The Effects of Navigational Control and Environmental Detail on Learning in 3D Virtual Environments

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ABSTRACT

Studying what design features are necessary and effective for educational virtual environments (VEs), we focused on two design issues: level of environmental detail and method of navigation. In a controlled experiment, participants studied animal facts distributed among different locations in an immersive VE. Participants viewed the information as either an automated tour through the environment or with full navigational control. The experiment also compared two levels of environmental detail: a sparse environment with only the animal fact cards and a detailed version that also included landmark items and ground textures. The experiment tested memory and understanding of the animal information. Though neither environmental detail nor navigation type significantly affected learning outcomes, the results suggest that manual navigation may have negatively affected the learning activity. Also, learning scores were correlated with both spatial ability and video game usage, suggesting that educational VEs may not be an appropriate presentation method for some learners.

KEYWORDS: virtual environments, virtual worlds, navigation, landmarks, educational software, learning.

INDEX TERMS: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 INTRODUCTION

It has been suggested that virtual environments (VEs) could help teach facts, concepts, and abstract principles [1, 2]. While researchers point to a variety of reasons why VEs could prove beneficial for learning (e.g., high levels of interactivity, support for active learning, social learning environments), all educational VEs share the challenge of how to best present learners with new information within 3D space. Many VEs have faced this challenge directly by providing information—in the form of text, audio, or graphics—at specific locations in the environment [e.g., 3, 4]. Many online virtual worlds employ a similar approach, with information locations often organized with the help of virtual buildings, rooms, and landmarks [e.g., 5, 6]. Despite the wide variety of educational VEs that have been developed over the years, little empirical evidence exists to show what aspects of VEs are most important for successful educational applications. Educational VEs must be carefully designed to support the learning process without introducing new distractions [1, 2]. The design features needed for successful educational VEs are not clearly understood.

To address this issue, our research investigates how specific design features influence learner strategies and the effectiveness of learning when information is presented at different locations in a VE. Previous research has provided evidence that learners do reference locations when trying to remember information [7], and that presenting items in different locations can improve recall [8, 9]. However, little is known about what factors influence these effects, and the flexibility of VEs leads to a large number of design factors for consideration. These factors include not only the design of the virtual content, but also the methods for accessing that content.

In a controlled experiment, we studied how participants learned facts distributed among various locations within a VE. We evaluated differences in learning performance and learner strategies due to the level of navigational control and the level of environmental detail. Considering the design of the virtual content, we aim to better understand how a VE's environmental details and landmarks influence learning. Environmental details could also affect users' abilities to keep track of where certain information was located and which locations have been previously visited. Thus, this issue is closely related to the choice of an appropriate method for navigation within a VE. Our study compares interactive and automated navigation methods. Compared to automated presentations, fully manual navigation provides the freedom for learners to control the order and duration in which information is viewed, but at the cost of additional interaction and decision-making.

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2 RELATED WORK

Researchers have suggested that VEs could provide advantages for conceptual learning by allowing opportunities for learners to view information within the context of meaningful locations [e.g., 4, 5, 10]. However, it is unknown whether a location is meaningful because of the information associated with that place or if the meaning is affected by other content at that area. Environmental details and objects could provide *situational context*, referring to the surroundings in which knowledge and meaning making are present [11]. Through episodic memory, this context can become part of what is remembered, along with the information itself [12]. Combined with spatial learning strategies, stronger contextual memory could directly strengthen retrieval cues. On the other hand, others have suspected that environmental detail could contribute to visual clutter, and potentially even interfere with memory of the environment or the information itself [13]. Our experiment investigates the effects of environmental context by comparing learning differences and learner preferences between a relatively empty VE and a VE with additional details.

The question of how to design with spatial layouts is complicated by navigational challenges in VEs, which can result in problems with spatial awareness or information gathering in 3D spaces [14]. Automating movement through the VE could relieve some of the problems of interactive navigation, but this effect can depend on the display and interaction methods [15]. Automatic navigation also risks losing the potential benefits of interactive methods. For learning activities, navigation can serve as a form of interactivity that offers meaningful, controlled exposure to information [16]. Additionally, research has provided evidence that interactive navigation, as opposed to the passive observation of transitioning through a 3D environment, improves memory of object location within the VE [17]. Depending on the learning strategies used, better spatial knowledge of the environmental layout could increase the effectiveness of learning.

While previous studies have contributed evidence that interactive experiences can provide learning benefits for complex learning activities [e.g., 18, 19], we focus on navigation in a simple learning activity for a controlled investigation of preferences and learning differences. We investigate the claims of the benefits of interactive navigation by comparing an automated navigation method with a fully interactive form of navigation.

