An Accessible Platform for Everyday Educational Virtual Reality

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ABSTRACT

Given the modern accessibility and affordability of requisite hardware, the use of immersive virtual reality is possible in almost any domain. However, there is insufficient evidence of the value of immersive virtual reality relative to alternative approaches. In addition, there are a range of displays and input devices with varying capabilities that are all competing in the marketplace. Our work is evaluating the benefits of a "baseline" interface that applications can target while simultaneously designing such an application and interaction techniques within it. We discuss our rationale for choosing the immersive VR platform, as well as studies planned to evaluate interaction techniques and metaphors designed for the platform relative to a "simulated" non-immersive VR platform.

Keywords: HMD, monitor, gamepad, joystick, smartphone, viewer, immersive, non-immersive

Index Terms: B.4.2 [Input/Output and Data Communications]: Input/Output Devices—Image Display; I.3 [Computer Graphics]: Hardware Architecture—Three-dimensional displays

1 INTRODUCTION

Much of the research concerning immersive virtual reality (VR) has been conducted in the context of a physical laboratory environment during relatively short (less than 15 minutes of user exposure) one-time experiments. However, recent advances in personal viewing devices have made it possible to use immersive VR outside of the laboratory in everyday settings for longer periods of time and at greater frequency, which may become the norm rather than the exception for VR applications. As a result, it may not be possible or acceptable in the majority of applications for designers to optimize the physical environment for a particular VR interface, which is currently the norm in VR research. In addition, VR designers must place greater emphasis on usability of an interface for longer periods of time and at greater frequencies. As a result, we contend that what is likely to arise is the use of a "low energy", "baseline" interface that will work in a wide variety of settings and applications for long periods of time.

As of early 2016, the most accessible immersive VR platform to the general population is the smartphone viewer (e.g., Google Cardboard, Samsung Gear VR). Using inexpensive optics, the smartphone's display and internal sensors (or an auxiliary inertial measurement unit in the case of the Gear VR), this platform allows for a tracked first-person perspective (device rotation only). Notably, this is less immersive than even the earliest laboratory-based VR systems [1] by some measures (e.g., degrees of tracking freedom). However, it may be the form of VR that can still be classified as *immersive* VR while requiring the least amount of expense, setup time, and physical exertion (i.e., low fatigue) to use. Applications that have been built for this platform typically use similarly accessible, low-fatigue input devices such as a magnetic slide switch that actuates the phone's magnetic field sensor or, in the case of the Samsung Gear VR, an integrated track-pad. A minority allow or require the use of a hand-held controller (e.g., a gamepad), which we consider to require less physical exertion to use, but is currently less accessible than the aforementioned slide switch or track-pad. Applications, such as the game Hoverboard Dive (available on the Google Play Store), do not use an interaction device at all, working entirely through head rotation and head gestures.

Aside from its accessibility, the popularity of smartphone viewers can also be explained by the impending arrival of more capable immersive VR platforms to the general marketplace (e.g., the upcoming Oculus Rift, HTC Vive, and Sony PlayStation VR). These devices afford display position tracking and provide 6-DOF tracked controllers (often with many analog axes each). The experiences that can be created with such platforms will be more immersive and generally higher fidelity than what is possible with a self-contained smartphone viewer. To achieve these features over experiences for the smartphone viewer, they are often tethered to computers and require end-user configuration of the space.

A major question is whether these features are practical, necessary, helpful, or possibly detrimental in the vast majority of *educational* applications. Likely, *training* applications will benefit from more closely matched psychomotor experience. However, the vast majority of instructional activities are designed to enhance cognition and affection. In addition, while training often takes place in dedicated facilities, education takes place everywhere and increasingly on mobile computing platforms. Indeed, beyond what is already possible with smartphone VR viewers, more capable platforms may be extraneous and impractical.

