suggests that advanced spatial learning is only acquired through allocation of attention and encoding of information into working memory [CW12]. By this theory, aids that discourage users from allocating resources to active exploration and mental manipulation of information would cause users to demonstrate diminished spatial learning. Recent work utilizes scavenger hunts to induce spatial learning in a real-world environment, which is evaluated using a pointing task where participants point from their current location towards the prompted location of interest [CMF*21, HS05]. To better understand the relationship between the level of task guidance provided by AR topographic map reading interfaces and environmental spatial learning, we employ a scavenger hunt and pointing task utilizing simulated AR interfaces in a simulated real-world landscape presented in VR.

3. Materials

3.1. Setup

Participants were asked to wear a Meta Quest 2 (128 GB memory, 1832 x 1920 resolution per eye, 106 degrees horizontal x 96 degrees vertical field of view) wireless VR head-worn display (HWD) with a single Meta Touch controller held in the dominant hand. Participants were seated in a swivel chair clear from obstacles such as desks or other chairs. The project was developed using Unity 2020.3 Long Term Support on Windows. The software for the experiment was deployed on the Meta Quest 2 VR HWD, i.e., not through Meta Quest Link.

3.2. Virtual Environment

Participants completed the experiment in a virtual environment (VE) presented using the VR HWD described in Section 3.1. As we were interested in learning of the environment and of topographic features, we chose to build the VE using real-world geographic features. To accomplish this, we based our VE on a 3D mesh of real-world geography generated by Mapbox's Unity package [Map] of the terrain at approximately 44°05'26.1"N 73°55'53.0"W, which corresponds to the mountains in northeastern New York State, USA. This terrain was chosen due to its full coverage of the United States Army's classification of five major land features; hill, ridge, valley, saddle, and depression [otA13]. We populated this mesh with a random selection of trees using the "Mobile Tree Package" created by Laxer and distributed on the Unity AssetStore [Lax16].

3.3. Task Description

We used the above VE to implement a scavenger hunt and a pointing task to assess the effect of topographic map reading aid on environmental spatial learning. Participants conducted the scavenger hunt to learn the location of a set of landmarks, similar to how prior work assessed spatial knowledge development [CMF*21]. An important distinction between traditional scavenger hunts and the one conducted in this study is that whereas traditionally participants move through an environment to find objects, in this work participants remain stationary and visually locate the target objects. We chose this design as many real-world uses for topographic maps are independent of exploring the environment itself [WF11] and instead are used in activities such as planning and surveying. For our work, the stationary visual scavenger hunt task more directly engages the topographic map reading skills we are interested in than a traditional scavenger hunt. Lastly, there is the added consideration that topographic maps are often used for landscapes so large as to make traditional scavenger hunts impractical. After the completion of the scavenger hunt, participants completed a set of pointing tasks to assess their understanding of the environment's configuration. The following describes the location landmarks, scavenger hunt, and pointing task.

Landmarks: During the experiment, the scavenger hunt and pointing task were conducted with a set of 6 landmark locations distributed throughout the VE terrain to address each of the major land features discussed in Section 3.2. Their locations can be seen in Figure 1. A second set of 2 landmarks were also implemented for use in a familiarization tutorial, discussed in Section 5.5, and were not used in the experiment itself.

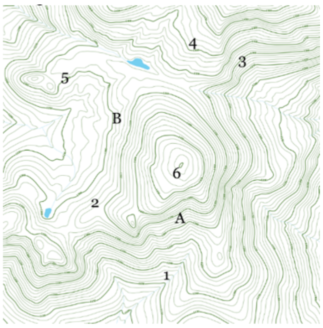

Figure 1: *Map locations of landmarks (1-6), scavenger hunt vantage point (A), and pointing test vantage point (B)*

Scavenger Hunt: A scavenger hunt was used to prompt learning landmark locations. Participants were positioned at an elevated location (see Figure 2) within the VE from which they were asked to use a topographic map interface to visually identify the location of each landmark. Section 4 discusses the designs used for the topographic map interface. The topographic map shows the location of each of the landmarks. At first, the landmarks are not visible in the VE and only marked on the topographic map. Participants point a reticle at the spot in the VE where they believe the landmark is located and trigger a correctness check. Pointing is implemented by head gaze and the correctness check is initiated by pressing a button on the controller. The correctness check is implemented using a gaze cone of about 4° in diameter. If correct, the landmark becomes visible and positive feedback is delivered through an audio cue. If incorrect, participants receive negative feedback through an audio cue. There was no disincentive for incorrect answers and participants were allowed unlimited chances. The scavenger hunt task was completed once all landmarks had been correctly located in the VE.

