3D STRUCTURE AND DISSECTION OF HUMAN BRAIN USING VIRTUAL REALITY

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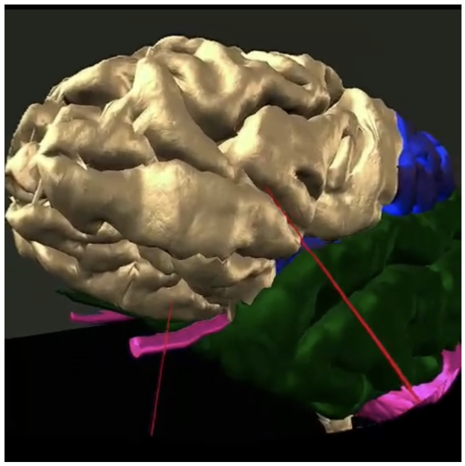

Fig. 1. 3D Human Brain

Traditional methods for studying the human brain often rely on two-dimensional representations, limiting the depth of understanding. By utilizing the spatial awareness ability of the virtual reality application, user would be able to experience more immersive and interactive learning. The project aims to implement a three-dimensional model of human brain and interactive dissection application in the virtual Reality (VR). The task completion time and usability test are performed to obtain the effectiveness of the application. The thematic analysis results of the usability test indicates that the users are satisfied with the application and doesn't experience any discomfort while performing the experiment. Additionally, an ANOVA test, assessing task completion time under sitting and standing postures, indicated no significant performance difference associated with changes in posture.

Additional Key Words and Phrases: 3D Brain Model, Quantitative Study, Qualitative Study, Thematic Analysis, Anova Test

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1 INTRODUCTION

1.1 Motivation to choose VR

VR applications are widely used in the healthcare industry for simulation of anatomy and surgeries thus aiming to improve the practical training which are not obtained through the real-world conditions [10]. Recent study showed that VR can deliver cost effective, improved knowledge transfer and safe training [14]. Souza et al evaluated the effectiveness of virtual reality in knowledge transfer and retention in the collaborative group-based learning by conducting neuroanatomy experiment. The mean retention and the learning effect score was greater in the virtual condition than the physical building environment [20]. Learning neuroanatomy in the Virtual Reality application has exhibited higher medical image interpretation skills compared to the traditional classroom education approach [15]. Moro et al studied the effectiveness of VR and AR in medical anatomy over the tablet-based application [17]. The average score from the anatomical assessment indicates that students exhibit superior performance when exposed to virtual reality (VR) and augmented reality (AR) learning compared to tablet-based learning. The Virtual Reality and Augmented Reality offers a secure and ethically sound alternative to cadavers, addressing issues of scarcity or access restrictions. VRA facilitates the creation of personalized learning experiences, enabling students to concentrate on particular anatomy areas or repeat exercises as required [16]. Vergel et al performed an anatomy training experiment to compare both the VR and AR suitability, experiment proved that the VR devices are more suitable for the anatomy training than the AR [19].

1.2 Exploring the Human Brain: A Virtual Reality Adventure in Anatomy Education

In the ever-changing world of educational tech, this project combines Virtual Reality (VR) with the study of the human body to create cool new ways to learn. We're using VR to explore the details of the human brain in a way that's never been done before, making anatomy lessons more exciting. We're using special tools like Unity software, Blender, Dotween Pro, and the Oculus Quest 2 VR headset to build a fun and interactive learning experience. With the VR headset on, you can step inside the 3D world of the brain and even virtually "cut" through it to see how it works. We're not just doing this for the tech – we want to know if it helps students learn better. By listening to what users think and how much they enjoy it, we're figuring out how to make this VR brain journey even more awesome. Join us on this adventure into the fascinating world of the human brain!

2 RELATED WORK

The human brain is a very complicated organ made up of small structures that are closely packed and connected through various pathways. With the advancement of bioimaging techniques,there's a rising interest in understanding the connections within the brain, both in terms of function and structure. Recently there are a lot of VR solutions proposed to understand the structure of the brain.