3 EXPERIMENT

We performed a controlled experiment to test the effects of environmental detail and navigational control on learning performance and learning strategies. This study was conducted as an early part of a larger investigation of how design features affect learning in 3D environments. To maintain control over the independent variables while limiting the effects of other factors on participant experiences, we designed a simplistic learning environment. Although the experiment's environment was not as complex or realistic as would be expected from an actual educational VE, it captured the essential element of such VEs—having information embedded at different locations within a 3D world. Given the emphasis on furthering the understanding of the use of locations and the perception of landmarks, a surround-screen CAVE-type display was used to increase the field of view and allow easier viewing of information in multiple locations. Due to the challenges of evaluating learning, a relatively simple learning activity was selected: participants learned facts about animals in the VE and then completed several tests to evaluate information recall, information understanding, and memory of locations.

We hypothesized that having manual control of navigation would allow learners to achieve higher performance scores than those viewing the information through an automated presentation. We expected that the ability to decide how to view the information and how much time to spend learning different facts would allow more effective learning strategies. It was expected that the freedom to control the order and duration of information viewing would outweigh the additional mental workload associated with the manual control and decision-making. For the level of environmental detail, we tested the hypothesis that additional detail would improve learning performance. This was based on the idea that additional detail increases the situational context of the information locations, providing stronger memory cues for recall.

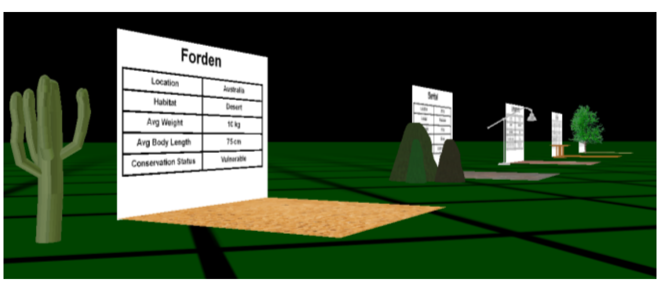

Figure 1. A view of the learning environment with the additional visuals used in the high environmental detail conditions

3.1 Task

To test our hypotheses, we designed a simple learning activity involving information about ten animals. The task used fictitious animals in order to avoid problems with participant familiarity with existing animals. For each animal, a fact card was provided in the VE. Figure 1 shows a view from within the VE. Each card had the name of the animal along with a table showing additional information about the animal (location, habitat, average weight, average body length, and conservation status). Participants were tasked with learning the animal information in the VE. The learning environment contained ten fact cards arranged in two rows of five cards. In virtual space, each fact card was ten feet wide and adjacent cards in the same row were positioned 20 feet apart. The two rows were separated by a distance of 60 feet.

After a learning period in the VE, participants completed tests to assess memory and understanding of the animal information, as well as memory of locations. All tests were completed outside the VE. Memory of animal facts was tested with a simple computer application that required participants to enter numerical fact values (weight and height) and select the appropriate values from drop-down lists for the other fact categories (location, habitat, and conservation status). To increase difficulty, the arrangement of the facts listed on the assessment tool was different than the arrangement of the fact card tables. This assessment covered each of the ten animals. After providing the corresponding information for the given animal name, participants could click the *Next* button to go on to the next animal. The assessment did not allow participants to go back to change their responses for previous animals.

Following the fact memory assessment, participants completed a test of information understanding. In this portion of the assessment, a computer application presented questions that required participants to think about the real-world meaning of the information in order to select the correct animal from a drop-down list. This portion of the assessment included 16 questions. Examples of these questions are:

- Which of these animals would you expect to fit in your hand?
- Which of these animals might you find in the United States?

We computed scores for both the recall and understanding tests by awarding one point for each correct response. Though participants were only informed of the recall and understanding tests in advance, we also tested memories of where the fact cards were in the VE. Based on a top-down view of the VE's layout, participants used a mouse to drag each animal name to the location where that animal's fact card was displayed in the VE. Location memory scores were calculated by counting the number of correctly placed animals.

3.2 Apparatus

Participants experienced the learning environment within a VisBox VisCube display composed of three rear-projected display walls and a top-projected floor. Each of the four display surfaces was 10x10 feet with 1920x1920 resolution. Manual navigation with a wireless wand was made possible by an Intersense IS900 motion tracking system. Neither stereo nor head tracking were enabled (as these features were not directly related to the focus of this study, and enabling them would have required significantly longer familiarization time in order to limit distraction during the learning session).

Participants completed the learning and location memory assessments outside the VisCube on a laptop computer, using a standard mouse and keyboard.

