Learning and Emotional Outcomes in an Immersive Omnidirectional Pilot Study

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ABSTRACT

The U.S. Army's Synthetic Training Environment (STE) capability development invites questions such as whether infantry Soldiers would benefit from more immersive simulation-based training capabilities. Results from an empirical mixed methods pilot study suggest the impact of combined immersion and embodiment positively influence learning gains. The study showed learning gains and emotional outcomes. The between-subject design experiment included 15 participants randomly assigned to one of three system configurations. Each configuration gradually increased immersion and embodiment as combined system features. The control condition was a desktop configuration, while the experimental conditions included a Virtual Reality headset (VR) configuration, and a novel configuration using an omnidirectional treadmill with a VR headset enabling full-body virtual environment (VE) exploration. Each condition accessed the same realistically modeled geospatial VE and learning content and completed the same VE-interaction measurement instruments. The pre-test included declarative information-focused questions or complicated tasks, while the post-test repeated the pre-test and included a situational awareness measurement or complex task requiring participants to draw a sketch map. Learning gains occurred in all three conditions, however, statistical tests revealed no significant differences between conditions. There were significant strong positive correlations between increased immersion-embodiment levels and emotional factors which contribute to learning. Reviewing graphical depictions combined with quantitative and qualitative data highlighted patterns worth noting. Patterns suggest learning task type interacts with system configuration. Increased immersion levels, increase subjective feelings of presence and immersion, and higher feelings of immersion are significantly and strongly correlated to emotional outcomes viewed as important for long-term memory retention. A larger sample is required for increased statistical power to determine the significance of identified differences. These results may inform Army senior leaders about the educational/training capabilities of immersive-embodied simulations for improved related decision-making.

ABOUT THE AUTHORS

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Learning and Emotional Outcomes in an Immersive Omnidirectional-Treadmill Pilot Study

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INTRODUCTION

United States (U.S.) adversaries are working actively to degrade the U.S.' military-power projection capabilities (Headquarters, Department of the Army (HQDA), 2021, p. 1). These actions are influencing the U.S. Army's transformation into the "Multi-Domain Army of 2035" (HQDA, 2021, p. 1). This transformation, informed by the Multi-Domain Operations (MDO) operational concept, will influence and shape how the Army operates, organizes, and modernizes (Feickert, 2022, pp. 1-2). To accomplish this transformation, the Army has prioritized six modernization efforts which range from networks to air defense to Soldier lethality (HQDA, 2021, p. 22). The Army's Synthetic Training Environment (STE) capability, its top training modernization effort, is aligned against the latter (U.S. Army Professional Forum (APF), 2020; Rozman, 2020, p. 3). From a Soldier lethality perspective, the STE's many training capabilities invite questions such as whether small unit dismounted infantry Soldiers would benefit from more immersive simulation-based training capabilities (U.S. APF, 2020).

Currently, there are virtual/simulation training systems in existence and under development which provide individual and collective training opportunities for dismounted infantry Soldiers. Although not an exhaustive list, existing systems/capabilities include the Engagement Skills Trainer II (EST II) and Virtual Battle Space 3 (VBS3) while systems/capabilities in development include the STE-Information System (STE-IS) and the Squad Immersive Virtual Trainer (SiVT) (Bohemia Interactive Simulations (BIS), 2017; PEO STRI, n.d.a; PEO STRI, n.d.b; United States Army Combined Arms Center (USA CAC), 2021, embedded slides).

Small, dismounted infantry units, fire team to company-level, currently seeking collective-simulation-supported training will likely find Virtual Battlespace 3 (VBS3) as the proposed solution. VBS3 gaming software resembles game series such as the commercially available Ghost Recon and ARMA (BIS, 2021). A VBS3 solution will most likely be supported by a desktop and mouse configuration with some unique peripherals such as a steering wheel and or joystick (BIS, 2021). Tools such as VBS3 can be valuable training enablers.

STE elements under development include the STE-IS and the SiVT. The STE-IS capability is set to replace VBS3 apparently through the integration of the STE-IS' internal Training Simulation Software (TSS) and One World Terrain (OWT) capability (PEO STRI, n.d.d, description section; USA CAC, 2021, embedded slides). The SiVT is a software solution which involves the use of the Integrated Visual Augmentation System (IVAS) which is derived from Microsoft Hololens headset technology (Bach, 2021; Rozman, 2020, pp. 4-5). The IVAS can support real-world operations, and it can also support training through its Augmented Reality (AR) capability by adding virtual objects to the live training space through the SiVT (Rozman, 2020, pp. 4-6; Thompson, 2022). Yet, AR technology may not be mature enough to meet Army training requirements which certainly require functionality in daylight illuminated environments (Broll, 2022, p. 319; Stone, 2021). Due to the IVAS's optical-see through design, environmental brightness may cause AR presented images to be partially transparent or partially invisible (Broll, 2022, p. 299). If these challenges remain and a simple evolution of VBS3 is produced, immersion, presence, and embodiment may not be improved effectively potentially limiting learning/training outcomes.