Pointing Test: A pointing test was administered to assess the participant's ability to orient themselves in the environment and remember the location configuration of the landmarks. After completing the above scavenger hunt, participants were teleported to a different vantage point in the environment, shown in Figure 2. At this point the topographic map and landmarks were hidden. One-by-one, the user is prompted to point in the direction of the location of each landmark, as shown in Figure 3. As the map and landmarks are hidden, participants must look around and identify terrain features they have seen from the scavenger hunt task to infer their new position. The pointing task ended once all landmarks had been pointed at. Participants were allowed to redo their choices but were not given feedback on their pointing accuracy.

Familiarization: As discussed below in Section 5.5, participants conducted a familiarization scavenger hunt and pointing test with a different set of landmarks prior to the experimental scavenger hunt and pointing test. The familiarization scavenger hunt and pointing test were conducted from the same vantage points as the experimental scavenger hunt and pointing test, respectively. Prior work suggests that familiarity with the environment does not translate to significantly better pointing test results [CMF*21], while in pilot testing we found that keeping the same vantage point helped participants better understand the experimental task.

4. Simulated Augmented Reality Topographic Map Interfaces

In our experiment we utilized three different designs of a topographic map, all presented in the VR experience as shown in Figure 4. As we were interested in the effects of differing levels of engagement reduction on spatial learning, we included one design that did not reduce engagement, "map-only", one design that eliminates engagement, "annotation", and one design intended as an intermediate, "support." Further details on our experimental design are described in Section 5.2.

4.1. Map-Only

The first interface, referred to as "map-only," is a 2D topographic map displayed on a virtual tablet device. Participants must use the map to interpret the locations of each landmark in the VE. Implicit in this task is interpreting the map to infer their own location, as the map does not mark the vantage point. As a result, this interface requires the user to allocate effort and attention to complete the spatial task.

4.2. Annotation

The second, referred to as "annotation," features the same map as the map-only interface augmented with a leader line connecting

Figure 2: *Views from vantage points starting from left: facing north, east, south, west; Top: scavenger hunt vantage point; Bottom: pointing test vantage point*

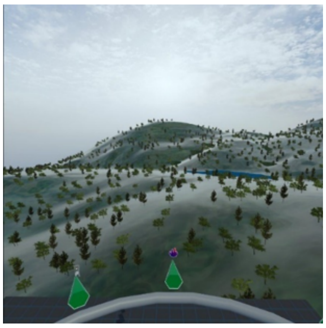

Figure 3: *Example of miniature landmark prompts shown during pointing test*

points of interest in the VE terrain with the corresponding locations on the map, simulating a typical AR task assistance interface where leader lines explicitly step users through a task [ZWP21, FMS93]. The location of each landmark is shown one at a time with a leader line directing the participant towards the landmark's location in the VE. Once the highlighted landmark is located, the leader line switches to highlight the location of the next, until the search task is finished. Additionally, the annotation interface places an icon on the map indicating the participant's current location and orientation. The leader lines and location tracking thus reduce the need for the user to perform any mental manipulations.

4.3. Support

The third and final interface, referred to as "support," is designed to assist users with interpreting map orientation without explicitly pointing users towards points of interest. Prior work suggests that technologies that discourage users from performing mental manipulation of spatial information degrade spatial learning, as discussed in Section 2.3. We created the support design to examine whether an interface that reduces the need for mental manipulation (annotation interface) but still requires allocated effort and attention (map-only interface) would still induce reduced spatial learning outcomes in a spatial task. To do this, the support design utilizes two linked representations of the topographic map of the area as seen in Figure 4. The two visual components target assisting in mental rotation and perspective taking cognitive tasks in order to alleviate the demand for users to imagine how the landscape might look from multiple perspectives, a critical aspect of reading topographic maps [KI06]. The first representation, the "3D map," was created by extruding the original map upwards by elevation, consistent with prior work investigating the uses of 3D topographic maps [SWD04]. The 3D map is fixed in orientation to the VE, such that the cardinal directions of the 3D map are always aligned to the cardinal directions of the VE. This design assists users by allowing the user to easily compare views of the 3D map with their current view of the VE landscape without needing to perform mental perspective taking operations. The second representation features a 2D topographic map suspended mid-air in a vertical orientation facing the user, as a map might appear if it were mounted on a wall. In its upright orientation, the 2D map rotates on axis in real time to match the user's current view angle of the 3D map. In other words, the 2D map rotates such that users always view the VE, the 3D map, and the 2D map in correct alignment, thus matching the current perspective. Without the 2D map, it is difficult for users to see the entire map at one glance, as the 3D map naturally occludes certain portion of the map from any given perspective. Unlike the annotation design, the support design does not explicitly guide participants toward the objects of interest nor mark their current location and orientation so participants must still infer their own locations as well as the locations of the landmarks. To complete the design, a large hula-hoop-shaped ring provides the affordance for grabbing and moving the interface, as there is no virtual tablet to grab and move as in the map-only and annotation designs.