2.1 Existing Implementation Strategies

Aceituno et al developed a mobile application for teaching brain anatomy using VR [9]. The application visualized the MR images and different brain structure by converting the unprocessed MRI data obtained from the patients scan into DICOM format. Then, this format is converted into the Neuroimaging Informatics Technology Initiative (NIfTI) file format, which contains the affine coordinate definitions and codes to denote the spatial and temporal order of the brain image slices. A three-dimensional vertex mesh of the brain cortex is created after the NIfTI file has been processed by the BrainSuite cortical surface identification tool. To display any segmentation of the brain accurately, this step is required. The major limitation of this approach is application's brain slicing feature was difficult to use and ineffective for teaching students. application's brain slicing feature was difficult to use and ineffective for teaching students. A VR-based method of MR DTI and fMRI visualization was put forth by Chen et al [5]. This method integrated high-resolution anatomical image segmentation, white matter fibre tractography visualization, and fMRI activation map integration of the human brain. SONIA a customizable brain network education application developed in VR showed to have attractive visual designs, good educational value, and high usability. The application allowed the user to customize the visualization styles of the brain structures [8]. Kosch et al developed a brain activity simulation in the VR using the LORETA algorithm. The model calculates the density distribution to estimate the origin of the brain activation [13]. This mechanism provides a better understanding of the relationship between external stimuli and brain activity. Neuroscape Lab developed the Glass brain project in VR which is three-dimensional visualization application which allows real-time exploration of source localization, incorporating interactive elements. Nevertheless, examining the internal details of the visualized brain is challenging due to the use of a consistent solid colour filling [3]. Keiriz, et al. developed NeuroCave applications, a web-based immersive visualization platform designed to explore connectome datasets on both desktop computers and virtual reality (VR) headsets[12]. With this tool, researchers can see and understand how different parts of the brain are connected. In NeuroCave, scientists can explore the brain data in different ways, grouping brain regions together and comparing different sets of information. The tool also has a default setup where you can see and compare two sets of brain data side by side at the same time.Schloss et al initiated the UW Virtual Brain Project, designed to instruct functional neuroanatomy through interactive 3D narrated diagrams[18]. The project operates on both VR devices and personal computer monitors. They did two tests to see if the lessons work well and to compare learning on VR and computers. The results show that the UW Virtual Brain lessons are good for learning about how the brain works on both VR and computers.

2.2 Quantitaive and Qualitative Analysis Approaches

The qualitative analysis method is commonly used in heath science and pharmacy education [4]. The qualitative data processing involves five essential steps—compiling, disassembling, reassembling, interpreting, and concluding—to yield valuable findings [22]. Thematic analysis enhances the significance of the results by reporting the patterns in the analysed data [6]. Kaminska et al explored the advantages of usability test in the VR application over the traditional methods and the possibilities of the automating usability testing of VR applications. The results shows that the usability test is more efficient in determining the usability issues and improve the design of VR applications [11]. Quantitative analysis for VR involves the systematic examination of numerical data to assess various aspects of VR experiences, performance, or outcomes [7]. A quantitative repeated measure design experiment was performed by Xu et al to compare the effect of sitting and standing posture while playing the gesture based immersive virtual reality exergames application. The author results indicated that the seated exergames provided better experience than the standing exergames. The sitting posture proves more suitable for confined spaces than their standing counterparts and potential to increase exertion. But the careful design of gestures for seated exergames is essential to minimize motion sickness, and users should be allotted more time to execute gestures in seated exergames as opposed to standing posture [21].

The collective research works of various scholars emphasizing the significance of developing the anatomy in VR applications inspired us to enhance existing VR applications for visualizing the brain. Prior applications primarily focus on visualizing the brain's structure, neglecting the aspect of brain dissection. Their approach involved displaying the brain's structure using CT scans, resulted in a colourless representation. This monochromatic representation imposes challenges in distinguishing various parts, given their identical coloration. The previous research works on qualitative, and the qualitative study helped us to understand the importance of usability test, thematic analysis, and the repeated measurement for various postures. Our application addresses this limitation by employing distinct colours to differentiate various brain structures, facilitating interactive dissection of the brain. The study includes qualitative analysis through usability surveys and thematic analyses, alongside quantitative analysis involving task completion times examination in both sitting and standing positions.

3 PRE-INTERVIEW : GATHER INSIGHTS FROM THE USERS

Before creating our 3D dissection of the human brain using virtual reality (VR), we talked to the people who might use our application. We wanted to find out what features they wanted and what would make the app useful for them. We used their feedback to design our 3D brain model, making sure it included the things they were looking for. We provided the user with two sample video demonstrations to give them an understanding of the current applications of 3D brain technology in virtual reality [2],[1]. The following screenshots Fig 2, Fig 3 shows the glimpse of videos we have shown to the users.

(a) Partial Brain Structure and Dissected part in 3D space

(b) Flow Diagram of Application

Fig. 2. Partial Brain Structure and Dissected part in 3D space

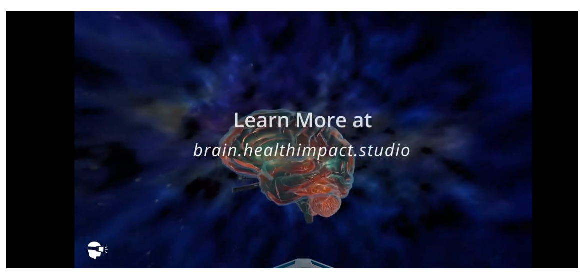


Fig. 3. Flow Diagram of Application

After showing the existing videos, the following Questionnaire were asked to user and consolidated responses from the users are articulated in table1.

