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Extended Abstract—The Impact of Guidance on Learning and Agency in a Virtual Reality Game for STEM Education

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Abstract. Educational research has long debated the benefits of structuring learners' experience through direct guidance versus allowing learners to engage in an unguided process of discovery. Educational virtual reality (VR) experiences require designers to confront this question. VR environments can be open-ended, allowing for a considerable amount of agency that either benefits learning or overwhelms the learner with stimuli. This extended abstract describes a work in progress to assess the impact of direct guidance on learning and agency in an open-ended STEM education VR game. The game was built in Meta's 'Horizon Worlds', a platform for social and self-directed experiences that is widely accessible on the Quest line of headsets. Titled 'Virtual Excursions for Science Learning (VESL)', the multiplayer game situates learners in the role of scientists on a research cruise to study plankton. In this study, we have pairs of university students play the game either unguided or with a researcher guiding their virtual excursion. We are assessing the impact of these two conditions on learners' content knowledge gains, retention of research procedures, sense of agency and changes in their STEM interest and identity.

Keywords: Virtual Reality, STEM Education, Agency, Learning.

1 Introduction and Research Questions

Educational research has long debated the benefits of structuring learners' experience through direct guidance versus allowing learners to engage in an unguided process of discovery. For example, nearly two decades ago, scholars like Cindy Hmelo Silver and Paul A. Kirschner debated the merits of guided instruction on learning in educational psychology journals [1,2]. On one hand, researchers point to the benefit of student-directed learning such as problem-based, experiential, inquiry, and discovery learning approaches to promote deeper learning, transfer, and intrinsic motivation [1, 3–5]. These approaches privilege learner agency to make choices and guide their own learning [6]. On the other hand, researchers point to the benefits of structured guidance to reduce cognitive load and improve fundamental understanding in novice learners [2, 7, 8]. These approaches privilege direct instruction of content while limiting the choice of students.

These questions are relevant for the design of learning experiences in virtual reality (VR), which provide the opportunity for student-directed and constructivist learning but which also are prone to inducing extraneous cognitive load [6, 9]. In this study, we are testing how guidance in an open-ended VR game for STEM education impacts learning and the learners' sense of agency in the game. In this study, we ask:

1. Does having a guide in an open-ended learning game increase learning of science content knowledge and retention of research procedures from the game?
2. Does having a guide in an open-ended learning game decrease learners' sense of agency over their experience and their learning?
3. Does having a guide in an open-ended learning game impact learners' interest, STEM identity, and feelings of embodiment?

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2 Theoretical Background and Related Work

Immersive technologies have been leveraged to give learners inquiry-based experiences in simulated environments, allowing them to engage in tasks and environments that are not possible in real life. For example, Chris Dede's framework for immersive learning technologies illustrates how first-person perspectives and heightened agency promote situated learning that engage learners in legitimate peripheral participation and promote inquiry-based learning [10]. Volumes on VR in education make the case that VR is especially well-suited for constructivist approaches that allow learners to construct their own knowledge and are at their most effective when focused on complex knowledge and skills that are not typically transferred from classroom instruction to real-world contexts [11]. The two primary affordances of VR for learning are that it heightens learners' presence, or the feeling of being in a place different than their physical location, and that it provides a great deal of agency by facilitating full-body interactivity [12, 13]. These affordances mean VR is capable of giving learners more real-feeling experiential learning opportunities which are more "hands-on" and better promote affective dimensions of learning. Systematic reviews and meta-analyses consistently find that VR enhances affective dimensions of learning more than other media, such as intrinsic motivation, engagement, and interest [14, 15], and studies show it can be more effective at promoting transfer [16].

Despite the promise of VR to enhance learning through student-directed, agentic, and constructivist learning, studies also consistently show that learners struggle in immersive environments due to heightened cognitive load. Many studies on learning with VR have been guided by the Cognitive Theory of Multimedia Learning (CTML), and often find that learners struggle to retain information from VR compared to less stimulating media, such as slideshows or videos [9, 17, 18]. Some studies have assessed ways of reducing cognitive load to make learning content easier, including pre-training learners with some of the content before using VR [19, 20] or utilizing a generative activity to summarize the content during or after a VR lesson [16, 21].