The research question was heavily influenced after experiencing a novel virtual reality (VR) system that combined a VR headset and an omnidirectional treadmill (ODT) with a realistic virtual model of a geospatial natural environment (see Figure 1). The photorealistic open terrain with plants in VR represented high levels of immersion. The seamless interaction and ability to walk through that virtual environment (VE) represented high embodiment, mitigating cyber-sickness. Combined, these system design features represent a novel configuration to compare with traditional desktop and VR configurations. Could higher levels of immersion and embodiment in this ODT configuration alone, increase the effectiveness of learning and training for certain tasks? Of high interest are tasks which require context, situational awareness, and complex decision making. Complex and complicated tasks and their associated learning gains could benefit from contextual cues produced from the environment. The assumption driving this pilot study is when Soldiers use more immersive training systems aligned against appropriate tasks, they will achieve greater learning gains better preparing them for future battlefields. A simulation-driven capability which enhances immersion, presence, and embodiment may better prepare small unit dismounted infantry Soldiers for future battlefields characterized by increased violence, degraded communications, and non-contiguous areas of operations (Freedberg, 2016; Rozman, 2020, p. 2). This capability may prepare them by providing a signal rich environment to learn in while they experience and interact with complex problems. The increased physical signal strength provided by more immersive systems may lead to better learning opportunities by positively affecting emotional signals which contribute to long-term memory retention (Hayes et al., 2013, p. 26).

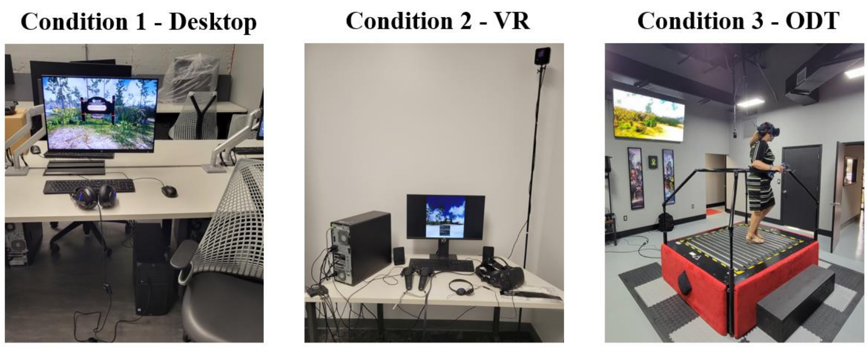

Figure 1. Experiment Condition Groups (Martin, 2023)

The findings reported here are the results of a pilot study from a Modeling and Simulation Master's thesis at the University of Central Florida (UCF) (Martin, 2023). The study examined the impact of combined immersion and embodiment on learning. The idea supposition is increased immersion-embodiment increases learning (Makransky & Peterson, 2021, p. 949; Skulmowski & Rey, 2018). While there is evidence in the literature that supports this, there is also contrary evidence when combined represents a gap in knowledge justifying the study (Hejtmanek et al., 2020; Makransky et al., 2019). This study used three independent conditions in an experimental between-subject pre/post-test research design. Critical for measuring learning gains, educational material was held constant and expressed in the same realistically modeled VE of the real UCF Arboretum, The Virtual UCF Arboretum application (UCF, n.d.). Each of the three technical configurations gradually increased in immersive-embodiment features. Learning outcomes were assessed using a pre/post-test measurement and supplemented with surveys to capture subjective evaluations. The results may inform U.S. Army senior leaders about the educational/training capabilities of immersive-embodied simulations for improved system configuration related decisions.