Table 1. Pre-Interview Quesionnarie and Responses

Quesionnarie	Consolidated Response
Based on the sample videos of existing anatomy applications in VR what features can be enhanced?	Participants expects the application to distinguishes between different structures in the brain using colors and display labels for each part of the brain.
Do you prefer an animated video showing the dissection of the brain or would you like to create an application that helps you to dissect the brain?	Most of the participants prefer creating an interactive application in which the user dissects the brain.
Do you prefer interactive and hands-on learning experiences, or are you more comfortable with traditional methods like textbooks and lectures?	Most of the participants responded that they would prefer digital and hands on application to understand the complex concepts better than the traditional textbook methods.
How much time are you willing to invest in a single VR session for learning anatomy?	10 to 15 minutes is the time participants like to invest for learning brain anatomy.

4 METHODOLOGY

The app does two main things. First, it lets you visualize various brain parts with distinguished colors. It also gives you information about these parts. Second, there's a feature that allows you to cut through the brain in different directions, like slicing it, from the viewpoint you're looking at.

4.1 Brain Slicing Mechanism

After looking at the virtual brain, the user can spin it around however they like. They can do three things: chop off a part by picking where to cut, focus on one area that has the same color, or bring the whole brain back to how it was at the start. You can see the steps in a picture called Fig. 1 to shows how the app works.

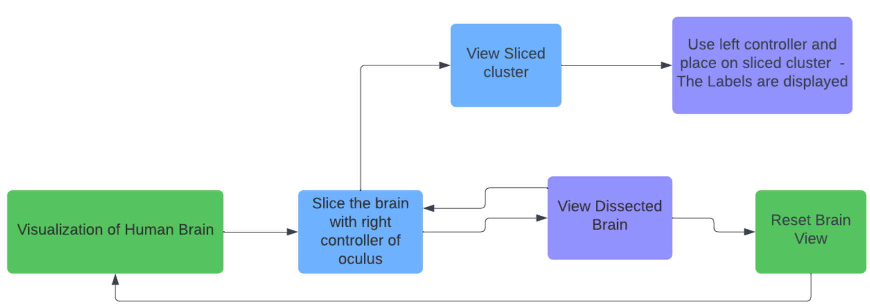
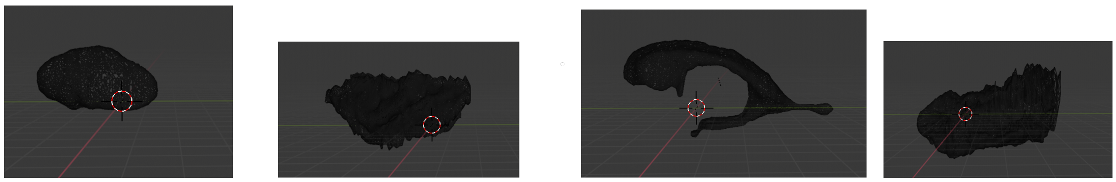


Fig. 4. Flow Diagram of Application

4.2 3D Brain Model built using Blender

Creating the 3D brain model involves a series of detailed steps, starting with building the brain shapes and connectors. We start with a quad sphere in blender, and then we shape it into the desired form of the brain by making slits and cuts. This process is repeated for each part of the brain. After that, we connect all the individual parts together to create the complete brain model. The following figure 5 shows the individual brain parts built using this blender.



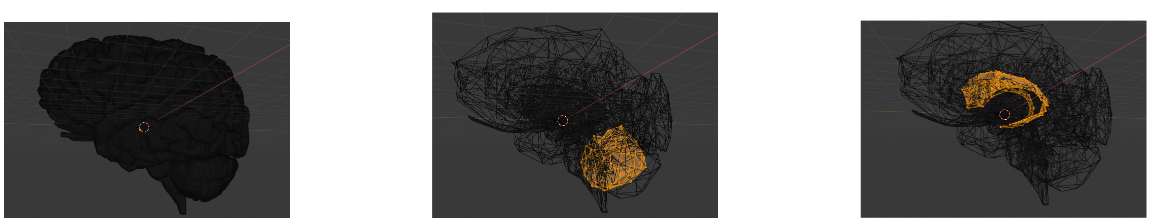
(a) Putamen Part (b) Thalamus.CL (c) Ventricle.R (d) TempralLobe

Fig. 5. Individual Brain Part Construction using Blender

In the slicing phase, users can freely rotate the view around the virtual brain, allowing for thorough exploration. Users can perform three main actions: cutting off a section, isolating same-colored regions, and restoring the entire brain. Cutting involves defining a plane using a point (P) and a normal vector (N), classifying voxels based on their position, and creating a second mesh revealing the cut faces.

