USER INTERFACE DESIGN IN VIRTUAL REALITY RESEARCH

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

User Interface Design in Virtual Reality Research

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Thesis Statement

The primary objective of this research is to develop and investigate a user interface that supports learning to be implemented in the virtual reality application Anatomy Builder VR, an ongoing project from the Department of Visualization. Through the conception of this interface, we will explore the research question “how can user interface design in virtual reality applications support learning and engagement?”.

Theoretical Framework

Through the use of iterative design, we will develop an interface to be implemented in the virtual reality application Anatomy Builder VR. To accomplish this, we will create several prototypes to be evaluated by a focus group before implementing a high fidelity interface into the application. The three prototypes will be used to conduct a user study that will improve the quality and functionality of the final interface as a whole.

Project Description

Effective user interface design is extremely important when creating an application focused on learning. If the application’s interface is misleading, the user will either incorrectly learn the information or stop using the application altogether. For this reason, we will center our

research on the question “how can user interface design in virtual reality applications support learning and engagement?”. Expected outcomes include designing a user interface that will provide an intuitive and engaging learning experience. Our interface will be implemented into Anatomy Builder VR, an application that allows users to assemble a human or canine skeleton while learning comparative anatomy. Anatomy Builder VR is a current collaborative project between Department of Visualization and Department of Veterinary Integrative Biosciences. We will investigate how our design impacts the user’s anatomy learning experience.

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INTRODUCTION

Anatomy is an essential part of human and animal science education. Traditionally, anatomy is taught through cadaver dissection, a subtractive method of learning how each organ, muscle, and bone fits together to form the human body [1]. While cadaver dissection allows the student to physically touch each component, it becomes visually confusing when starting with a complex living being in its entirety [2]. This complication also makes it more difficult to visualize the human body from the inside out, especially since the majority of learning material is presented in a two-dimensional medium [3].

The existing virtual reality application titled Anatomy Builder VR allows students to learn both human and canine anatomies through a constructive approach. Rather than starting from the skin and making their way to the bone, students have the opportunity to study and manipulate each individual component and how it relates to its counterparts. However, this application will not be nearly as effective without user interface design that fosters an immersive learning experience.

User interface design is incredibly important when creating a virtual reality application, but not much research is readily available on the topic. If designed effectively, user interfaces featured in the Anatomy Builder VR application can support and even enhance learning. To accomplish this goal, we intend to consult Dorian Peter's *Interface Design for Learning* so that we can better understand design elements essential to creating a compelling interface meant to facilitate learning [4]. From there, we will design three high fidelity mockups of the different interfaces through iterative design, which we will then test in a user study.

CHAPTER I

BACKGROUND

Literature Review

Anatomy is one of the primary focuses of science education. However, students often have a hard time mentally visualizing the three-dimensional (3D) body [2]. In reality, students spend most of their time memorizing anatomical terms shown in two-dimensional (2D) graphics from a textbook, since the majority of learning material is presented in this medium [3]. Recently, virtual and augmented reality applications have been developed to support many areas of education. However, there are not many anatomy-based virtual reality applications that are readily available. Most applications do not provide an effective user interface for the new learning environment, because they are based off of traditional materials. This makes our research simultaneously challenging and groundbreaking, as we must pave the way ourselves.

Prior Work Review

Before designing interfaces to be implemented in Anatomy Builder VR, a vast array of goal-oriented applications was examined in order to better understand how two-dimensional interfaces affect three dimensional user experiences. The focuses of these applications ranged from exploratory drawing to anatomy based applications similar to our own. The featured user interfaces were analyzed in terms of functionality, aesthetics, and how they contributed to the application's overall environment. The dissection of these applications greatly contributed to both the aesthetic design and functionality of the three prototypes tested by study participants in Anatomy Builder VR.