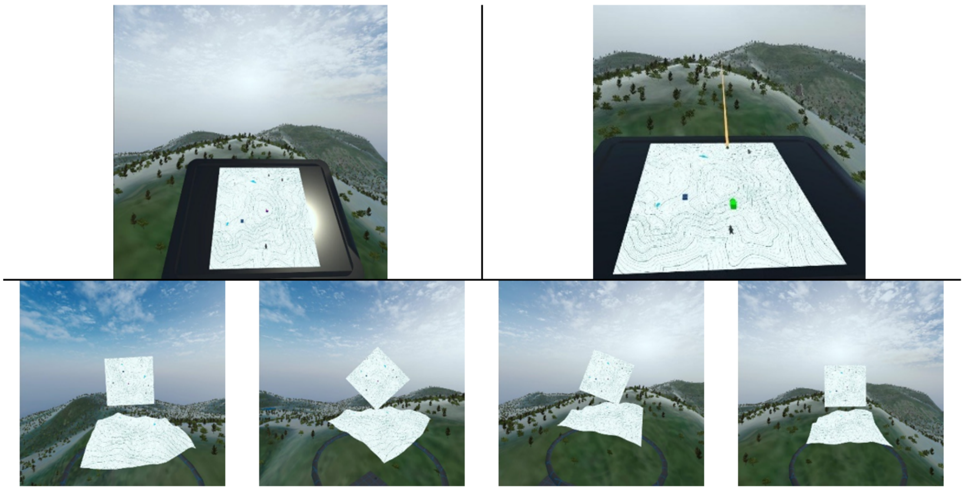

Figure 4: *Views of map interface conditions; Top Left: Map-only condition; Top right: Annotation condition with leader line connecting point on map to corresponding location in the environment; Bottom: Support condition with demonstration of automatic map rotation to match user perspective of the environment; In all conditions the maps feature figures displaying the locations of scavenger hunt target landmarks*

The support interface design was based on prior work on topographic map education in the geosciences, a field where teaching topographic map reading skills is a critical issue [RCKM07]. We conducted a pilot study to assess different approaches to helping users read topographic maps using 5 graduate students from the same lab as the authors. These techniques included perceiving how terrain slope is translated into line patterns on a topographic map, an animated extrusion transition from the 2D map to the 3D map, and creating markers of the user's current orientation and location on the map. These candidate techniques were based on prior work categorizing important skills for reading topographic maps [RCKM07]. The feedback from this pilot study showed that animations were unhelpful and distracting while showing the user's current location and orientation made the task too easy. We chose our final design based on the pilot feedback that it allowed users to better connect the features on the topographic map with the landscape around them.

5. Method

In this section we describe the experiment we conducted to understand the effects of topographic map reading aids on spatial map development. The study protocol was approved by the institutional review board (IRB) of our university under protocol number: SBE-17-13446.

5.1. Participants

A power analysis, conducted in G*Power [FELB07], determined that a sample size of 39 was needed for a repeated measures, between factors ANOVA with $\alpha = 0.05$, $\beta = 0.8$, a partial $\eta^2 = 0.15$ for large effect sizes, and 6 measurements corresponding to the 6 trials to be described in Section 3.3. We recruited 37 participants for our user study; 10 females and 27 males, aged 18 to 39 (M=22.2, SD=4.1). All participants were members of the local university community, reported having normal hearing and normal or corrected vision. One participant had reported receiving some prior instruction on and experience with topographic maps. 36 participants reported previous experience using a virtual reality (VR) head-mounted display. Participants were randomly sorted into four groups in a between-subjects design. Gender was recorded based on participants' self-reporting. No exclusions occurred due to gender related reasons. To ensure as equal a gender representation as possible, we recruited participants through forums with equal gender access.