One of the longstanding research themes in VR is the design and relative merit of various real-walking interfaces and techniques. For example, natural walking interfaces may outperform indirect interfaces, such as gamepads, even enhancing higher level cognition [2]. However, these natural walking interfaces tend to require more physical space and external trackers and thus might not be as plausible to use outside of a lab. In some instances, natural walking is not even possible to use as an interface, such as if a user were riding a bus or wheelchair-bound. Therefore, while these systems might yield a "better" experience in the lab, they might not be practical to use outside of it.

A further--and perhaps more relevant--debate may be had about the utility of immersive VR over non-immersive VR, particularly in the context of smartphone-based VR. *If the only obvious feature that makes these different is how the virtual camera is controlled (head-motion vs input device), is it worth the additional fatigue from such motion?* We address this question in the following sections, which present our target platform, application, and plan for study.

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2 Application and Motivation

Education is likely a large future market for immersive VR and augmented reality, both in the classroom and in informal learning environments such as museums and the home. A substantial repository of 3D content already exists, particularly in the biological sciences (e.g., human bodies and internal anatomy). One strategy to quickly deploy VR experiences is to provide unique experiences involving the existing 3D content. Our application is an incarnation of this strategy.

Furthermore, the variety of contexts in which education can take place, ranging from a classroom setting to sitting on a couch at home, may eliminate certain types of VR systems, such as those that require extensive body motion. In addition, many populations, such as those with motion disabilities, cannot utilize these interfaces. Thus, we are motivated by the notion of a theoretical "baseline" VR system that provides a foundation upon which more immersive systems can be built.

The educational motivation for using VR stems from a demo created within our lab that was a "rollercoaster ride" through the heart using a smartphone viewer. While it was engaging, it suffered from many problems including a lack of educational utility and tended to cause extreme nausea in users. Several aspects of the heart-travel demo also were intriguing from an interface design standpoint:

- Movement through the heart involves true 3D travel (as opposed to planar travel common in VR)
- There is no obvious viewpoint orientation
- Gravity is not the dominant force
- There is a "natural" movement direction (the path of blood flow)
- The space is organically structured (no hard lines, smooth curves)
- The interior of the heart is tightly confined

In other words, most traditional VR systems, especially those used for training, focus on mimicking actual or plausible reality. However, educational VR may take users to many unfamiliar places, such as the heart or even abstract spaces, such as a visualization of an atom. These spaces allow for great freedom on the part of VR designers, as there is no "real" way that a person can enter them. With that freedom comes increased risks of usability issues, simulator sickness, and *diminished* educational value relative to traditional educational materials or less immersive platforms.

Thus, in summary, we have two overall application objectives in this work. The first objective is to design an application consisting of an intuitive, baseline VR system for exploring a virtual human heart. The second objective is to expand this system by trying to create an immersive educational experience that promotes learning relative to a less immersive approach.

3 Hardware Platform

The immersive platform that we chose is the smartphone viewer (Samsung Gear VR Innovator Edition + Samsung Galaxy Note 4 smartphone) with a Bluetooth-connected gamepad (MadCatz CTRL^{R}). This platform is a compromise between immersion and fidelity and the application goals (to be a usable, practical, accessible educational experience), leaning more towards the latter.

As discussed in the introduction, the smartphone viewer is the most accessible immersive VR platform available today. The particular model chosen, the Samsung Gear VR (a collaboration with Oculus) is, we believe, the best available incarnation. The Gear VR Innovator Edition we currently use has a 2560 x 1440 resolution (1280 x 1440 per eye) with the Galaxy Note 4 smartphone. The optics provide approximately a 96-degree field-of-view, have adjustable focus (by moving the lenses toward or away from the display), and though it does not have pupillary distance adjustment, the lenses are large enough to accommodate a wide range of distances. It also provides an auxiliary inertial measurement unit within the viewer. This enhances its tracking capabilities relative to other smartphone viewers, which use the orientation sensor within the smartphone (which, presumably, has lesser performance).