KEY TERMS AND CONCEPTS

Immersion, Presence, Virtual Reality, and Complicated Versus Complex

Immersion and presence lack clear and universally accepted definitions (Doerner et al., 2022, p. 17; Nilsson et al., 2016, p. 108; Slater, 2003, p. 1). In support of this project, immersion can be understood from a technological perspective, and presence can be understood from a psychological perspective (Ragan, et al., 2010, pp. 525-526, 528; Stevens et al., 2015, p. 525; Waltemate et al., 2018, pp. 1645, 1649, 1651; Witmer & Singer, 1998, p. 225). Additionally, it is assumed "[p]resence is a human reaction to immersion" (Slater, 2003, p. 2). Immersion is objective in nature and can be achieved by "the technology used to produce the [VE]" (Ragan, et al., 2010, p. 528; Stevens et al., 2015, p. 525). It is objective because concrete technical specifications can enhance the level of immersion. For example, a new VR headset which produces a million colors and includes a wide field of view is considered more immersive than a 20 year-old VR headset which offers only black and white and a narrow field of view. Presence can be understood "as the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998, p. 225; Stevens et al., 2015, pp. 525-526). So, the proper aggregation of immersive technical specifications can enable feelings of presence (Slater, 2003, p. 2).

As the Army moves forward with the development of the STE, the importance of immersion and presence cannot be overlooked in terms of its potential to impact dismounted infantry simulation-based training. Existing solutions for dismounted infantry training may be lacking in their ability to generate immersion and presence as typified by the common use of VBS3 with a desktop configuration (BIS, 2021). A configuration's immersion-embodiment output matters because more presence may lead to increased learning outcomes; VR-technology is 'a way' to increase immersion-embodiment (Selzer et al., 2019, p. 13). VR involves a solely computer-generated world; a VR "environment is one in which the participant observer is totally immersed in, and able to interact with, a completely synthetic world" (Harrington et al., 2019, p. 179; Milgram & Kishino, 1994, p. 2). Interaction with a VR-VE typically occurs via a headset and handheld controllers. With proper design support and task selection, infantry units could train for nearly any situation in a VR-VE.

A task's type may impact learning outcomes. Mikropoulos' and Natsis' (2011) review of empirical research concerning educational VEs found "that immersion compared to a desktop system has a great advantage only when the content to be learned is complex, 3D and dynamic…" (p. 774). A way to delineate a task's type is through the paradigm of complicated or complex where difference is a matter of type rather than degree (Poli, 2013, section 2). A complicated task/system/problem involves a situation where a specific set of inputs always leads to a predicted output (Poli, 2013; R. D. Walck, personal communication (PC), 27 October 2016). A complex task/system/problem involves a situation where known inputs cannot lead to a predictable outcome (Poli, 2013; R. D. Walck, PC, 27 October 2016). The best feasible outcome for interacting with a complex system/problem is the attainment of desirable influence which is likely temporary if even possible (Meadows, 2001, p. 59; Poli, 2013, section 1). Distinguishing between complicated and complex learning tasks is important when assessing the performance of simulation systems because a task's type may impact learning results. Since complicated and complex systems/problems/tasks are different, it is safe to assume each type may benefit from a different method of learning (R. D. Walck, PC, 27 October 2016). This pilot study's experiment involved complicated and complex tasks allowing for an analysis of the impact of immersive-embodiment features and task type on learning gains.

Interaction Fidelity, Embodiment, and Embodied Cognition

Studies employing technology ranging from the low-end of immersive capabilities through the high-end suggest and demonstrate that virtual media, and its associated degree of immersion-embodiment, can influence learning outcomes (Dong et al., 2022; Harrington, 2011; Harrington, 2023; Hayes et al., 2013; Radhakrishnan et al., 2022; Reitz & Richards, 2013; Selzer et al., 2019, p. 13). In this paper, desktop configurations are viewed as the low-end of the immersion spectrum with leading commercial VR systems and accompanying peripherals (e.g., ODT) representing the high-end of the spectrum. The highest degree of immersion-embodiment is achieved by the live environment because "the Real environment represents the highest degree of Presence possible, with many signals and redundancy gains" (Harrington, 2011, p. 184). System immersion-embodiment levels are determined by the number of senses affected in combination with the degree of interaction fidelity/embodiment produced.