3.3 Experimental Design

We controlled navigation mode and environmental detail as independent variables between subjects in a 2x2 design. Participants were forty undergraduate students (16 male and 24 female, ages 18 to 25) from a variety of academic disciplines. Participants either had automated navigation, in which the learner was taken to pre-recorded navigation points without any user control, or used a manual navigation method, in which learners used a wand and joystick to control viewing within the VE. In both navigation modes, participants began at the same position in the VE. For the automated presentation, the view would automatically move through the cards, with the view stopping in front of the each card for 15 seconds before sliding to the next card in the row. At the end of the row, the view rotated 180 degrees, moved straight across to the other row, and progressed down this row in the same way as the first row. The automated presentation followed this path three times, taking a total time of 9 minutes and 30 seconds. For the manual navigation mode, the total viewing time was limited to 9 minutes and 30 seconds, so the amount of time in the learning phase was constant across conditions. To navigate manually, participants physically pointed the wand device to indicate direction and used the wand's joystick to move and rotate.

We also controlled two levels of environmental detail. In the low-detail condition, the VE contained only the information items on a green grid in a black 3D space. The high-detail condition used the same cards and environment, but each card also had a square ground texture at its base and an object beside it (as seen in Figure 1). For half of the cards, the ground textures and objects were chosen to relate to the animals' habitats. For example, an animal that lives in the desert had a cactus for its object and a ground texture resembling sand. The other half of the cards had objects and textures that were purposely chosen to not relate to the animal information. For example, one animal had a car for its object and a bright red ground texture. Cards were not spatially grouped by related and unrelated landmark types.

3.4 Procedure

After asking participants to complete a background survey, the experimenter explained the learning task. The experimenter then introduced the VisCube system and further explained the task with the aid of a familiarization VE, which used the same type of navigation and the same level of detail as the primary learning task. The familiarization VE had the same general layout as the learning VE used for the primary task, but had only six cards (the primary learning VE had ten). Different animal fact cards were used in the familiarization setup, and different ground textures and objects were used for the high environmental detail conditions. For participants in the manual navigation conditions, the experimenter taught participants how to navigate and coached participants while they practiced navigation. After familiarization, participants performed the primary learning task in the VE.

After the learning phase, the participant moved to a nearby desk. The experimenter first administered a brief auditory number-span memorization test in order to help clear working memory before the information assessments, helping to establish that the assessments would rely on long-term memory. Participants then completed the fact recall test and the understanding test. Next, participants took the memory of location assessment, followed by a cube-comparison test to provide a measure for spatial ability. Finally, the experimenter interviewed the participant about the learning task and the information tests. Participants in conditions with environmental detail were also asked to verbally list as many landmarks or objects from the VE as they could remember, providing the metric for landmark recall.

3.5 Quantitative Results

A two-way independent ANOVA test of the effects on fact memory scores found no significant differences due to environmental detail. Though not significantly different, the mean fact memory score was higher with automatic navigation ($M = 22.05$, $SD = 9.54$) than with manual navigation ($M = 17.85$, $SD = 6.76$), with $F(1, 36) = 2.46$ and $p = 0.13$. There was no significant interaction between landmark and interaction, with $F(1, 36) = 0.11$. We analyzed understanding scores and total learning scores with non-parametric two-way Friedman ANOVA tests. No significant effects on understanding scores were found for environmental detail, with $F(1, 36) = 0.03$. Though not significant, the scores with automatic navigation ($M = 6.4$, $SD = 3.69$) were higher than those with manual navigation ($M = 4.8$, $SD = 3.35$), with $F(1, 36) = 2.00$ and $p = 0.17$. No significant differences were found for total scores, with $F(1, 36) = 0.11$ for environmental detail and $F(1, 36) = 2.58$ for navigation. No significant interactions between variables were found for understanding scores. Though not significant, the learning score results show that the participants generally performed better with the automatic navigation method (see Figure 2). In this experiment's time-pressured type of learning activity, it is possible that the manual navigation did increase mental workload and detracted from the learning.

No effects of environmental detail or navigation mode were found for location memory scores, with a two-way independent ANOVA showing $F(1, 36) = 0.73$ for detail and $F(1, 36) = 1.81$ for navigation. There was no significant interaction between the two variables, with $F(1, 36) = 0.96$.

For the 20 participants in conditions with environmental detail, we tested for effects of navigation method on landmark recall (memory of either ground textures or models). The one-way independent ANOVA found a significant main effect, with $F(1,18) = 6.37$ and $p = 0.02$, showing that participants remembered more landmarks with automatic navigation. Our primary explanation for this effect is that the additional cognitive effort needed for manual navigation detracted from the learning task and the perception of the environment. This explanation corresponds to the trends with the learning scores and location memory metrics, where automatic navigation outperformed manual navigation (see Figure 2).