While focusing on the functionality of each interface, it became clear that some applications were more successful than others when developing a user-centric experience. These applications included Google's Tilt Brush, Fantastic Contraption, and 3D Organon Anatomy VR. Since these experiences set a goal for the user to accomplish upon entering the environment, the interfaces are focused on leading the user to the appropriate navigational cues. For example, Tilt Brush's tablet interface is mounted onto the user's hand controllers, allowing easy access to the application's variety of brushes, colors, and environments [5]. By incorporating haptic feedback and intuitive icons to communicate each button's purpose, the user interface easily initiates the creative drawing process that the application was designed to encourage [5]. By the same token, Fantastic Contraption guides users to achieve the game's goal through an original cat character that prompts the user to complete various tasks [6]. While Fantastic Contraption does not have a specific two-dimensional user interface, the environment and instructional cues offer the same guidance towards the application's objective as a traditional interface [6]. Finally, the illustrative interface featured in 3D Organon Anatomy VR allows the user to pinpoint the exact bodily function they wish to learn about [12]. Because the application's primary aim is to teach the user about anatomical functions, the interface is extremely successful [12]. After comparing and analyzing these applications, the conclusions reached were taken into account when designing three different interfaces to be tested in our own application.

Conversely, some applications were unsuccessful at communicating instructions and various functionalities to the user. These were later used as examples of what techniques to avoid when building an interface to be used in a virtual reality setting. For example, the lack of interface in Job Simulator left the user without any direction or instruction on how to participate in game play [7]. Because of the lack of visual and auditory cues, the user is stranded in an experience that is more confusing than intuitive, causing them to become impatient and frustrated [7]. Although the overall concept of the game is intriguing, the execution of tasks prove to be illusive, as the “simulation” of each occupation is guesswork originating from user experimentation in the virtual environment [7]. The anatomy-based application entitled YOU by Sharecare is ineffective because of an entirely different issue, but still yields the same end result [13]. While the application is equipped with an aesthetically stunning interface, it does not communicate the functionality or purpose of the various environments [13]. The user is once again left to explore the virtual world without auditory and visual direction, wasting an inordinate amount of time experimenting with the interface rather than the environment [13]. This obstacle becomes exceedingly challenging when attempting to navigate an innovative application such as YOU by Sharecare [13]. In this specific case, the user could not rely on past experiences to guide them, because its revolutionary approach rendered any previously intuitive actions useless [13]. These virtual reality applications reinforced the importance of creating an easily understandable interface that prompts and engages the user throughout the game’s duration.

Additionally, the application interfaces were examined in terms of aesthetics and how their appearance contributed to the overall virtual experience. Just like the previous criterion, there were obvious successful and unsuccessful approaches demonstrated in the scrutinized applications. Once again, Tilt Brush and Fantastic Contraption were frontrunners in this category. Both applications boast an interface that match each game’s general aesthetic and continually contribute to the application’s success by enhancing the user’s experience [5 and 6]. Tilt Brush’s interface is so lucrative that it inspired the design for the tablet-based interface to be tested in Anatomy Builder VR. Its sleek and modern design both complements and enhances its virtual environment while guiding the user through task completion [5]. Another application noted for its aesthetic quality is Anatomy Viewer, a beta test featured in Play the Body VR: Journey Inside a Cell. Its interface contributed to the clinical, laboratory-like feel of the virtual environment without appearing disinteresting to the user [11]. Furthermore, the interface elevated the user's learning abilities by displaying additional information on the interactive pieces of the environment [11]. This spatial association allows the user to draw direct connections between the interface and the item of interest [11]. When designing the spatial interface to be tested in our research, Anatomy Viewer was referenced to create another education centric option that incorporated spatial relationships. With these applications as examples, three visually appealing and fully functional interfaces were developed for experimentation in Anatomy Builder VR.

After exploring nine different virtual reality applications with varying focuses, a table of collected observations and inferences was made to better organize the effective aspects of each experience. From this table, conclusions regarding the quality of each interface were drawn and recorded. To ensure the success of newly designed interfaces, these deductions were taken into account when designing and implementing the three interface prototypes to be evaluated during the study.

CHAPTER II

STUDY

Creation of Interfaces

To ensure that the final interface to be implemented into Anatomy Builder VR is intuitive for all users, three different iterations were created for testing. Each interface displays the same lesson material in a different organizational manner. The logic behind these interfaces is geared toward various types of learning so that study participants can evaluate the successfulness of each approach. After the study's completion, the best scoring interface will be included in the final version of the Anatomy Builder VR application.