Interaction fidelity causes desktop configurations to be less immersive-embodied when compared to VR systems (Bowman et al., 2012, pp. 3, 9; Stevens et al., 2015, p. 529). Interaction fidelity is "the degree to which user actions in a system match their real-world counterparts" (Bowman et al., 2012, p. 3). A desktop system typically affects vision and hearing while a VR headset affects vision, hearing, proprioception, and equilibrioception to a limited degree by allowing the turning of the head and body to observe the VE. A VR headset supported by an ODT is more immersive because it not only stimulates the same senses as the VR condition, but it also allows for natural movement or 'walking.' Simply put, the VR-ODT configuration has a higher interaction fidelity or degree of embodiment than the other conditions because it is more natural to observe the world by turning one's head and walking than using a keyboard and mouse (Ruddle et al., 1999, p. 158; Stevens et al., 2015, p. 529). The degree of interaction fidelity/embodiment generated by a configuration is important because it can directly affect learning (Makransky & Peterson, 2021, p. 949). From a theoretical perspective, interaction fidelity/embodiment influence learning in a manner consistent with theories of embodied cognition/learning (EC) (Makransky & Peterson, 2021, p. 949; Skulmowski & Rey, 2018). EC theory infers "that there is a connection between motor and visual processes; and the more explicit the connection the better the learning, suggesting that embodiment is important for learning" (Makransky & Peterson, 2021, p. 949). Physically performing certain tasks, such as riding a bike, will result in more learning than simply reading about them. So, increased learning may occur when interaction fidelity/embodiment is maximized through the proper alignment of immersive systems and tasks whose "physical activities are meaningful for the learning outcome" (Makransky & Peterson, 2021, p. 949).

METHODOLOGY

This pilot study's experiment enables learning when viewed from a perspective shaped by information processing, cognitive resource, and embodied cognition/learning theories (Merriënboer & Bruin, 2014, p. 26; Skulmowski & Rey, 2018, p. 1). Regarding cognitive resource theory, the experiment's learning model recognizes that humans have limited working memory resources (Merriënboer & Bruin, 2014, pp. 25-26; Miller, 1956, p. 93; Wickens & Hollands, 2000, pp. 250-251). The availability of working memory resources during an activity is what enables learning, with greater resources better supporting information processing and storage into long-term memory, or "genuine learning" (Merriënboer & Bruin, 2014, p. 26). Concerning information processing and embodied cognition/learning theory, the experiment's learning model acknowledges a link between the body and the environment through interaction (König et al., 2021, p. 1). While interacting, the body perceives the environment through its sensory register and develops a multisensory representation or mental model of the external environment; see Figure 2 (König et al., 2021, p. 1; Merriënboer & Bruin, 2014, p. 26; Skulmowski & Rey, 2018, pp. 1-2).

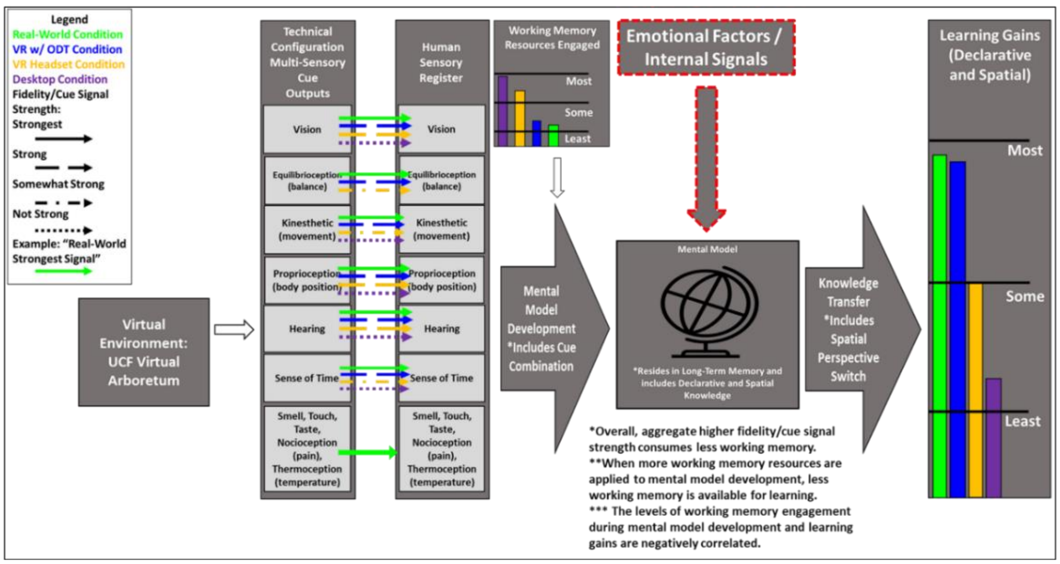

Figure 2. Experiment Learning Facilitation Model (See Conclusion for Red Elements) (Martin, 2023, p. 100)

Before entering the VE, participants are informed they should explore the VE and be prepared to communicate geospatial information to an unknown individual following their interaction. This guidance should prime participants to knowingly construct a detailed mental model of their experience. Priming is important to this pilot study because the experiment involves sensing the environment, constructing a mental model of the environment based on sensory inputs, and then referring to that mental model, which includes the cognitive map, to transfer and demonstrate learning gains. Participants accessed the VE through one of the respective technical configurations which provide varying sensory cues at differing degrees of fidelity/strength. These signals are received through the participant's sensory register for processing. As sensory cues are received in the sensory register and sent to working memory, mental model formation begins and then refinement occurs as information is transferred to long-term memory from working memory (Golledge, 2005, p. 330; Merriënboer & Bruin, 2014, pp. 25-26).