5.2. Experimental Design

We ran a between-subjects design study for our experiment with the topographic map interface as the single factor. Participants were randomly assigned to a condition. Each of the interfaces provides a different level of spatial task assistance.

- **Map-only** - No map reading assistance or task guidance
- **Support** - Assistance with map reading but no explicit guidance
- **Annotation** - Explicit task guidance

For an explanation of the way these levels were implemented, see Section 4.

5.3. Measures

To explore the effects of map reading assistance on spatial learning, we measured the following:

- **Scavenger hunt completion time** - The time taken by participants to find all 6 landmarks in the scavenger hunt
- **Pointing test error** - The mean error between recorded orientation and true orientation towards the 6 landmarks in the pointing task

In assessing participants' environmental spatial learning, pointing error is often used as a measure of performance in the pointing task, so we chose to do the same [CMF*21, HS05, Law96, WS00].

We had originally included spatial skills tests within the experiment because of how they relate subject spatial skills to tasks and challenges relevant to topographic map reading [KI06]. We used several tests such as an online version of the GZ orientation survey [KG09], the Perspective Taking Spatial Orientation Test [HW04], Piaget's Water Level Test [PI97], and the Redrawn Vandenberg and Kuse Mental Rotations Test [PLL*95]. However, pilot testing revealed that is was unfeasible to include these tests if participants were to complete the experiment within a reasonable time frame.

5.4. Hypotheses

H1 Scavenger hunt completion time: $Annotation < Support < Map-only$

H2 Pointing test error: $Map-only < Support < Annotation$

Hypothesis **H1** is informed by expectations that assistance in reading the topographic will reduce scavenger hunt time.

Hypothesis **H2** is informed by by expectations that less assistance induces higher attention and memory resource allocation for spatial tasks, inducing higher levels of spatial learning. The annotation condition completely removes the need to exercise map-reading skills, while the support condition partially alleviates the burden of a portion of important map-reading skills, as discussed in Section 4.3. Therefore, we expect that both the annotation and support conditions will reduce spatial learning, but the support condition less so than the annotation condition.

5.5. Experimental Procedure

Before the start of the experiment, participant consent was obtained in accordance with the IRB-approved protocol (see Section 5). The researcher presented them with a demographic questionnaire to complete. The participant was then given a PDF to read about and become acquainted with topographic maps. Participants were then introduced to the HWD and the controls, followed by getting fitted with the headset and placed into the VE To familiarize participants with the scavenger hunt and pointing test tasks, participants were given a tutorial, where they completed the scavenger hunt and pointing test tasks once, before completing them both again with a different set of landmarks. Both sets of tasks were done from the same vantage points for scavenger hunt and pointing test tasks, respectively. Then participants performed the scavenger hunt and pointing test tasks for the main set of 6 landmarks, as described in Section 3.3. After finishing the pointing test for all landmarks, participants were asked to respond to an exit questionnaire. The exit questionnaire asked participants to provide their thoughts about how their understanding and usage of topographic maps changed throughout the experiment. In addition, it asked them to identify what features they saw helped or did not help and to describe the methods they employed to complete the scavenger hunt and pointing test.

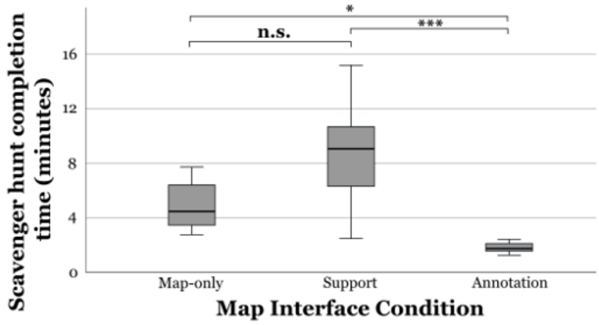

Figure 5: *Box and whisker plots for scavenger hunt completion time (in minutes) by topographic map interface condition; * indicates significant pair-wise difference, p = 0.019; *** indicates significant pair-wise difference, p < 0.001; n.s. indicates no significant pair-wise difference*

6. Results

We conducted a one-way Analysis of Variance (ANOVA) to see if the topographic map reading aid interface conditions had an effect on scavenger hunt completion time and pointing test error. Post-hoc Bonferroni corrected pairwise comparisons were conducted for measures with significant main effects.