The first iteration, nicknamed the "bubble interface" shown in Figure 1, conveys the lesson material through hierarchical organization by grouping similar, more detailed terms under a broader title. This general outline allows the users to view the main topic and its subcategories all at once, giving them control of what information they would like to focus on. Visuals that relate to each term are shown next to the definitions so that the user experiences both auditory and visual cues while learning. Additionally, the interface guides the user through the lesson's material to prepare them for the concluding quiz. From a design standpoint, the bubble interface is extremely intuitive and does not require much thought to operate. The user understands its interactivity through scaling changes and haptic feedback given by the handheld Vive controllers. When selected by the user, the bubbles interchange in a dynamic and intriguing fashion that is consistent with the interface's modern aesthetic. This iteration is most useful when visualizing how all of the lesson material fits together.

Figure 1. “The Bubble Interface”

The second iteration displayed in Figure 2 is inspired by Google Tilt Brush’s interface. Because Tilt Brush is a three-dimensional drawing application, the interface is similar to a painter’s palette that is constantly attached to the user’s handheld Vive controller. By the same token, the second iteration is in tablet form so that the user has access to the information and navigational tools at all times. The user is also able to remove this “tablet” and place into the virtual space to use as a reference similar to the bubble interface. The handheld device guides the user through the lesson from start to finish while visually illustrating each term on the interactive skeleton. This allows the user to complete the lesson material needed to pass the concluding quiz while exploring the bones of the body at their own leisure. The tablet interface has a futuristic aesthetic that compliments the application's virtual environment while remaining extremely intuitive to the user.

Figure 2. "The Tablet Interface"

As seen in Figure 3, the third iteration emphasizes the spatial relationship between the lesson material and the skeleton itself. The positioning of the interface prompts the user's participation so that they are aware that the skeleton is interactive. Additionally, the user is able learn both the term's definition and its associated body part by its corresponding node. This simplifies cognitive comprehension and assists with long-term retainment of the material. To ensure that the lesson is focused on the necessary terminology, the spatial interface guides the user through the most important terms that will be presented on the concluding quiz. From an aesthetic perspective, the interface has a holographic inspired yet easily readable design that gives the interface a high-tech feel, enhancing Anatomy Builder VR's clinic-like environment.

To summarize, this interface is best for learning the relationship of the terms to the location on the human body.