Based on our results, we conclude that simple interactive view control did not significantly improve learning outcomes for simple factual learning. While highly interactive VEs may provide benefits for more complex or exploratory forms of learning, this study shows that the addition of interactivity does not always aid learning. Moreover, the significant finding for landmark recall and the trends for learning scores and location memory show better results with automatic navigation. In this time-pressured learning activity, we suspect that manual control actually increased mental workload and negatively affected learning.

We also tested for correlations among variables, with the most notable results involving learning scores, gaming, and spatial ability. Total learning scores and spatial ability scores showed a significant one-tailed correlation ($\rho = 0.35$, $p = 0.01$) suggesting that participants with higher spatial ability might find it easier to learn in a VE. The spatial context of the environment might actually make learning more difficult for those with lower spatial abilities. Reported gaming hours were also significantly correlated (one-tailed) with total learning scores ($\rho = 0.34$, $p = 0.02$). This is evidence that experience and practice with interactive software or in virtual spaces can affect learning in VEs. Gaming hours were also significantly correlated with location memory, with $\rho = 0.42$ and $p = 0.003$, suggesting that experience could potentially influence the ability to use spatial learning strategies.

3.6 Qualitative Results

From the interviews, we identified several common strategy categories used for the learning activity. Every participant used multiple strategies, and strategy usage did not seem to be affected by condition. Moreover, correlation testing indicated that the quantitative metrics were independent of strategies, suggesting that strategy usage may mostly be a matter a personal preference.

All but one participant (97.5%) reported using rehearsal in the VE to aid memory. Many participants (80%) used letters or parts of the words in the fact cards to make creative associations with different facts on each card. Some participants (25%) tried to visualize a familiar animal or imagine a new creature to represent each animal. During the assessment, it was common (52.5%) to try to visualize the fact cards to help recall the information.

A number of the participants (27.5%) reported that they tried to use the layout of the cards or their locations to try to remember certain details or to relate animals with similar characteristics. Similarly, during the assessment, many participants (67.5%) indicated that they did think back to the locations where the information was to aid recall. Many participants (45%) reported visualizing the environment itself or the entire layout of the cards. These results show that many learners did use spatial learning and recall strategies – even without explicit instruction to do so. Though the effectiveness of these strategies for this particular task is not clear, previous studies have shown that having information at different locations can improve recall [9].

Of the 20 participants in the conditions with environmental detail, twelve participants (60%) intentionally tried to use the landmarks or textures to help remember information during the learning session. Participants also provided opinions of whether they found the environmental details helpful or distracting. Some participants' opinions of whether landmarks were helpful or distracting depended on whether the landmarks were related or unrelated to the information. While many participants thought that related landmarks were helpful or unrelated landmarks were distracting, others found all landmarks to be distracting, while still others thought that they were all helpful. Further, the relevance of the environmental details depended on the individual. Though half of the environmental details were designed to directly correspond to the habitat, some participants did not find these landmarks to be relevant, and some participants even found landmarks that were chosen to be unrelated to be relevant to them.

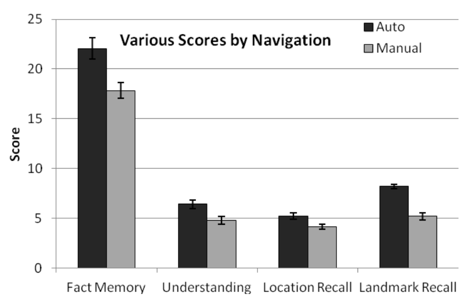

Figure 2. Mean scores and standard error by navigation method. All mean scores were consistently higher with automatic navigation, though only significantly higher for landmark recall.

4 Conclusion

Through a controlled experiment, we studied a collection of issues to help evaluate how users learn new information within a VE. Though increased levels of interactivity may provide learning benefits for more complex or exploratory forms of learning, the results of this experiment do not support the hypothesis that that interactive navigation affects learning positively. Our results suggest the possibility that interactive control could even have negative consequences.

Though we did not instruct participants on what strategies to use, many participants did attempt to use locations to assist in learning or recall. Additional research is needed to evaluate the effectiveness of different strategies, though previous work has provided evidence that mapping information to locations can improve recall [8, 9].

The results also demonstrate the importance of consideration for individual differences, as learning outcomes were correlated with both spatial ability and video game usage. These results suggest that an educational VE may not be an ideal presentation method for some learners.

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