6.1. Scavenger Hunt Completion Time

Mean scavenger hunt completion time, in minutes, was lowest for the annotation condition (*M*=1.3, *SD*=0.9, 95% CI [0.8, 1.8]), then the map-only condition (*M*=5.6, *SD*=5.3, 95% CI [2.0, 9.2]), and finally the support condition (*M*=8.0, *SD*=3.6, 95% CI [5.9, 10.2]). The one-way ANOVA demonstrated a significant main effect, $F(2,34) = 11.48$, $p < 0.001$, $\eta^2 = 0.40$. Post-hoc Bonferroni-corrected pairwise comparisons demonstrated a significant difference between the annotation condition and the map-only and support conditions. Thus we find that H1 is partially supported. No other pairs were significantly different.

6.2. Pointing Test Error

Mean pointing test error, in degrees, was lowest for the map-only condition (*M*=21.3, *SD*=15.3, 95% CI [11.0, 21.5]), then the support condition (*M*=36.62, *SD*=28.1, 95% CI [13.6, 59.6]), and finally the annotation condition (*M*=67.4, *SD*=31.9, 95% CI [48.2, 86.7]). The one-way ANOVA demonstrated a significant effect, $F(2,34) = 7.184$, $p = 0.002$, $\eta^2 = 0.30$. Post-hoc Bonferroni corrected pairwise comparisons demonstrated a significant difference between the annotation condition and the map-only and support conditions. No other pairs were significantly different. Thus we find that H2 is partially supported.

6.3. Subjective Feedback

Participants' responses to the exit questionnaire (see Section 5.5) were coded into three groups on whether they felt the VR experience

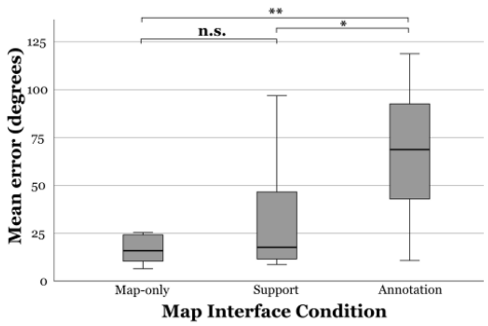

Figure 6: *Box and whisker plot for mean pointing test error (in degrees) by topographic map interface condition; * indicates significant pair-wise difference, p = 0.045; ** indicates significant pair-wise difference, p = 0.002; n.s. indicates no significant pair-wise difference*

helped, did not help, or was neither/neutral, to their understanding of topographic maps. Frequencies for responses in each group are shown in Table 1.

Table 1: *Frequency of participants' responses to if the VR intervention helped their understanding of topographic maps, by topographic map interface condition*

	Map-only	Support	Annotation
Helped understanding	6	10	3
Did not help understanding	1	1	6
Neither/neutral	4	2	4
Fraction helped	6/11	10/13	3/13

Participant responses were also coded for the techniques they used to complete the scavenger hunt and what type of map or interface features participants found useful for completing the scavenger hunt. Frequencies of each technique type are shown in Table 2. Table 3 shows examples of responses coded into each technique category.

While coding for technique, we found that some of the responses seemed to describe a much clearer and detailed strategy than the others. Of the responses that indicate a technique or strategy, we also coded for how many described a specific or coherent strategy. Table 4 shows frequency for each condition. and Table 5 shows example responses for each code.

7. Discussion

7.1. Explicit task guidance through topographic map interface improves task performance but hinders spatial learning

In the scavenger hunt task, participants in the annotation condition finished faster than participants in the other two groups. On the other hand, participants in the annotation condition demonstrated greater error than participants in the other groups in the subsequent pointing task. This matches expectations of improved task performance

Table 2: *Frequency of different techniques participants used to complete scavenger hunt, by topographic map interface condition*

	Map-only	Support	Annotation
Using previously found landmarks as references	1	4	3
Compare view with 3D model	0	4	0
Compare 2D map with 3D model	0	1	0
Using landscape features as landmarks	4	8	2
Using elevation numbers	1	0	0
Comparing map contour intervals with landscape	0	0	1

Table 3: *Example responses for each category of technique used to complete scavenger hunt*

Using previously found landmarks as references	"[O]nce I started finding objects, I was able to estimate where they were in the map using the found ones as points of reference"
Compare view with 3D model	"The map rotating together with the view when dragged was helpful"
Compare 2D map with 3D model	"The two maps (2D and 3D) helped in identifying the objects a lot"
Using landscape features as landmarks	"I generally focused on certain 'landmarks' of the map and located myself accordingly"
Using elevation numbers	"The numbers on how high the line is helped a lot and it really helped me to complete all the tasks given"
Comparing map contour intervals with landscape	"[U]sing the contour intervals and evaluating the surrounding areas and also trying to imagine the presence in the environment"