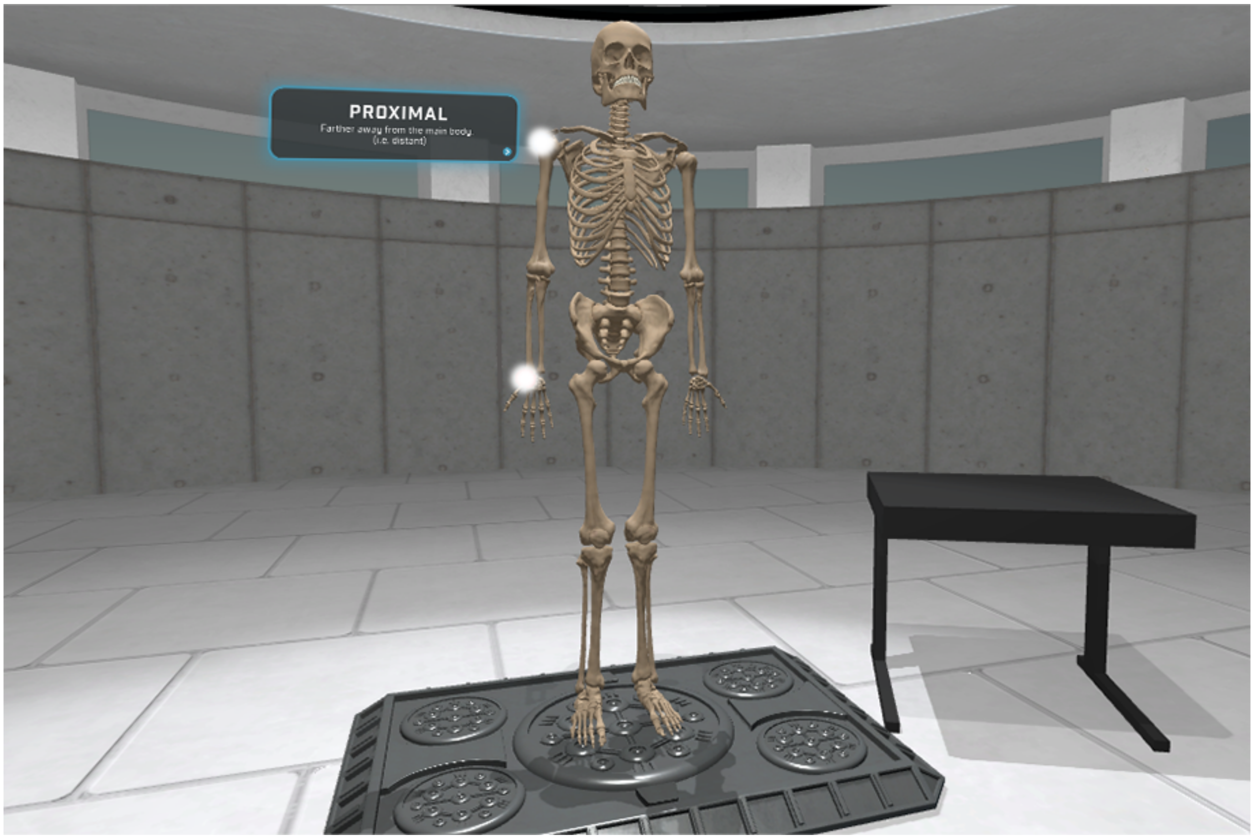

Figure 3. “The Spatial Interface”

In conclusion, each of these interfaces is organized differently so that study participants can select the interface personally most conducive for learning. These interfaces were developed through an iterative design process, meaning that multiple versions were made until a final, functional design was reached for each organizational style. Before proceeding to the next steps of the study, the interfaces were implemented into the Anatomy Builder VR application via backend coding in the Unity Game Engine. From there, the design aspects were added to flesh out and complete each interface prior to testing. The most intuitive and best-designed iteration will be determined through the testing process.

Research Methods

Before beginning the actual experiment, research methods and techniques were agreed upon to decide what data would be collected and how this would be accomplished. Both qualitative and quantitative data was gathered to gain a better understanding of the intuitiveness of each interface design. This was done by timing the participant during the use of each interface, keeping track of their in-game quiz scores, and recording their responses during post-study interviews. Timing the participants and quantifying their quiz scores allowed the researchers to analyze tangible conclusions pertaining to the usability of each interface. In addition, this quantitative data verified the participants' verbalized opinions or qualitative data. Other pertinent information collected included the participant's name, age, gender, major, and previous experience in educational virtual reality applications. Once again, this data lent itself to understanding each participant's individual experience at a more analytical and psychological level. The planned research methods of this experiment were incorporated into the final study procedure to be examined during the study's conclusion.

Study Procedure

Before the official study began, our research team first sought approval from the Texas A&M University's Institutional Review Board. To do this, I successfully completed the necessary training for human testing and submitted the extensive online application explaining the nature of our study. Once the application was approved, we then moved on to writing the script to be used when recruiting participants via university-wide email. This script covered participant eligibility and requirements as well as the date, time, and location of the study. It also offered two types of contact information in the event that the recipient was interested in learning more about our research or participating in the study itself. This set up ensured that participation was totally voluntary. When replying to potential participants, another scripted response was used to communicate further details about the study in addition to a link that they could use to book an hour-long participation session. This follow-up message concluded the recruiting portion of the study procedure.

Before the start of each session, the testing room was prepared by cleaning the virtual reality headset and hand controllers, printing consent forms, setting up the pre-study questionnaire, and determining the individual's counterbalanced testing order. Upon their arrival, the participants were greeted and ushered to a seat to listen to the initial briefing. The study was then generally described and time was allotted for any questions before beginning the experiment. Next, the participant was issued a consent form that explained their rights to the results being collected, reiterated that the study was entirely voluntary, and explained that participation could be terminated at any time. The individual then signed the paper before returning it to me, signifying their agreement to continue the study.

After the consent form was collected, the participant was shown to a laptop on which they filled out a pre-study questionnaire. Questions asked included the age, major, previous experience in anatomy courses, and familiarity with educational virtual reality applications. The answers were submitted via Google Form so that all information remained private. Upon the completion of the pre-study questionnaire, the participant was guided back to their previous seat where the function of each wearable virtual reality piece was described to them. This included the Vive headset and two hand controllers as seen in Figure 4. They were then asked to explore each interface in its entirety, briefed on the flow of the experiment, and told that assistance would be nearby if they were to need it. Confirming that the participant was ready to begin the primary part of the study ended this verbal overview.