When multiple cues are presented together, these cues become redundant and inform the development of a more detailed cognitive map/mental model; the cues are combined leading to a more salient signal representative of the environment (Chen et al., 2017, p. 108; M. C. R. Harrington, PC, June 6, 2022; MICHAELHE, 2016). The experiment's learning model assumes cognitive map construction in the real-world establishes the baseline for cognitive map development since it is the most cue producing and experienced environment by participants (Harrington, 2011, p. 184). Due to this viewpoint, it is reasonable to assume the level of mental effort required to generate a cognitive map is negatively correlated to a VE experience's level of fidelity when compared to the real-world (Waller et al., 1998, pp. 130, 133, 141). In other words, a more realistic interaction with the VE enables more "genuine learning" because less mental resources will be allocated to the mental model's development (Merriënboer & Bruin, 2014, p. 26). A more detailed mental map is then developed because participants have more mental capacity available for learning since they do not have to mentally create/imagine missing cues or strengthen weak cues. Also, found in desktop VEs, the higher visual fidelity, produced by higher graphical and informational fidelity, transmits accurate and salient data in photorealistic detail and complexity, and when combined with free choice in navigation can double learning gains over combinations of cartoon imagery with no free choice navigation (Harrington, 2023). Thus, this study's results should indicate that infantry Soldiers performing a complex training task in a realistic environment, such as a squad attack against a thinking enemy, will learn more while training with a more immersive-embodied system. Since this type of task requires a Soldier's entire sensory register for successful execution, a more immersive-embodied system should lead to increased learning since it stimulates more of a Soldier's sensory register during training resulting in a highly detailed mental model. If this type of training task is performed with a low immersive-embodied system, which stimulates less of the Soldier's sensory register, it would likely result in less learning due to the resulting lower quality mental model. So, Soldiers conducting a squad attack with a more immersive-embodied system should gain a more natural feel, or learn more, about how they should physically behave and array themselves during a squad attack's execution than Soldiers on a low immersive-embodied system. For example, physically crouching while firing a weapon simulator in a VR-VE is different than crouching and firing a weapon on a desktop configuration while seated using a mouse and keyboard.

The experiment was IRB approved, of a between-subject design, and recruited fifteen participants (n = 15) via mass email. The null hypothesis is all learning gains between conditions will be the same (all mean ranks are equal). The independent variable is the technical configurations allowing VE access, and the dependent variables are learning outcomes and survey responses. Each of the three conditions, desktop, VR, and ODT, received five randomly assigned volunteers (n = 5); see Figure 1. VE interaction involved participants exploring the UCF Virtual Arboretum and clicking on objects (plants/trees) to learn about them via a pop-up informational window. The VE was realistically modeled in terms of the terrain, the location and dispersion of plant/tree families, and included 247 acres of space (Harrington et al., 2021). Desktop participants interacted with the VE using a keyboard and mouse. VR participants interacted with the VE using an HTC VIVE VR system with two controllers; one for movement via teleportation or smooth movement while the other allowed for object selection. The ODT condition interacted with the VE through an HTC VIVE Pro 2 headset, a single controller, and moved through the VE using an Infinadeck ODT; this ODT supports natural walking "in any direction" (Infinadeck, n.d.). For generalizability, the control condition replicates VBS3 using a desktop while the VE itself, with its realistic geospatial modeling, replicates the OWT initiative which seeks to develop a digital twin of the Earth to support training (PEO STRI, n.d.c, para 2).