Isolating regions lets users focus on specific areas by selecting a seed voxel. The cortex mesh is hidden, emphasizing the isolated cluster. A restoration option brings the entire brain back, resetting cortex mesh triangles.

Calculations for cuts involve selecting a plane with a point (P) and a normal vector (N). Voxels are classified based on their distance to the cut plane. The cortex mesh updates by removing unnecessary vertices, updating the triangle list between the cut plane and the user camera. Triangulation of the inner brain mesh calculates visible faces, studying $2\times2\times2$ vertex neighborhoods for optimal triangulation. The visualization of the mesh structures are shown in the figure 6.



(a) Brain Structure and Dissected part in 3D space (b) Mesh Structure of Cerebellum CR Part (c) Mesh Structure of Caudet Part of Brain

Fig. 6. 3D and Mesh Visualization of Brain

Users can select an isolation seed, marking other voxels as invisible. Restoration brings all voxels back, resetting cortex mesh triangles. In summary, this process results in an interactive 3D brain model, allowing precise exploration of both the outer cortex and inner structures.

4.3 3D Brain Construction

The way we show the human brain in 3D involves letting users do three main things: cut parts off, focus on specific colored areas, and bring the whole brain back. Users can spin the view around the brain freely.

When users do something like cut a part, we create a second picture showing what's inside the brain. The inside picture comes from data about the brain's structure. We use special points called voxels to make this picture, and each voxel has a color based on the brain's activity.

The step by step procedure is listed below on how this 3D Constructed Brain Model is build and Fig.7 shows the constructed Brain Model.

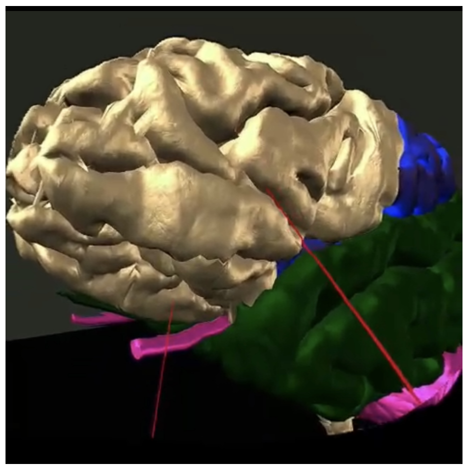


Fig. 7. 3D Brain Model Build

The process involves a few steps:

Cutting Parts: Users pick a spot and direction to cut. We then figure out which part to cut based on what the user chose.

Updating the Inside Picture: The inside picture changes every time you cut something. We do this by figuring out which parts to keep or remove, making sure everything looks right.

Picking a Spot to Cut: To cut a part, we need a point (P) and a direction (N). We get these from where the user is looking. P is at the center of the closest active brain spot the user is looking at.

Updating the Outside Picture: We also update the picture of the brain's surface when a part is cut. We only change the parts you can see, making sure the hidden parts stay hidden.

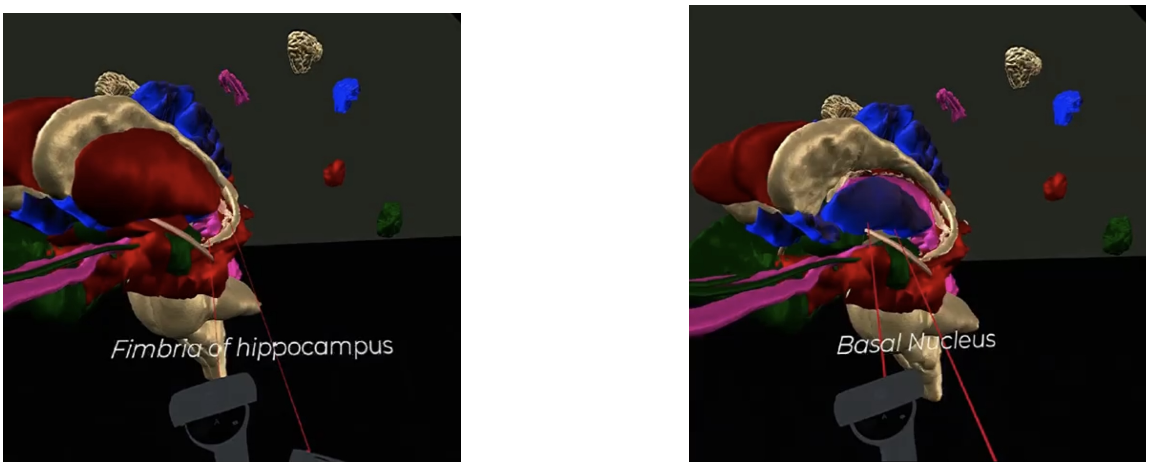
Calculating Faces Inside the Brain: We look at groups of points inside the brain to figure out what you can see. We've already done the hard work of figuring out how these groups look, so we don't have to do it every time.