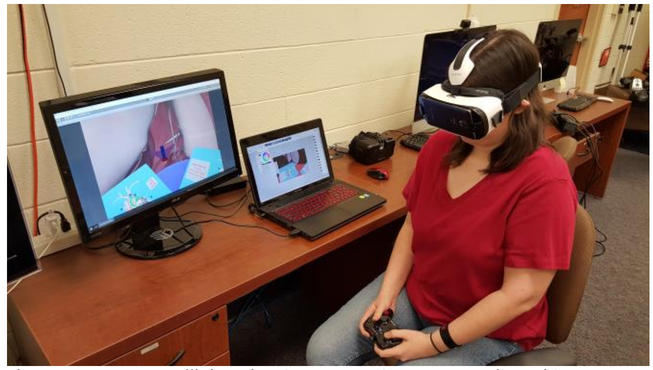

Figure 1. A user utilizing the Samsung Gear VR and MadCatz CTRL^{R} to interact with a virtual heart.

In contrast to a higher performance (though notably lower resolution) head-mounted display such as the Oculus Rift Developer Kit 2, the smartphone viewer offers several important advantages. It relies only on the smartphone for both processing and display. This makes the overall system less expensive, entirely wireless, and usable anywhere the user is. Passing the device from user to user is simplified with no wires to tangle or location where the user must sit or stand. Also, the lack of a wire allows for uninhibited head rotation. As such, no indirect viewpoint rotation scheme is required (i.e., mouse or joystick rotation).

One significant advantage the Rift does have over these smartphone viewers is device position tracking (external optical tracker). This tracking affords 6-DOF natural viewing of the virtual environment. This can be achieved on smartphone viewers using only a rotation sensor (i.e., on the Gear VR) by mapping sensor data to a head and neck model, provided users move their heads only and not their bodies. In addition, it is possible that future iterations of smartphone viewers will use markerless optical tracking (that leverage built-in cameras and other device-mounted sensors) that should achieve a similar effect.

The Gear VR also includes a trackpad input device on the side of the device. However, we did not choose to utilize this input device for several reasons. First, it is not a feature on most smartphone viewers and while we wanted to work with the highest performing one, we also did not want to be incompatible with others. Second, while it is more sensitive and capable than the slide switch found on most Google Cardboard viewers, we still found it somewhat uncomfortable to use and limited.

Instead, as previously stated, we chose to use a Bluetooth gamepad. Unlike the input devices on the side of the viewers, users can rest a gamepad (and, more importantly, their arms) in their laps while using them (provided that they are seated), which we found to be a major improvement in terms of user comfort over the trackpad. While there are many different gamepads to choose from, they generally consist of some combination of analog "thumb" joysticks and buttons, providing more ways to interact with our virtual world than the trackpad alone. Specifically, the MadCatz CTRL^{R} has 6 analog axes (two analog joysticks, two analog triggers) and 8 digital buttons. It is similar to the gamepads found in popular console gaming platforms such as the Microsoft Xbox or Sony PlayStation.

There many benefits of gamepads for VR input relative to alternative input devices. First, they do not require a lot of space to setup and use, making them very portable and can be utilized in various environments, such as a classroom or a bus, with relative ease. Second, gamepads can be used while seated with hands and arms in a comfortable position, and thus are less fatiguing to use than devices requiring significant physical interaction (such as a tracked hand-held wand). This means that they can be used for longer periods of time before users need to take a break. Relative to a keyboard and mouse (the dominant interface for PC gaming), they may be easier to use by touch and do not require a tabletop or similarly flat surface. Finally, gamepads are a staple of modern day gaming, or at least, console-based gaming, and many youths will already be familiar with the input devices.

However, the indirect nature of interaction using gamepads means users are less likely to predict the outcomes of their actions in the virtual world intuitively as they would with natural walking. This is a major problem as user's uncertainty in the direction they will be moving can quickly result in frustration and discomfort [3]. We explore this problem more in the next section.