The recruitment message sought participants who were at least 18 years old, UCF students, could speak English, had normal vision and hearing, could walk without assistance, had VR headset and treadmill experience, and were not susceptible to VR, cyber, or motion sickness. These restrictions mitigated the impact of confounding variables. The target population is U.S. Army enlisted Soldiers since they are the majority of Soldiers in small dismounted infantry units. The actual sample likely consisted of graduate students; although a sample of convenience, this group supported the target population thus increasing external validity. After granting consent, participants completed pre-surveys/tests. Pre-surveys collected data about demographics, attitudes, and perceived knowledge. The pre-test had two complicated questions/tasks requiring participants to list plants/flowers, and natural communities/habitats native to central Florida. These tasks are complicated because known facts/inputs can result in a predicted outcome or the identification of a plant/habitat. Participants then interacted with the VE. Preceding VE interaction, participants were instructed to "explore it as fully as they" could and they would be required to communicate geospatial information or 'what they found' to another person; the method of communication was not provided (Billinghurst & Weghorst, 1995, p. 42). Post VE interaction, post-tests/surveys were issued. The post-test repeated pre-test questions and added a third complex question/task requiring participants to draw a sketch map for "someone unfamiliar" with the VE to follow and find what they discovered (Billinghurst & Weghorst, 1995, p. 42). This task is complex because the participant cannot predict how the 'unfamiliar someone' will interpret (the output) their sketch map (the input). For questions 1 and 2, correct and partially accurate answers received full or half points. Question 3 maps were scored by "relative object positioning" and distance and "object classes" (Billinghurst & Weghorst, 1995, p. 42). Higher accuracy resulted in higher scores. Post-surveys were similar to pre-surveys but focused on VE interaction impact.

DATA RESULTS

Learning was analyzed using the Kruskal-Wallis non-parametric statistical test due to the small sample size (n = 15). This test compared the mean ranks of the test scores generated by condition groups (Geert Van Den Berg, n.d.; Laerd Statistics, n.d.; Siegel & Castellan, 1988, pp. 206-216). Learning occurred in all three conditions; see Table 1.

Table 1. Descriptive Statistics: Score Percentage Changes for Questions 1-2 and Question 3 Scores

Condition Group		Q1. (List Plants)	Q2. (List Communities)	Q3. (Sketch Map Score)
Desktop	Mean	93.9117	76.6667	31.20
	Std. Deviation	6.82210	32.48931	14.601
VR	Mean	94.2857	29.6667	34.80
	Std. Deviation	7.82461	31.36700	19.344
ODT	Mean	89.9242	46.6667	47.20
	Std. Deviation	7.49770	46.24812	23.679

The first two sets of scores compared were the percentage change from the pre-test to the post-test concerning the listing of plants/flowers and natural habitats/communities native to central Florida; higher numbers represent higher learning gains (questions 1 & 2 to measure declarative knowledge). The third set of scores compared were the sketch map task's cumulative scores (question 3, post-test only to measure contextual spatial knowledge). The results of the statistical test showed no difference between the scores generated by each of the condition groups for each of the three questions. For questions 1, 2, and 3 the results were the following: Q1: $H(2) = 1.332$, $p = .514$, Q2: $H(2) = 3.857$, $p = .145$, and Q3: $H(2) = 1.638$, $p = .441$. So, the null hypothesis is accepted, and the alternate rejected.

Using post-test raw scores for questions 1 and 2, we still accept the null hypothesis, but the results present a very strong trend for Q1: $H(2) = 5.798$, $p = .055$. A pairwise comparison of the questions by condition group reveals the trend is between the desktop and VR conditions ($p = .051$) (stikpet, 2017). The desktop group achieves higher scores on question 1 (list plants) with a mean rank of 11.60 versus the VR condition's 4.90.

Spearman's rho correlation test results highlight multiple strong, positive, and significant relationships. The condition group variable, coded in SPSS, showed significant positive correlations with post-survey questions: Q4: (imagination stimulation; $r_s(13) = .569$, $p = .027$), Q6: (feeling of immersion; $r_s(13) = .602$, $p = .018$), Q7: (feeling of presence; $r_s(13) = .541$, $p = .037$), and Q11: (interest to learn about natural communities now; $r_s(13) = .608$, $p = .016$). These correlations indicate as combined immersive-embodied features increase, so do feelings of immersion, presence, imagination stimulation, and interest to learn about natural communities.

Next, the feeling of immersion variable shared significant ($p < .05$) positive correlations with post-survey questions concerning variables or factors which can contribute to learning or the design of effective learning systems. The feeling of immersion variable correlates to Q1: (ease of learning; $r_s(13) = .599$, $p = .018$), Q2: (engagement during experience; $r_s(13) = .793$, $p = <.001$), Q4: (imagination stimulation; $r_s(13) = .694$, $p = .004$), and Q5: (curiosity stimulation; $r_s(13) = .759$, $p = .001$). These relationships suggest a configuration's level of immersion-embodiment could improve learning since feelings towards ease of learning, engagement, curiosity, and imagination increase with immersion and can easily be understood as factors which contribute to learning (Hayes et al., 2013, p. 26).