Isolating Colored Areas: When you see inside the brain, you can pick a starting point. Everything around that point with a similar color becomes visible, forming a cluster. We hide the surface of the brain so you can see this cluster clearly.

After looking at the virtual brain, the user can spin it around however they like. They can do three things: chop off a part by picking where to cut, focus on one area that has the same color, or bring the whole brain back to how it was at the start. You can see the steps in a picture called Fig. 1 to shows how the app works.

4.4 3D Brain Model Interaction

The Oculus right controller acts like a tool for picking and choosing different colorized sections of the brain. When a section is chosen, pressing the controller's knob dissects that part. If you place the left controller on the dissected area, labels appear, giving information about that specific part. Different colors are used to distinguish between various sections of the brain, making it easy to identify them. The shapes of each part are clearly visible, enhancing understanding. You can see visual representations in Fig. 8 and Fig. 9, showing a partially dissected brain with sliced parts and a fully dissected brain in 3D space, complete with labels.



(a) Partial Brain Structure and Dissected part in 3D space

(b) Partial Brain Structure and Dissected part in 3D space

Fig. 8. Partial Brain Structure and Dissected part in 3D space

Fig. 9. Dissected Parts in 3D space

4.5 Material

We developed the project in Unity software supported by Blender, Dotween Pro and Oculus Integration Package. Oculus Quest 2 is used as the VR headset and linked to the HP laptop(AMD Ryzen 3 3250U with Radeon Graphics 2.60 GHz, 8.00 GB RAM) for the VR Output Display.

5 QUANTITATIVE AND QUALITATIVE STUDY

5.1 Participants

A group of 6 participants were introduced to a newly developed VR application among which 3 are female and 3 are male participants.

5.2 Quantitative Study

5.2.1 ***VR Application Feedback.*** To collect feedback on the application's performance and utility, an anonymous satisfaction questionnaire was administered. The questionnaire used a five-point Likert scale to gauge the students' opinions. Statistical measures such as the mean, standard deviation, and confidence interval were derived from the questionnaire responses. The Questionnarie and computed Statistical measures are listed in the table 2.

Table 2. Quantitative Study - Usability Questionnaire Analysis

Usability Questionnaire	Mean	Standard Deviation	Confidence Interval
Different 'paint areas' helped me better grasp where the major lobes are and understand their shapes.	4.64	0.49	[4.62 - 4.85]
I like that 'Brain dissection' allows me to make any cuts I want in the brain volume, which is helpful.	4.68	0.64	[4.42 - 4.86]
The dissection helped me figure out where each part of the brain is and what shape it has.	4.75	0.62	[4.47 - 4.61]
The interface of the Brain dissection functionality is intuitive and easy to use	4.44	0.67	[4.20 - 4.67]
The presented brain model have reduced the time required to learn the brain anatomy	4.09	1.33	[3.63 - 4.55]
Did this application make you feel uncomfortable	2.28	1.11	[1.78 -2.45]
How well was the application self-explanatory	4.38	0.94	[4.05 - 4.70]

5.2.2 ***Brain Dissection Time Evaluation.*** Participants were told to put on the Oculus Headset and make sure they could see clearly by adjusting it. They were given a demo on how to perform the experiment and asked to perform dissection trial before starting the experiment. The participants would perform the experiment in both sitting and standing position and the time taken to completely dissect the brain is recorded in both the position. Some participants performed the experiment while sitting first and later standing and others performed the experiment while standing

first and later sitting to prevent the learning effect. The anova test is performed with the noted task completion time .
Dependent Variable: Task Completion Time
Independent Variable: Posture (Standing and Sitting)

6 RESULTS

The ANOVA (Analysis of Variance) test table provides a statistical analysis of the factors influencing the task completion time in the context of a dissection task. Here's an explanation of the table:

Effect: This column lists the factors being analyzed. In this case, two factors are considered: Gender and Position.
df (Degrees of Freedom): The degrees of freedom indicate the number of independent values or quantities that can be assigned to a statistical distribution. For Gender, there is 1 degree of freedom, and for Position, there is also 1 degree of freedom.
SS (Sum of Squares): The sum of squares measures the total variability in the data. For Gender, the sum of squares is 0.087, and for Position, it is 0.224.
MS (Mean Square): The mean square is the sum of squares divided by the degrees of freedom. It represents the average variability. For Gender, the mean square is 0.087, and for Position, it is 0.224.
F (F-statistic): The F-statistic is the ratio of variances between groups to variances within groups. It is used to test whether there are significant differences between group means. For Gender, the F-statistic is 0.590, and for Position, it is 4.788.
p (p-value): The p-value is the probability of obtaining results as extreme as the observed results of a statistical hypothesis test, assuming that the null hypothesis is true. A smaller p-value suggests stronger evidence against the null hypothesis. For Gender, the p-value is 0.4851, and for Position, it is 0.0939.

Table 3. ANOVA Test Result for Task Completion Time Analysis

Effect	df	SS	MS	F	p
Gender	1	0.087	0.087	0.590	0.4851
Participant (Gender)	4	0.587	0.147		
Position	1	0.224	0.224	4.788	0.0939
Position X Gender	1	0.101	0.101	2.154	0.2161
Position X P(group)	4	0.187	0.147		

6.1 Interpretation:

For Gender: The p-value (0.4851) is greater than the commonly used significance level of 0.05, indicating that there is no significant difference in task completion time between genders.

For Position: The p-value (0.0939) is slightly greater than 0.05, indicating that there is no significant difference in task completion time between positions.Thus the application operates effectively regardless of its of position.

From the graph we can infer that the mean time taken to complete the dissection task in the standing position is greater than the sitting position. The mean time taken by female participants is greater than the male participant.

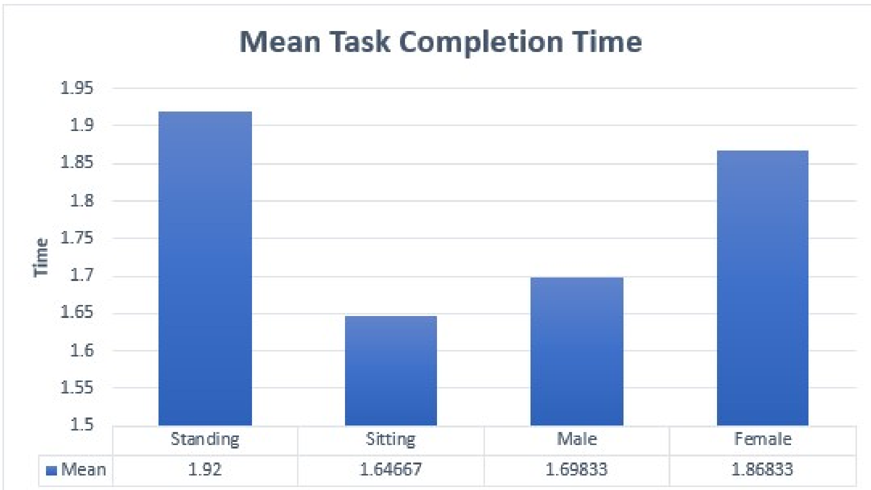


Fig. 10. Mean Task Completion Time bargraph

7 QUALITATIVE STUDY

We did a study to understand what people wanted in a new app. First, we talked to users and learned a lot about what they like and need. Using their feedback, we designed the app to fit their preferences. Later on, we asked these users to try out the app and share their thoughts. We had some questions about how easy it was to use, and we also wanted them to rate their experience. But we didn't just stop at the ratings – we asked them why they felt that way. We put all their responses together and looked for common themes. This helps us see what works well and what we can make better in the app, so we can keep making it more user-friendly and helpful. The thematic analysis is described in table 4.

7.1 Thematic Analysis

Thematic analysis is like a detective work we use in our VR brain project. It helps us sort through what people say about their experiences with our 3D brain dissection. We look for patterns and themes in their feedback to understand what's working well and what could be better. It's like putting together a puzzle to see the big picture. We follow a step-by-step process to go through what people are saying, find common ideas, and then organize them into themes. This way, we can really understand what users like, what they want more of, and how we can make our VR brain project even cooler for them. Thematic analysis is our tool for digging deep into what people think and feel about our virtual reality experience. The thematic analysis is described in table 4.