Figure 4. Person in Vive Virtual Reality Headset and Hand Controllers

Once acclimated in virtual reality, the participant was asked to complete the first prototype to be tested according to the individual's pre-determined order. After finishing the lesson, they were then assisted out of the gear and asked questions about the usability of the interface. By asking specific questions after the first experience, the participant was able to more easily communicate their opinions regarding the interface. The participants were asked to elaborate on the interface's overall design, expand upon their favorite and least favorite components, and describe any issues they encountered during the experience. This process was repeated two more times so that all three interface designs could be examined and discussed individually. All of the participant's verbal responses were recorded via smartphone once securing the their permission.

After exploring and conversing about each interface separately, the participant's general experience was discussed in depth. The questions asked aimed to understand the reasoning behind each individual's favorite and least favorite interfaces as well as their preference regarding the way the information was presented. Additionally, the participants were asked which interface was easiest to learn anatomy terms from and how they thought these interfaces could impact learning in the future. Again, these verbal responses were recorded using a smartphone for later review. This post-study interview brought the entire session to a close, and the participant was lastly thanked for their time prior to their exit.

The study procedure was strictly adhered to for all participants, ensuring a uniform experience for each individual. After the session's conclusion, I went through the information collected by the computer and recorded it on the conglomerative data sheet for later analysis. I also gathered information from the pre-study questionnaire and input it on the data sheet for easier cross-comparison. The room was then prepared for the next participant or closed down for the day.

Data Collection and Analysis

For this research, a small sample size was evaluated because of time constraints and the need for thoroughness through out the study. The recorded demographics of the twelve study participants included the individual's name, gender, age, and majors. Of the sample size, 66.7% of participants were girls and the remaining 33.3% were boys. The age range of these individuals spanned from 18 to 23, and each age was represented by roughly the same amount of people. However, a mere 8.3% of participants were 23 years old. Finally, the participant's majors varied from one another except for engineering majors, which was represented by 33.3% of participants. This information was included on the combined data sheet to be evaluated at the study's conclusion.

The primary data collection during this experiment was done using a computer. The interface testing application had a built-in processing system that recorded the duration of each interface use and the participants' quiz scores. Because this information was for three separate interfaces and was therefore located in three separate files, I entered the logged information into the overall data sheet at the conclusion of each session. The results of the pre-study questionnaire were recorded via Google form to ensure the privacy of all participants. Again, I personally went through each individual's responses and input the necessary information into the collective Excel spreadsheet.

As mentioned before, both the short interviews between each interface and post-study interview were recorded via smartphone for further review in the future. In order to respect their personal rights, the participant was asked to give their consent before recording. The total interview running time averaged around six minutes. Once I had collected recordings from all of the study sessions, I went through each interview individually and wrote down the pertinent answers into the spreadsheet. The integrity of the answers was preserved by directly quoting the participant when entering their responses. Paraphrasing was only employed when communicating a simple answer that did not require much elaboration.

Once the data was condensed into a single Excel document, we were able to analyze the results of the study. We first assigned a color code to visually connect the results from each interface with one another across all of the information. This made it significantly easier to compare the duration times of each participant with those who had a similar testing order.

Additionally, the participants total quiz score was calculated by adding together the number of attempts it took them to answer three questions correctly at the end of the first interface test. This quantitative data allowed us to understand the ease and effectiveness of each interface from a numerical standpoint. Other information taken into consideration was the participants' majors since some had prior knowledge of the terms presented on the interface. This would in turn effect their duration time and quiz scores because of their familiarity with the material. Finally, the favorite and least favorite interface responses were tallied to find an overall frontrunner. These findings were then compared to the results of the "easiest interface for learning anatomy terms" category. The conclusions drawn from analyzing the study's results were also recorded on the collective spreadsheet so that all information could be found in one location.

CHAPTER III

RESULTS

Study Results

Once the study's quantitative and qualitative results were compiled into one Excel sheet, the findings were then analyzed in order to understand the outcomes of the experiment. Components examined included the overall duration of the participants' virtual reality experience, their quiz attempts and scores, their favorite and least favorite interfaces, the interface they felt was most intuitive for learning, and their experience as a whole. Because the order of the interfaces was counterbalanced, we were able to collect an accurate first impression of each interface from a variety of participants. Since the same information was presented on all three interface designs, this was a crucial component in the success of the study.