Table 4: *Frequency of coherent and vague scavenger hunt strategy descriptions*

	Map-only	Support	Annotation
Coherent strategy	2	7	0
Vague strategy	4	6	6
Total responses describing strategy	6	13	6

Table 5: *Examples of coherent and vague strategy description coding*

Coherent strategy	"I identified landmarks ... in order to approximate my position ... then I used the 3D map to find the geography around my target."
Vague strategy	"Tactics I used were using the lakes as a marker to try [and] understand my location."

due to the explicit task guidance as well as expectations of reduced development of spatial knowledge of the environment configuration than participants in the other two groups. We see support for this idea in participant subjective feedback, where fewer participants in the annotation condition reported feeling that the experience helped them understand topographic maps or reporting a coherent strategy compared to the other conditions. This result supports the generalization of the detrimental effects of technological aids on spatial learning seen in navigational contexts to stationary topographic map interpretation exercises. Future designs for topographic map interfaces must carefully consider this tradeoff between task performance and spatial knowledge acquisition.

7.2. Positive Subjective Feedback for Support Topographic Map Interface

Performance of participants in the support condition was not significantly different than the map-only condition, indicating that while the features for assisting map reading did not hinder spatial learning, it also indicates that they did not improve scavenger hunt task performance. On the other hand, subjective responses show that participants in the support condition used a greater variety of techniques with greater frequency in the scavenger hunt, more frequently provided coherent scavenger hunt strategy descriptions, and reported that the experience improved their understanding of topographic maps more frequently compared to the other conditions. One possible explanation for this is that the support interface design made the spatial skills required for topographic map interpretation more salient to the participants, triggering more conscious thoughts about the way the topographic map is interpreted. This could have led to more self-reflection of map interpretation strategies and higher response rates in the subjective feedback. It is also possible that participants simply perceived a more positive experience due to the presence of the interface itself. Prior work has demonstrated that higher image realism and higher fidelity 3D interfaces tend to elicit higher levels of reliance and higher subjective ratings compared to lower fidelity 2D interfaces while harming actual task performance [SCMC08, YW01]. The addition of the 3D map and the automatic map orientation features may have been perceived as being higher fidelity, leading to overestimation of the usefulness of the interface. More work is needed to understand the effects of interface elements designed to make map interpretation easier without explicitly guiding the user through the task. Instruments such as the Topographic Map Assessment [NWA*15] that measure topographic map reading skill could be used to assess whether designs like the support interface have a real impact on user map reading ability or if it is simply naive perception.

7.3. Limitations and Future Work

There are many environmental, systemic, and individual differences that may explain differences in topographic map reading performance and in spatial skill performance in general. Follow up research that captures such covariates would be valuable to better explain the variance in our results and corroborate the ecological validity of conducting VR user studies to better understand the effects of AR topographic map interfaces. Future work including these factors may be necessary to properly evaluate the effects of more subtle interface elements.

In the real world, the adoption and utilization of new user interfaces is influenced by many more factors than task performance [DBW89]. Follow up work utilizing tools such as the NASA Task Load Index [HS88] can help shed light on other aspects of interface performance that is of interest to the community.

Prior work has shown that the usability and perception of AR interfaces is dependent on AR system factors that we did not address, such as registration performance, display factors, and more [LA08, YW01]. Future work could use virtual displays to control these aspects of AR systems to help us better understand how robust AR topographic map interfaces are to variations in AR system performance.

8. Conclusion

In this work, we presented a between-subjects experiment (N=37) that uses simulated AR interfaces in a VR simulated real-world environment to investigate how three levels of topographic map interface; map-only, support, annotation; affect environmental spatial learning. Our results show that topographic map interfaces designed to reduce spatial task engagement can improve task completion time but worsen spatial learning. We also found that the interface designed to assist map interpretation without explicitly guiding users elicited more conscious engagement with map reading strategies and perceived skill improvement. Better understanding the effects of interfaces for topographic maps is important given the difficulty of reading topographic maps and their use in various, potentially high-stake, real life domains. These results demonstrate the successful use of VR to study the relationship between AR topographic map interfaces and spatial cognition outcomes important for continued success in these domains.

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