Table 4. Quantitative Study - Usability Questionnaire Analysis

Participant	Time	Transcript	Describe	Action	Theme
P1	03:45	Oh, the 'Brain dissection' functionality was brilliant. I could make any cuts I wanted in the brain volume, and that was so helpful for me. It's like having a virtual scalpel, but without the stress of a real dissection. It made exploration and learning feel dynamic and interactive.	A positive feedback	No Modification	No Modification
P2	03:22	The dissection part was fine. It helped a bit in understanding the spatial relationships between brain parts, but again, It could have been benefitted with added context to the part along with label	User is satisfied with existing features but is expecting additional features	Add descriptive content to part along with label	New Feature
P2	02:05	The interface was straightforward. It didn't take much time to get the hang of it, and I appreciate that. It gets the job done.	Satisfaction level in terms of User Interface is high	No Modification	No Modification
P3	02:33	The dissection feature was helpful to some extent in understanding the location and shapes of different parts of the brain. Tracking labels with the help of right controller only would be beneficial	The user is expecting to use single controller only to dissect and track the labels	User finds it comfortable to use single controller	Modify the existing feature
P3	03:39	The visual representation and interactive elements definitely sped up the learning process. It's much more engaging than traditional methods.But, Letting the users allow to choose the colors would be great.	A positive feedback is given and user is expecting flexibility in terms of color coding.	Give options to user to choose their own color coding	Add New Feature

Table 5. Quantitative Study - Usability Questionnaire Analysis

Participant	Time	Transcript	Describe	Action	Theme
P4	03:35	Maybe just the ability to switch the functions of the controllers easily. If I could draw with my left hand and use the tools comfortably, that would be perfect.	User is expecting to have flexibility in choosing controller to dissect the brain parts	Flexible controller settings need to be made	Modify existing controller settings
P4	04:20	The dissection feature, you know, it really helped me get a sense of where each part of the brain is located and what their shapes are like. It's not just about reading about it; it's about actively exploring and discovering, and that made a big difference.	A positive feedback	No Modification	No Modification
P5	02:22	If feasible, enable multiple users to join the VR session simultaneously. This can be useful for collaborative learning, research discussions, or group projects.	User is satisfied with existing features but is expecting multi-user interaction	Advanced feature of multi-player support would be beneficial	New Feature
P5	03:44	There is smooth and comfortable navigation within the VR environment. No motion sickness or discomfort is observed during extended use .	User is satisfied with overall VR experience of project	No Modification	No Modification
P6	04:11	Integrate quizzes or assessments within the VR environment to reinforce learning objectives and test users' knowledge.	User is expecting interactive elements like adding quizzes	Add interactive elements to foster leaning environment	Add New Feature
P6	03:23	Provided Color schema is very useful in differentiating the brain parts and to understand them clearly and the VR experience is fun	A positive feedback	No Modification	No Modification

7.2 Inference from Thematic Analysis

The thematic analysis of participant feedback from the usability study on the Virtual Reality (VR) project focused on brain anatomy exploration reveals a generally positive reception of the "Brain dissection" functionality. Users appreciated its brilliance for dynamic and stress-free exploration, emphasizing its role in making learning feel interactive. While satisfaction is evident, participants suggest improvements, including the addition of descriptive content during the dissection process to enhance contextual understanding.

Users really liked how easy the app was to use and found the interface simple and straightforward. They think it's great but have some ideas to make it even better. They want to be able to do more with the controllers, like switching between functions more easily. People also want to pick their own colors for different parts of the brain, which sounds like a lot of fun. They're excited about working together and suggested having quizzes and tests in the app to make learning more interesting. Overall, users are happy with the app, but they think it could be even more awesome with a few improvements.

8 CONCLUSION:

In conclusion, the evaluation of our Virtual Reality (VR) application designed for the 3D dissection of the human brain has yielded valuable insights through approach—quantitative and qualitative analyses. The quantitative component, as assessed through ANOVA tests, indicated that gender and posture (sitting or standing) had no statistically significant impact on task completion time .Thus our application is efficient and independent of postures.

Complementing these statistical findings, the qualitative insights obtained through thematic analysis revealed a generally positive reception of the application. Users commended the brilliance of the "Brain dissection" functionality, emphasizing its contribution to dynamic exploration and stress-free learning. However, their feedback illuminated avenues for improvement, including a desire for added context during dissection, flexibility in controller settings, and the option to personalize color coding.

The integration of quantitative and qualitative findings highlights the success of the VR application's current features while also indicating areas for improvement. Finding a balance between data analysis and user preferences, this thorough study not only confirms that the app helps with learning about anatomy but also gives useful ideas for making it even better in the future. As we explore the connection between immersive technology and education, this method ensures that improvements match what users want, making learning interesting and effective for diverse audiences.