4 User Interface Design

As previously mentioned, the design of our application was motivated by a "roller coaster ride" demo through the human heart. We sought to extend and improve this demo to provide an educational tool for learning about the human heart which might provide a unique perspective to learners relative to traditional methods (textbooks, video). Towards optimizing this demonstration for education, a major change was to divide the experience into two major phases. The first phase takes place in a virtual laboratory and the second within the virtual heart model.

Phase 1. On one of the walls of the virtual laboratory is a large flat-screen monitor (see Figure 2). The user is placed such that when viewed directly with the head-mounted display, the virtual monitor takes up nearly the entire field-of-view (the entire field of view including the virtual bezel). During the first phase, the user interacts with content on the virtual monitor. At startup, the monitor shows information regarding game controls and objectives. While the instructions are presented, the player is able to test the gamepad input and ensure they are pressing the appropriate buttons. This is done by providing a representation of the gamepad on the monitor and highlighting which button is being pressed or joystick is being moved (see Figure 3). A translucent cursor also appears in the center of the user's view, and the user is instructed on its use to click various interactive elements by centering the cursor by rotating their view and pressing a gamepad button. After dismissing the instructions, a rotatable (on its vertical axis) 3D heart model is displayed on the virtual monitor. On this model are anatomy pins that the user can click to select (see Figure 2). Once selected, the name of the region and its function are displayed on the screen.

The first phase is important for several reasons. The external heart interaction provides context to where the player is once they are inside the heart. In addition, since the goal of the application is to be used as an educational tool, we thought it would be beneficial to provide multiple perspectives for viewing the heart. This way, users would not have to take off the HMD in order to view the more traditional external model of the heart and the internal tour. Starting in a familiar place may provide comfort to users [4], i.e., a staging area, rather than suddenly appearing inside the heart, allowing them to learn the interface without significant distraction. Finally, such a "normal" location also provides a convenient, familiar way to display the tremendous amount of 2D information that already exists for education, such as the descriptions for each anatomical region.

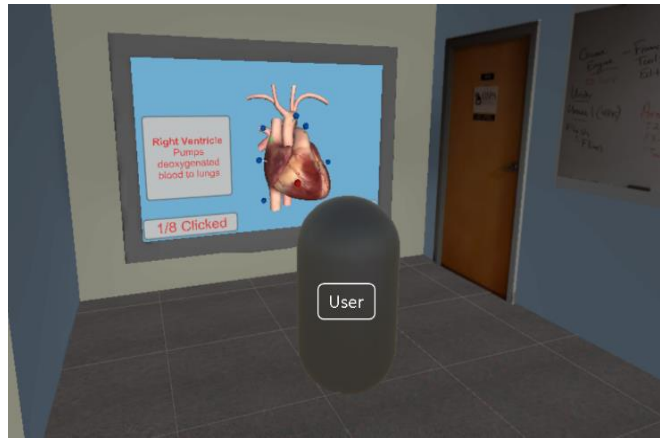

Figure 2. A virtual monitor is used to display instructions as well as an interactive 3D heart model. This 3D heart model has clickable pins used to display information about regions of the heart. The user is located such that the virtual monitor occupies the majority of the HMD field-of-view when faced.

Figure 3. Interactive instructions displayed on the virtual monitor before each phase of the experience with information detailing the task that must be completed and the controls to do so.

Phase 2. When ready, the user clicks on a button on the monitor to transition to a tour through the same virtual heart model from the external view. However, instead of manipulating the model, players navigate a blood cell through the heart using the left joystick on the gamepad. To provide both a metaphor for motion and a ground plane to help users orient, we chose to use a blood cell as the vehicle as it fits the context of the heart.