Many of the studies focused on CTML illustrate how heightened immersion and presence lead to greater distraction and extraneous cognitive load due to the overwhelming stimulus. Recent studies have also begun to study the impact of interactivity and agency, VR's other primary affordance for learning. For example, a study of a 360 video in middle school science education found that increased learning was mediated by a greater sense of agency in VR versus a desktop computer [22]. Other studies have compared higher-interactivity conditions in VR to watching a recorded play-through of a learning experience and find the interactivity increased learners' sense of agency but not their learning [23, 24]. A study comparing sitting versus standing in VR found participants who stood and moved around learned less content knowledge but had greater increases in their self-efficacy, or their belief in their learning capabilities [25]. Studies further highlight how sense of agency in VR is a complex construct that goes beyond simply giving participants more interactivity, but also relies on how the learning activities are structured [6, 26].

Together, this research raises questions about learning design in VR related to overarching debates about student-directed versus guided learning approaches. Yet to date, little research has explored the impact of varying levels of guidance within a VR learning environment on both content retention and affective dimensions of learning including agency and intrinsic motivation. Our study contributes to the literature on learning design in VR to better understand the benefits and limitations of guidance in VR to promote learning and affective outcomes.

3 Materials and Methods

3.1 VESL VR Game for Science Education

This study utilized VESL (Virtual Excursions for Science Learning), a VR game for science education created in Horizon Worlds. This game is an open-ended and self-directed experience, and a perennial world within Meta's social networking platform that any user can join and play on their own without guidance. Rather than prescribe a pathway through the game, the world consists of information plaques that players read and follow to complete tasks and score points in the game at their own pace. The game is multiplayer, allowing up to four people to engage in the research excursion at one time.

VESL was developed by VR researcher Dr. Danny Pimentel in 2023 as a virtual recreation of a real-world marine biology excursion based on Dr. Kelly Sutherland's NSF-funded project: Plankton Size Spectra & Trophic Links in a Dynamic Ocean. Pimentel joined Sutherland's 2022 research cruise to create reference materials, where he logged all the core research activities on the ship, captured photos and videos, and 3D photogrammetric scans of core equipment and spaces. Afterwards, Pimentel and Sutherland co-created a game design document, synthesizing all reference materials for use by the development team to create game mechanics, environmental designs, and other functions needed to create a virtual simulation of the cruise. Using this game design document, Pimentel collaborated with VR developers at Old Hara Studios to iteratively design the VESL game.

Upon launching VESL, users immediately join a virtual harbor alongside their teammates. Each player must choose a role for the excursion, then board the virtual vessel to complete scientific tasks (e.g., device assembly, biological sampling). After role assignment, users inspect and transport all scientific instruments that will be used during the cruise on board the ship. The research team then collaboratively begins the mission by navigating to three research stations to collect and analyze plankton samples. For example, one player must operate the Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS) instrument, a net system for capturing plankton in the ocean, while the other player operates the A Frame and Winch system to collect samples at various depths. They then take samples to a wet lab to extract plankton and analyze them in a dry lab to identify and learn about the different species collected. When the full mission is completed, the players debrief at port where they receive their final score.

Fig. 1. Screenshots of gameplay in VESL: (1) Greeting players at the port; (2) Collecting plankton samples with the MOCNESS; (3) Extracting plankton in the ship's wet lab; (4) Analyzing plankton in the ship's dry lab.

3.2 Research Methods

To answer our research questions, we designed two conditions: guided and unguided. In the guided condition, a research team member and author of this paper joined the participants inside the VR experience from a remote location. He greeted the participants when they arrived in VESL and introduced himself as their guide. For each step of the process, he gave them instructions and explanations and guided them through the game. For example, after participants collected plankton samples, he showed them the steps to analyze the samples in the lab and pointed them to the information about each plankton species found. In the unguided condition, participants played the game on their own without instructions from a person. These participants read informational plaques about what they needed to do throughout the game and devised how to complete each task themselves. In some cases, they could choose not to complete some of the tasks, and they could choose where to direct their attention. For example, they needed to figure out on their own how to extract plankton from the samples collected, and they could choose not to read the information provided while analyzing the species.

Table 1. Survey Measures.

Measures	Sample Item	Pre	Post
Content knowledge – multiple choice	What do zooplankton eat? *Phytoplankton/ Nothing, they use photosynthesis to produce energy / Coral reefs / Mollusca*	X	X
STEM Interest & Self-efficacy [22, 27, 28] – Likert scale	I am interested in learning more about marine science. I can do the kinds of things scientists do.	X	X
Sense of Presence- Place, Body & Social [29] – Likert scale	It felt as if I was visiting another place. It felt like the other people in the VR environment were with me.		X
Sense of Agency- Learning, Actions & Attention [6] – Likert scale	I learned more when I controlled what to do. My experiences and actions were under my control.		X
Avatar Embodiment [30] – Likert scale	I felt like I could control the virtual body as if it was my own body.		X

While the game can accommodate up to four players at a time, participants in this study played in a pair. When participants arrived in the VR lab, they were greeted by the research team, asked to read and sign an informed consent document. Each participant used a PC to customize a Meta Horizon avatar to their liking and completed a pre-survey. The pre-survey included content knowledge about plankton and research excursions and their level of interest in STEM fields. The pre-survey also included a preview of the VESL and the tasks involved for participants to read. The researcher also explained key steps in the process before starting to ensure the unguided groups had some prior knowledge about navigating the game.