DISCUSSION

Although the Kruskal-Wallis test found no significant differences in learning outcomes by condition group, graphical representations of the data shown in the boxplots/box-and-whisker diagrams, Figures 3 and 4, combined with quantitative, qualitative, and correlational data suggest patterns worth noting. The small sample size and low power negatively impacted the ability to find statistically significant differences between group learning outcomes.

Boxplots offer a simple way of comparing the raw score changes for post-test questions 1 (list plants/flowers) and 2 (list communities), post-test question 3's score (draw sketch map), and the raw total score changes from the pre-test to the post-test (combined pre-test scores subtracted from combined post-test scores). The boxplots tell a story which involves task type (Figure 3). Question 1's and 2's boxplots imply there is a technological impact on learning outcomes linked with declarative knowledge or complicated tasks. It seems low-immersive and low-embodied (desktop) or highly-immersive and highly-embodied (ODT) technological configurations are better suited for learning declarative information (e.g., complicated tasks). The mid-immersive and mid-embodied VR condition performed the worst.

A post-survey response offers a potential reason for the decreased performance by the VR group. On the survey, a participant stated, "*…using the controllers definitely brought me out of the experience. I spent more time and effort using the tech than learning about the plants.*" User behavior in the desktop and ODT conditions supported mastered tools for interactions, such as standard desktop devices, or natural interactions such as walking, looking around, and pointing at objects with a handheld controller. We suspect the desktop and ODT configurations reduced cognitive load. The ODT condition's score variance skews higher than the VR group's most likely because the subjects could walk and observe the VE naturally. So, if a configuration interacts with complicated tasks/information, the information should be accessed through a low-immersive (desktop) or high-immersive (ODT) system which minimizes cognitive load by maximizing interaction fidelity; see Figure 3. Of note, the difference between the desktop and VR condition groups' scores approach significance for question 1 (list plants) when comparing post-test raw scores.

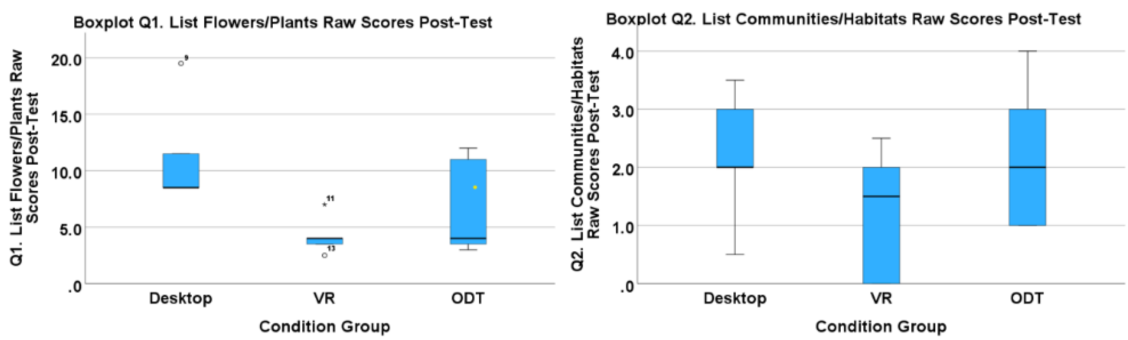

Figure 3. Post-Test Question 1 Raw Scores (Left) and Post-Test Question 2 Raw Scores (Right)

Conversely, complex tasks, such as situational awareness-centric tasks like drawing a sketch map to communicate geospatial information to an unknown individual, appear better suited for more immersive-embodied systems (VR and ODT); see Figure 4 - Left. Post-test question 3 (draw sketch map) mean scores gradually increased by condition as configuration immersion-embodiment features increased; see Table 1. Learning gains appear to be affected by the pairing of a learning task's type and a configuration's level of immersion-embodiment features.

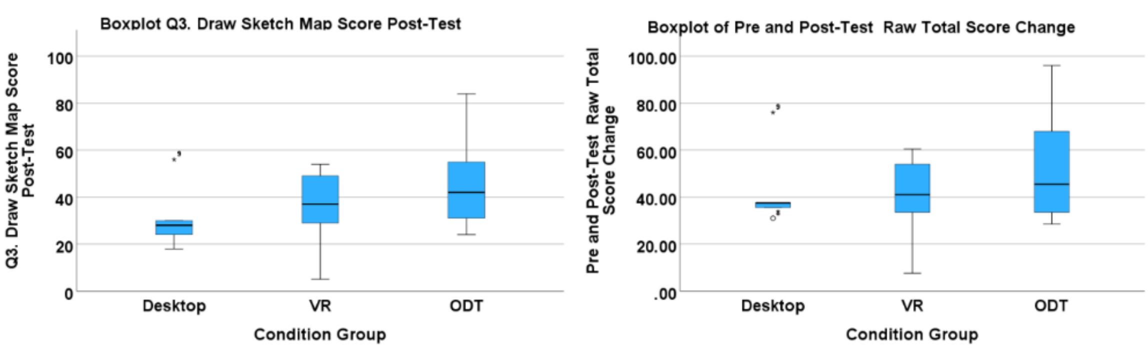

Figure 4. Question 3 Post-Test Scores (Left) and Pre/Post-Test Total Raw Score Change (Right)