Designing the navigation scheme for this section was particularly challenging. Since the human heart is an environment we cannot normally traverse, there is not a real world equivalent to look toward for how we should move through it in the virtual world. However, the human heart can be looked at as a sequence of smooth curves connecting larger chambers with a pre-defined "forward" direction (the direction of blood flow). So, thinking of blood flow as a path through the heart a sort of natural "rail" emerges. By confining users' movements to this rail, we not only mimic the natural flow but reduce the amount of control the user has over where he can move in the virtual world.

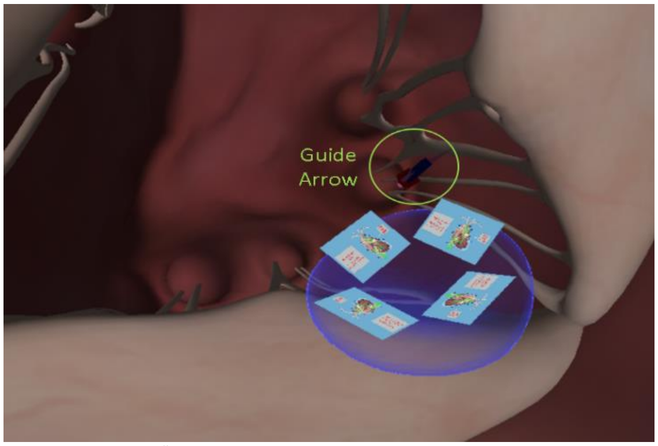

Figure 4. Users "ride" a blood cell, which changes color to indicate oxygenation, around the inside of the heart. A guide arrow indicates the forward direction of travel and 3D mini-maps are arrayed around the user to indicate location.

In order to address challenges associated with navigating an unfamiliar space, we provide two navigational aids. The first is a 3D mini-map, which we placed below the user on the blood cell on several podiums arrayed around the heart (see Figure 4). The visibility of the mini-map can be toggled (default on) by the user during the interaction if they happen to obscure the view. This mini-map is the same view of the heart and provides the same region name and function information from the external view (including the ability to rotate the map via the triggers). Additionally, it displays where the user is inside the heart. The other aid we added was a guide arrow, which always points in the direction the user will be moving when they indicate they want to move "forward" using the joystick (see Figure 4).

While the idea of constraining freedom of movement seems counterproductive to exploration and potentially very frustrating for a user, it might help since they will be using an indirect interaction device to move through the world [5, 6]. By reducing potential movement from 3D to 1D, it also simplifies the mental mapping of what pressing "forward" means in terms of movement in the virtual space. Additionally, this allows a user to look around while moving through the heart without fear of bumping into a wall or some other unseen obstacle. In other words, this approach takes mental effort away from the part of the task that is a means to an end (the actual moving about the heart) and allows the user to use it elsewhere (perhaps where it matters: learning about the anatomy and physiology of the heart).

5 Planned Study

Several research questions emerged during the application design. The first question we are addressing is the value of head-rotation to directly control the viewpoint while in the internal view. If this is not valuable, there is significantly less justification to use immersive VR over, for example, an ordinary monitor for this particular application. To address this question, we have made two versions of the internal view: the virtually immersive version and virtually non-immersive version. The only differences between these two versions are how the viewpoint is controlled during Phase 2 and necessary control changes. Both versions still utilize the Gear VR and a gamepad. The immersive version enables the user to change the viewing direction by turning their head and to move using the left joystick. The non-immersive versions presents Phase 2 on the virtual monitor in the lab, simulating a monitor-based VR experience. In the non-immersive version, the user still uses the left joystick to move through the heart but must use the right joystick to look around the internal heart as turning their head makes them look around the virtual lab instead. Of note, this allows for somewhat reduced viewing control, as the user cannot "roll" the camera. However, we consider this a necessary tradeoff to mimic the viewing control normally present in first-person video games that use gamepads.

We hypothesize that participants using the immersive interface first will show improved performance and greater satisfaction with the interface over those using the non-immersive interface first. Our rationale is that the immersive interface is more natural to use, and enables users to better orient themselves over time because of 1:1 matching between their head and virtual view. This is expected to allow for better focus on the experience.

