Back to the Future: Constructivist Learning in Virtual Reality

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Figure 1: Left: Arnold's original drawing from 1971 of his conceived experimental setup (Reprinted with permission from the University of Illinois), Middle-Left: our replication of Arnold's setup, Middle-Right: a modern implementation of the same system, Right: an example Hypercube generated by our system used in both conditions.

Abstract

A proposal was first made in 1971 for a study attempting to investigate radical constructivism as a valid learning theory, though the study was never formally conducted. This work describes our Virtual Reality interactive four-dimensional Hypercube system used as our investigative medium, and our initial implementation of the historic study proposal for validation. Our lessons learned are leading to further experimentation and investigation into learning applications in Virtual Reality.

Keywords: Virtual Reality, Learning, Education, Pedagogy.

Index Terms: H.5.1 [Information Interfaces and Presentation (e.g. HCI)]: Multimedia Information Systems — Artificial, augmented, and virtual realities

1 Introduction

Can Virtual Reality help with learning? Interest is currently increasing within various domains for the use of VR including application spaces such as entertainment, health, training simulations, and the space we are interested in, education. Outstanding questions remain however, and are not only limited to the technological factors involved, but also to the domain of pedagogy itself. Prior research has investigated how immersive technologies could be used for education [1-3], though a lot of this work is application specific. The outstanding pedagogical issue also remains that researchers and experts are not settled on any specific theory of learning and the commonly accepted theory is constantly morphing. We pursue this line of research to shed light on the issue of learning and furthermore extend that research to the Virtual Reality space.

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P. Arnold first proposed a study in 1971 which he was unable to conduct at the time [4,5]. In his proposal, Arnold presented a system which allows a user to manipulate a 4-dimensional (4D) construct – a Hypercube – by turning six dials on a board which rotate the Hypercube in 4D space. The construct is then projected into 3-dimensional (3D) space and displayed on a stereoscopic display, so the user can visualize the resulting manipulations in 3D (or 2x2-dimensional) space (Figure 1 – left). The purpose of the system is to present users with a concept that is likely to be completely novel to them and one that they would likely never have interacted with. Arnold then proposed an experiment where one participant would sit and manipulate the Hypercube for a time, and another participant observes all that they do. A set of evaluations were devised to be presented to both the user and the observer to assess any learning gains that were made. Arnold hypothesised that the user of the system, who interacted with the content rather than only watching, would gain a deeper and more constructive grasp (comprehension; *begreifen*) of the subject matter. This was referred to as one's internal representation of a concept. We see potential in this proposal as it could help to provide insight into how we can effectively deliver material to learners to maximise learning outcomes.

We present an initial study validating Arnold's proposed study. We also extend Arnold's approach by including a fully immersive VR implementation in addition to the original stereo system.

2 System

We built two main systems for the initial validation study: 1) the original system described by Arnold and 2) the extended modern implementation of the same system with fully immersive technology, here the HTC Vive.

Both systems use the same core application but take input from, and render the visualization to, different mediums. The system is built using the Unity3D engine. We implement the Hypercube using C# by defining each of the 16 vertices (i.e. [x, y, z, w]) and 32 corresponding edges in 4-space. To manipulate the Hypercube, the rotation operations need to be applied to the vertices on each frame. A 4D rotation matrix is generated by combining two 3D rotations represented by quaternions in Unity [6].

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For the original system replication, the input device for interaction is a 6-dial device containing six analog dials each mapping between 0-360 degrees for two x, y, and z-axes (see Figure 2). A purpose built A/D USB controller (Arduino Leo stick) was used as a hardware interface. The two Quaternions are generated by combining the two 3D axes from the input device.

For the modern system implementation, the user interacts with the two HTC Vive controllers. Each of the controller's rotation in Unity is represented by a quaternion so we can attain both quaternions to combine into the 4D rotation which is then applied to the Hypercube.

Figure 2: Our version of Arnold's six-dial device for manipulation of the Hypercube (left) and HTC Vive controllers used for the immersive VR condition (right).

Once the rotations of either interactive medium are applied to the Hypercube (each frame), the 4D Hypercube vertices are projected to 3D vertices. The appropriate vertices are connected using a Line Renderer component provided by Unity ready for visualization on the respective visual medium (see Figure 1 right).

The original system has a user viewing the Hypercube in stereoscopic 3D. Our replicated system runs on an Alienware laptop (i7-2860, GTX580M). The Unity project is built to run on a stereoscopic 3D display and the user wears Nvidia stereo glasses while manipulating the Hypercube with the six dials.

The modern system is running on a desktop PC (i7-6700, GTX970). The Unity project includes the SteamVR plugin for integration of the HTC Vive and the user wears the head-mounted display (HMD) while using the Vive controllers to manipulate the Hypercube.

3 Validation Study

The main purpose of this study is to implement the design outlined by Arnold though it was only a proposal and therefore it consisted of more suggestions rather than a concrete description of a study design. Arnold proposed to assess the learning gains of a system user against those of an observer through an evaluation. Rather than focusing on a comparison between an actor and an observer, we need to validate the evaluation techniques which assess the learning gains. Furthermore, we can use the opportunity to validate the efficacy of our systems for a full study in the future.

We run the study in a two-by-one factorial between-subject design where the independent variable is the visual and interactive medium (original system and modern system – see Figure 1 middle-left and middle-right respectively).

22 participants are first presented with a demographics questionnaire collecting data on age, gender, ethnicity, vision impairments, and prior VR experience. A short knowledge questionnaire is then presented as a self-assessment of knowledge on the subject matter. Once completed we present each participant, regardless of their assigned condition, a video which provides context for participants. The video contains basic theory of what a Hypercube is. For the second part, participants are given the knowledge questionnaire (we would expect a gain based on the video). Participants split into their appropriate condition and are given 5 minutes where the task is to interact with a single Hypercube and gain competency over manipulation of it. After the 5-minute interaction period, participants are given the self-assessment knowledge questionnaire for the third and final time. Arnold proposed an evaluation which presents users with images of both possible and impossible (obscured) Hypercubes (rotated in various ways) which they should tick or cross. We had a total of 36 Hypercube images for participants to mark. Arnold proposed a further "matching task" where users should attempt to rotate one Hypercube to match an already rotated Hypercube. At the end of the study we had all users, regardless of condition, complete this task using the modern system.

4 Outcomes

Participants overall self-report on the knowledge questionnaire showed they believe they had gained knowledge of what a Hypercube is, though reported less of a gain in understanding the concept of 4D-space itself. The most significant gains reported were between the beginning and after watching the sample video, and then a smaller gain between the video and use of the system.

We found the assessment technique of showing pictures of Hypercubes to be rather ineffective and is potentially an insensitive measure. It is difficult for participants to judge 4D Hypercubes on paper although we provided the pictures of Hypercubes to 11 separate subjects after the study that had not used the system at all and they scored lower which shows the system provided something for participants and that the measure is not totally insensitive.

Participants who had their experience in the Stereo (original) condition took longer to complete the matching task presented at the end than those in the Immersive system. Given the task is held in the immersive system, this is not a surprising result, although the difference in time taken to complete the task is not significant ($p > 0.05$).

5 Conclusion

We were able to replicate a historic VR experiment proposal and could shed light on flaws in Arnold's original design in that experience-based assessment is not a necessarily a robust comparison of learning methods. An interesting result was found in that stereo participants did not take significantly longer than immersive participants even though stereo users had no experience with the modern system interface. We can use the outcomes of this validation study to inform future studies into learning and developing assessments within Virtual Reality environments.

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