When exploring each interface and completing the concluding quiz, the participant was timed to determine the lesson's duration. The times from the three interfaces were added together to calculate the total time it took for the participant to finish all three prototypes. Generally, it took 2 minutes to complete the bubble interface, 1.5 minutes to complete the tablet interface, and 2.1 minutes to complete the spatial interface. This brought the average total duration to roughly 5.6 minutes. Interestingly, the total duration was not effected by the counterbalanced order of the study.

Additionally, participants' quiz scores were recorded alongside the duration of each interface. The scores were calculated by counting the number of attempts it took for them to answer the quiz questions correctly on the interface first presented to them. By focusing on the quiz scores from the first interface test, we were able to ensure that the participant had not memorized the answers from the previous interfaces. The attempts until correct for each of the three questions were added together to generate a total quiz score, which was then compared across all first interfaces of the counterbalanced order. The bubble interface had the highest number of attempts until correct, averaging at a total of 5.25. The tablet interface took 4.25 attempts, meaning this interface was slightly easier to learn from than the former. Lastly, the spatial interface boasted the lowest average attempts, coming in at a total of 3.75. While these quiz scores are indicative of the interface's effectiveness when presenting the lesson's material, the results did not affect the outcome of the remaining categories.

In order to understand the positives and negatives about the three designs, the participants were interviewed after using each interface. Their answers were then compared to one another to determine an overall favorite and least favorite design. The reasoning behind these opinions was also recorded so that the current prototypes could be improved in the future. From these interviews, we found that the majority of participants favored the bubble interface, although this opinion was not overwhelming as only 41.7% concurred. The spatial interface came in second place with 33.3% of participants listing it as their favorite, while the tablet interface came in last with 25% of the vote. When interrogated, participants stated they favored the bubble interface for its intuitiveness, aesthetics, and hierarchical layout. Most said that this interface was easiest for them to follow because the information was listed in a singular location, so the user always knew where to find it. Those who favored the spatial interface commented that the structure of the lesson and the proximity of the terms to the skeleton itself were most helpful to them. Lastly, participant's who preferred the tablet interface liked that they had control over the information's location and could position it to view the skeleton and the text simultaneously. In light of these results, one particular front-runner could not be determined as the final percentages were so close to one another.

After discussing the participants' favorite design, we then questioned them on their least favorite interface and the reasoning behind this decision. Interestingly, the majority of participants disliked the tablet interface most with 58.3% of participants communicating this opinion. These individuals felt that the tablet's setup was unnatural and required too much physical effort to view and manipulate. Additionally, they did not understand how to advance through the material without prompting and auditory explanation. The spatial interface was the least favorite of 33.3% of participants, which intriguingly matched the percentage of those who said it was their favorite. However, those who disliked the design stated that the operating instructions were unclear and the structure of the lesson was too fragmented to make coherent sense. Some even mentioned that this design was more akin to interacting with a computer screen as opposed to a virtual reality environment. Finally, the bubble interface was listed as the least favorite of only 8.3% of participants. This individual said that the bubble interface focused more on the lesson material rather than the terms' relation to the skeleton, which made the anatomy terms difficult to understand. After analyzing this data, it became increasingly clear that most participants felt that the bubble interface was the most effective design approach. However, this design had the worst quiz scores out of all of the three interfaces, rendering our previous findings somewhat inconclusive.

Although the bubble interface was chosen by most as their favorite, this does not necessarily mean that it was the most effective for learning anatomy terms. This became evident during the post-study interview, where participants were asked which interface best assisted them in learning the lesson's material. The spatial interface was most consistently chosen with

50% of participants supporting this design. These participants felt it was most effective because the anatomy terms were intentionally positioned to be associated with a certain place on the skeleton. Furthermore, they thought that the more structured lesson helped with learning the terms individually instead of all at once. This outcome was slightly counterintuitive, because the bubble interface was most popular in all of the previous categories. Interestingly, the bubble and tablet interfaces had the same score in learning effectiveness with both receiving support from 25% of participants. Once again, these results did not align with earlier findings, as the bubble and tablet designs received such vastly different scores in the favorite and least favorite categories. This data reiterated the notion that an interface may boast the best aesthetic design and be the overall favorite, but also may be the least effective at meeting the primary goal.

At the conclusion of the interview, each participant was asked to give their opinion on their overall experience and the impact of virtual reality applications on learning. During this discussion, most participants communicated that learning anatomy terms in a virtual reality environment helped them visualize the information more effectively than if they read the material from a textbook. Additionally, they believed that this approach enhanced their learning experience and would engage all types of learners. It was a popular opinion that this application would be incredibly useful in a classroom setting and could later be expanded to include more complex material such as muscle movements and dissection demonstrations. In summary, the participants communicated an overwhelmingly positive experience that was extremely effective in presenting information traditionally found in a two-dimensional medium.