5.1 Population and Environment

Participants will be recruited from engineering students at our university. As these are not necessarily students who need to learn about the human heart, they are not necessarily the target audience for an expansive educational tool concerning the human heart. As such, for designing this particular application, their views might not be representative in regards to the actual content included in the application. However, they should be able to evaluate the strengths of general interface characteristics, such as immersion, and should represent a more general population than students already enrolled in a domain-specific course.

The study is intended to be run across several days in an approximately 30 minute session for each participant. Although we are interested in an interface which can be deployed across environments, this particular study will only be run in our lab to avoid environmental confounds, leaving this perhaps for a future study. Finally, an investigator will be present during these sessions for any questions or problems a participant might have during the course of the study.

5.2 Measures

Participants will complete a background questionnaire, which will include a basic demographic survey as well as two questions specifically concerning their gaming experience. The first asks how many hours per week they generally play video games with choices ranging from 0 to 10+ hours per week. The second asks how proficient they feel they are at playing games on a scale from 1 to 10. The rationale being since our participants will likely be students, the time they typically spend playing games may be presently reduced and may not accurately reflect how familiar they are with playing video games.

We are particularly concerned with the potential for simulator sickness. To this point, participants will also complete the Kennedy-Lane simulator sickness questionnaire [7] three times throughout the course of the study. We expect that simulator sickness will be higher in the virtually immersive version, where users will likely rotate their head more, and thus be subject to latency effects.

Although all participants will complete the tour of the heart using both the immersive and non-immersive interfaces, they will be randomly assigned either to the immersive first or to the non-immersive first group. Participants will be given a quiz after their first tour through the heart to evaluate their knowledge of the heart regarding its functions and the path of blood flow. The results of this evaluation will be compared between the immersive first and non-immersive first groups.

Upon completion of both the immersive and non-immersive tours of the heart, participants will also be asked questions regarding their interface preference as well as their rationale behind this preference. They are also asked to provide any additional comments or feedback they have about the system. These interface preference results will also be compared both within subject and between the immersive first and non-immersive first groups.

Participants' head rotation and path data are tracked and logged every second throughout the experience. Since the non-immersive interface utilizes another camera during the internal tour of the heart, the orientation of this camera is logged as well since participants' head rotation data would reflect where they are looking in the virtual lab and not in the virtual heart. For the immersive interface, this orientation is still logged but it reflects the same orientation as the head rotation data.

The time it took participants to complete each phase as well as navigate each region of the heart is also logged. Potentially, time taken to read the instructions as well as to navigate the heart could have an impact on several factors, such as the recall task performance, overall interface satisfaction, and severity of simulator sickness experienced. Finally, any interaction with the GUI, such as clicking a button/pin or toggling the mini-map on/off is also logged. We aim to analyze this data to determine the extent to which participants were engaged with the interface and compare engagement to task performance and simulator sickness severity.

5.3 Procedure

Before using the application, participants first complete the background survey and the pre-simulator sickness questionnaire. They are instructed that they will be learning about the human heart and that they will be quizzed after the experience on their knowledge of both the functions of and path through the heart. They are shown how to exit the application in the event that they feel they cannot complete the tour of the heart. Participants are then randomly assigned to either the immersive first or non-immersive first group.

During the experience, participants are seated in a common task-chair in the real world. Importantly, this chair allows for unconstrained rotation about its vertical axis. Upon putting on the Gear VR, they are initially seated in front of a virtual monitor in a virtual lab, where they go through the interface tutorial. After the interface tutorial they begin phase 1 (external heart) and are required to select each pin on the heart to continue.

Phase 2 differs based upon experimental condition. The immersive tour places the participant inside the 3D heart model whereas the non-immersive tour shows the same tour on the virtual monitor. The only difference in controls for the two groups are how they control the tour camera: the immersive group moves the camera based on their head rotation whereas the non-immersive group must manipulate the camera using the right joystick on the gamepad. Upon completing one loop through the heart, the application asks if the participant would like to exit. Participants are allowed to complete the tour as many times as they wish but they cannot go back to a previous section of the application.