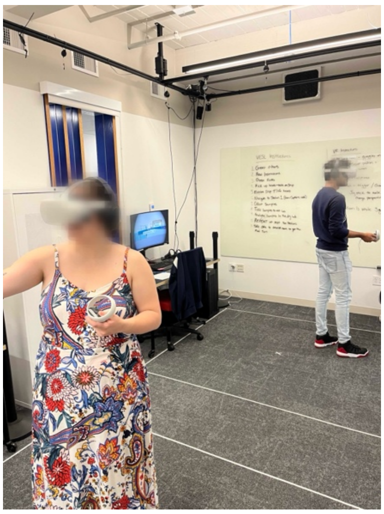

Fig. 2. Participants playing VESL.

After the surveys and explanations, each participant was given a Quest 2 headset and assisted in fitting it. Each participant had a separate area of the room to move around in, indicated by a square boundary, depicted in Figure 2. Participants were given a maximum of 30 minutes to play the game. Participants were video recorded from outside VR. Upon completion of all the game tasks or the 30-minute time limit, they removed their headsets and completed a post-survey. The post-survey had the same items as the pre-survey and additionally included recall questions about the game itself and the research excursion's procedures. It also presented questions about participants' subjective experiences, including their sense of agency, presence, and embodiment in VR. It concluded with demographic characteristics including age, gender, ethnicity, and program of study.

4 Work in Progress: Data Collection and Future Work

Participants were Northeastern University undergraduate and graduate students recruited from across the university via listservs, class announcements, and flyers. Based on a power analysis, we determined that a sample of 100 participants clustered into 50 groups would allow us to observe an effect of the guidance condition. Data collection was completed at the end of the fall 2024 semester. 106 people participated in the VR experience, but six participants (three groups) were excluded from the sample due to issues such as one participant of a group leaving before completion, inaccurately filling out the surveys, and inability to navigate the VR properly. Table 2 illustrates characteristics of the sample.

Table 2. Participant Characteristics.

Gender Identity	
Female	53%
Male	42%
Non-Binary	3%
No Response	2%
Mean Age	22
Degree Level	
Undergraduate	52%
Graduate	47%
None Selected	1%
Major/Program*	
Design/Media/Technology	54
Business/Management	25
Computer Science	24
Natural/Physical/ Social Sciences	12
Engineering	6
Music	3

*Students with two majors are counted in both categories, leading to a total greater than 100.

We are currently conducting data analysis to assess differences between the guided and unguided condition on learning outcomes, sense of agency, and changes in participants' STEM interest and self-efficacy. To estimate the changes in knowledge and interest, we are estimating mean gains by condition and using a t-test to assess significance. We are also using random effects regression models that allow for random variation by group as well as individual, accounting for the multilevel nature of the data. We will control for participant characteristics, gender, age, whether they are a STEM major, and how well they knew their partner, and group characteristics, the condition and whether they experienced technical difficulty or cybersickness disruptions. For example, the model for estimating changes in content knowledge is:

$$PostKnowledge_{ij} = \beta_{oj} + \beta_1 Demographics_i + \beta_2 STEMmajor_i + \beta_3 Familiarity_i + \beta_4 PreKnowledge_i + \epsilon_{ij}$$
$$\beta_{0j} = \gamma_0 + \gamma_1 Guided_j + \gamma_2 TechDifficulty_j + \gamma_3 Sickness_j + u_j$$
$$\epsilon_{ij} \sim N(0, \sigma_y^2)$$
$$\beta_{0j} \sim N(\mu, \sigma^2)$$

The findings of this study will illustrate to what extent guidance in a VR game for STEM education helps or hinders learning and agency, leading to recommendations for future educational VR designs. However, there are limitations to the study. While we aimed for a large enough sample to model the participants in groups and attempted to recruit participants from across many departments, the sample is fairly homogenous as the participants are all students at a selective university in Boston. The study also is conducted in a controlled lab environment, and our findings may not represent results that would be gained from classroom use of a STEM education multiplayer game. While the Horizon Worlds platform provides an accessible experience for learners and educators to use, the level of freedom and lack of guidance in such an environment and some of its design features may not be comparable to other educational VR experiences.

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