Future Work

In the near future, the suggestions given by study participants to improve the interface designs will be implemented to create the best design possible. The current plan is to combine the positive aspects from the bubble and spatial prototypes into a singular interface, a suggestion made by several participants. This proposal was backed by the study's data that concluded the bubble interface's design was the most aesthetically pleasing and the general favorite while the spatial interface was most successful in teaching anatomy terms presented in the lesson. Furthermore, the feedback regarding the intuitiveness of each interface will be incorporated so that instructions and prompts given by the environment match the visual design. This will aid in navigation and allow the user to focus on the presented material rather than the interface's functionality.

While the suggestions given by the study's participants were incredibly helpful, it is important to remember that the sample size was only twelve people. This was a limitation throughout the experiment because of our consistently close results that prohibited us from discovering a definite frontrunner when comparing the three interface designs. However, the data collected during this study allowed us to determine that a hybrid interface would be most effective for reaching our end goal. Once this interface is complete, it will be implemented into the commercial version of the Anatomy Builder VR application that is still currently in production, bringing our research to a close.

CONCLUSION

This extensive research process was completed with the intent of discovering an optimal interface design to incorporate into a virtual reality application that teaches anatomy education. Centering our research around the question "how can user interface design in virtual reality applications support learning and engagement?" ensured that all prototypes created were geared toward specific aspects of learning and presented the lesson's material in a lucid manner. Through our efforts and discoveries, we found that the combination of a hierarchical layout as seen in the bubble interface and structural layout as demonstrated by the spatial interface would be most effective when communicating anatomical information. This conclusion was supported by both the quantitative data of the participants' quiz scores and qualitative data gathered from the participant interviewing process. Our experimentation and data collection allowed us to reach this conclusion that simultaneously answered the primary research question and prompted the future work on this project.

Another important discovery made throughout the course of this research was that a user's quiz scores could be greatly affected by an interface's design. If the interface does not communicate the instructions and the questions clearly, it can lead to a disconnect between the task at hand and the interface itself. Furthermore, this disconnect can also create problems when the user is attempting to learn the material when it is first presented to them. This dilemma reiterates the importance of successful user interface design. Without an intuitive interface to reference, the user can become easily confused and frustrated, possibly causing them to suspend use of the application all together. In this regard, our research is extremely helpful for implementation purposes in both our own educational application and for others who encounter this same issue.

Researching the unique combination of user interface and virtual reality application design proved to be an intriguing challenge, because our team was designing a two-dimensional product to be presented in a three-dimensional medium. This obstacle forced us to think about how the user would interact with the interfaces while in an immersive environment. To create a successful experience, we had to take into account the physical movements needed to navigate through the two-dimensional interface so that the physicality was more engaging than off-putting. The challenge of merging these two mediums confirmed the need for more research in this area of user interface design.

Finally, the importance of effective communication between technical developers and the aesthetic designers became extremely apparent throughout the course of our research. Because visual designers tend to focus on technology conducive to two-dimensional design, they have limited knowledge pertaining to three-dimensional gaming systems required to create a working virtual reality application. To overcome this obstacle, I personally collaborated with an expert in Unity Gaming Engine to bring my interface designs to fruition. His technical expertise was crucial to the success of the research, because he took my initial designs and implemented them into a single interactive build to be used in the study. When conducting research under this topic, the team must consist of individuals with varying expertise in order to be successful.

In summary, our yearlong research efforts attained several important conclusions. First, our initial interface prototypes must be combined into an entirely new design that will unite two types of organizational learning to yield a more effective result. Secondly, user interface design is extremely important when determining the usability of an application as it can prohibit an individual from understanding its primary goal. By this same token, research combining two-dimensional user interface design with three-dimensional environments is important when creating an effective educational virtual reality application. Physical movements connecting the interface and corresponding material must be considered when determining the usability and intuitiveness of the design. Lastly, technical developers and visual designers must work together and share their expertise so that a beautiful interface design that is functional within virtual reality can be implemented into the application. These findings will continue to propel our research forward until the completion of our final interface and its implementation into Anatomy Builder VR.

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