After completing their first tour, participants remove the Gear VR and complete another sickness questionnaire and quiz over the heart. After completing the quiz, participants are then instructed that they will complete another tour of the heart using the alternative interface. They are told that they will not be quizzed, instead they will be asked to compare this experience to their previous one. They then complete another tour of the heart using the opposite interface. After they are done, participants fill out the final sickness questionnaire, preference survey, and any feedback/suggestions they have concerning their experience with the system.

6 Preliminary Results

We have run 7 participants through the study thus far, consisting of 4 participants in the immersive first group and 3 in the non-immersive first group. Thus far we have not seen a major effect of simulator sickness in either group. Although the current experience is intended to be relatively short (around 5 minutes per tour), this is surprising given that we are using a constrained rails system combined with an indirect interaction device to move through the heart. Both of which generally lead to increased levels of simulator sickness or other adverse effects.

All 7 participants indicated that they preferred the immersive interface over the non-immersive interface. A common theme in their rationale behind this choice based on their free-response answers references the ease of use of the natural head rotation interface to look around the environment. Interestingly, one participant indicated that the internal heart camera controls for the non-immersive interface were very distracting due to the inverted y-axis controls. Following this comment and additional feedback, we opted to update the non-immersive camera controls to no longer invert the y-axis. However, without providing an option to toggle inversion, other individuals might find this new setting to be equally distracting. This is interesting because it demonstrates another issue that must be considered when using an indirect input device to interact with a virtual world.

There appears to be two significant trends regarding tour completion times. First, all but one participant spent about half the time on their second tour compared to their first. This is somewhat expected as the participants were quizzed only after their initial tour and have also already seen the application in some capacity. The remaining participant actually took more time to complete their second tour than their first. This participant was in the non-immersive first group.

The second completion time trend is rather interesting in that members of both groups spent significantly more time during their immersive tour compared to the other group's equivalent non-immersive tour. This means that participants in the immersive first group spent more time completing their first run than the non-immersive first group did. Similarly, the non-immersive first group spent more time completing their second run than the immersive first group did. Since both groups appear to be affected, it does not appear to be an order effect. This may be due to the different controls or levels of immersion between the two tours. Another explanation might be due to increased "excitement" or engagement associated with exploring the heart in an immersive context. Given that all the participants preferred the immersive tour, it seems unlikely that the difference could be attributed to the non-immersive tour providing more intuitive and easier to use controls.

Finally, there does not seem to be a meaningful difference between the groups in regards to performance on the assessment quiz thus far. However, we might want to revise our assessment regarding participants' knowledge of the heart and its functions. Currently, the assessment is more open-ended, leaving it up to the participant to list what they can recall and deem important about the heart rather than asking specific factual questions (e.g., "What is the function of the right atrium?"). As a result, the responses are widely varied, although the majority of participants listed at least one region of the heart with an associated function. It brings up the question of how we should weight these responses. For example, how much weight should be given to only remembering the name of different regions or various function as opposed to remembering that there are so many valves or chambers? Additionally, we might want to utilize a pre-tour assessment of prior knowledge of the heart to provide a baseline of comparison.

7 FUTURE WORK

This study is currently under review and will be conducted soon. Following this study, we aim to explore the design choices surrounding constrained navigation, such as incorporating speed, direction, and orientation controls, and their impact on usability, simulator sickness, and performance. In addition, incorporating the 3D mini-map more directly in locomotion as is done in the World-in-Miniature technique [8] may improve navigation.

As this study focuses more on interface usability than on learning objectives, further study is needed to assess these aspects and compare the learning outcomes of this application to those of traditional methods of learning about the heart. Finally, further study on the effects of deploying and using this interface in environments outside of a controlled lab setting also needs to be explored.

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