Furthermore, the boxplot presenting overall learning outcomes (Figure 4 - Right) showed there is little to no difference in the central tendency between the condition groups' learning outcomes, but it also showed a different story in terms of the direction of variance. For question 3 and the overall learning outcomes, (Figure 4), the desktop condition showed virtually no variance and had the lowest scores, the VR condition skews down with a tail below the mean score but had slightly increased scores, and the ODT condition skews up showing a tail above the mean score and had the highest scores. The direction of variance suggests running the study with a larger sample size and higher power is needed to clarify these results. The overall scores, (question 3 and overall learning gains with all questions combined), improve when participants interact with the VE in more immersive-embodied configurations.

CONCLUSION

Learning occurred in all three conditions, but statistical test results indicate no difference in learning outcomes between groups. Yet, this data indicates overall learning outcomes skew positively with increased immersion-embodiment. Task type and system configuration affect learning outcomes. Results displayed a very strong trend $H(2) = 5.798$, $p = .055$ for question 1 (list plants) when post-test raw scores are compared by condition. The most important contribution is the discovery that task type pairing with system configurations with varying levels of immersion-embodiment correlate with emotional factors which contribute to learning. Emotional factors, or internal signals, may contribute to the achievement of increased learning gains by adding to the physical signals provided by the environment during mental model formation (see red elements in Figure 2). Graphical data representations combined with quantitative, qualitative, and correlational data suggest a larger sample size would permit a more conclusive analysis and evaluation.

This experiment's results may better inform Army senior leaders about the educational/training capabilities of immersive-embodied simulations as the Army transforms into the Multi-Domain Army of 2035 supported by the development of the STE capability. These senior leaders should walk away from this study knowing the following points. First, the impact of immersion and embodiment appears to positively influence learning outcomes. Second, a technological configuration's associated level of immersion and a task's type matters because this pairing can affect learning outcomes. Complicated tasks appear to be best suited for either low or highly immersive systems, with in-between systems potentially being less effective or distracting, and complex tasks appear to be best suited for more immersive configurations. If training objectives involve learning declarative information, such as weapon system ranges, a low immersive system like a book or desktop is likely enough. Conversely, if training objectives involve Soldiers learning how to conduct squad operations in a realistic environment against a thinking enemy, a high immersive system is likely necessary to maximize learning gains. Selecting a mid-immersive system for either of these tasks would likely lead to a waste of resources. A mid-immersive system does not appear to be required for learning declarative information (e.g., plant names or weapon ranges), and it appears that it can be distracting when learning complex information (e.g., arboretum geospatial information or squad operations). Lastly, increased immersion and embodiment share a positive and statistically significant relationship with emotional factors which contribute to learning and the design of effective learning systems (e.g., ease of learning, curiosity and imagination stimulation, and engagement). And, these variables' relationships may lead to better long-term memory retention, recall, or learning.

This pilot study expands the knowledge base focused on determining the impact of combined immersion and embodiment on learning outcomes. It was unique because it allowed for an examination of the Infinadeck ODT's impact on learning outcomes. This ODT allows for a natural walking experience via a treadmill belt which can move in 360 degrees as opposed to other ODTs which simulate walking via the sliding of feet over a slippery surface (Hejtmanek et al., 2020; Infinadeck, n.d.; Wehden et al., 2021). Additionally, this study looked at the impact of combined immersion and embodiment on learning outcomes a layer deeper than other studies by considering the influence of a task's type (complicated or complex). Concerning future work, we first recommend running a larger iteration of this study with sufficient statistical power which adds a longitudinal repeated measures aspect to the post-test to measure long-term memory retention. Next, we recommend revising the pre/post-test instruments to measure complicated and complex learning tasks more precisely to include the impact of emotional factors. Fielding a more immersive simulation-based training capability could lead to dismounted infantry Soldiers who are better prepared for future complex battlefields; data indicates technical configurations which enhance immersive-embodied experiences are positively correlated with emotions largely recognized to enhance long-term memory retention.

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