REFERENCES

[1] [n. d.]. https://sidequestvr.com/app/5442/vr-brain-exploration
[2] 2017. https://www.youtube.com/shorts/e5evlgKZ-fY
[3] 2023. https://neuroscape.ucsf.edu/technology/interventions-and-diagnostics/
[4] Ashley Castleberry and Amanda Nolen. 2018. Thematic analysis of qualitative research data: Is it as easy as it sounds? *Currents in pharmacy teaching and learning* 10, 6 (2018), 807–815.
[5] Bin Chen, John Moreland, and Jingyu Zhang. 2011. Human brain functional MRI and DTI visualization with virtual reality. In *World Conference on Innovative Virtual Reality*, Vol. 44328. 343–349.
[6] Victoria Clarke and Virginia Braun. 2017. Thematic analysis. *The Journal of Positive Psychology* 12, 3 (2017), 297–298. https://doi.org/10.1080/17439760.2016.1262613 arXiv:https://doi.org/10.1080/17439760.2016.1262613
[7] Joseph L. Gabbard, J. Edward Swan, and Stephen R. Ellis. 2012. VR 2012 tutorial: Quantitative and qualitative methods for human-subject experiments in Virtual and Augmented Reality. In *2012 IEEE Virtual Reality Workshops (VRW)*. 1–1. https://doi.org/10.1109/VR.2012.6180945
[8] Owen Hellum, Christopher Steele, and Yiming Xiao. 2023. SONIA: an immersive customizable virtual reality system for the education and exploration of brain networks. *arXiv preprint arXiv:2301.09772* (2023).

[9] Javier Hernández-Aceituno, Rafael Arnay, Guadalberto Hernández, Laura Ezama, and Niels Janssen. 2022. Teaching the Virtual Brain. *Journal of Digital Imaging* 35, 6 (2022), 1599–1610.

[10] Andreas Pierre Hvolbek, Philip Mørkeberg Nilsson, Francesco Sanguedolce, and Lars Lund. 2019. A prospective study of the effect of video games on robotic surgery skills using the high-fidelity virtual reality RobotiX simulator. *Advances in Medical Education and Practice* (2019), 627–634.

[11] Dorota Kamińska, Grzegorz Zwoliński, and Anna Laska-Leśniewicz. 2022. Usability Testing of Virtual Reality Applications—The Pilot Study. *Sensors* 22, 4 (2022), 1342.

[12] Johnson JG Keiriz, Liang Zhan, Olusola Ajilore, Alex D Leow, and Angus G Forbes. 2018. NeuroCave: A web-based immersive visualization platform for exploring connectome datasets. *Network Neuroscience* 2, 3 (2018), 344–361.

[13] Thomas Kosch, Mariam Hassib, and Albrecht Schmidt. 2016. The brain matters: a 3D real-time visualization to examine brain source activation leveraging neurofeedback. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 1570–1576.

[14] Bhone Myint Kyaw, Nakul Saxena, Pawel Posadzki, Jitka Vseteckova, Charoula Konstantia Nikolaou, Pradeep Paul George, Ushashree Divakar, Italo Masiello, Andrzej A Kononowicz, Nabil Zary, et al. 2019. Virtual reality for health professions education: systematic review and meta-analysis by the digital health education collaboration. *Journal of medical Internet research* 21, 1 (2019), e12959.

[15] Mildred Lopez, José Gerardo Carrillo Arriaga, Juan Pablo Nigenda Álvarez, Ricardo Treviño González, José Antonio Elizondo-Leal, Jorge E. Valdez-García, and Belinda Carrión. 2021. Virtual reality vs traditional education: Is there any advantage in human neuroanatomy teaching? *Computers Electrical Engineering* 93 (2021), 107282. https://doi.org/10.1016/j.compeleceng.2021.107282

[16] Ilia Miltykh, Edgar S Kafarov, Serghei Covantsev, Ali S Dadashev, Apostolos A Skarlis, and Oleg K Zenin. 2023. A new dimension in medical education: Virtual reality in anatomy during COVID-19 pandemic. *Clinical Anatomy* 36, 7 (2023), 1007–1015.

[17] Christian Moro, Zane Štromberga, Athanasios Raikos, and Allan Stirling. 2017. The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical Sciences Education* 10 (04 2017). https://doi.org/10.1002/ase.1696

[18] Karen B Schloss, Melissa A Schoenlein, Ross Tredinnick, Simon Smith, Nathaniel Miller, Chris Racey, Christian Castro, and Bas Rokers. 2021. The UW Virtual Brain Project: An immersive approach to teaching functional neuroanatomy. *Translational Issues in Psychological Science* 7, 3 (2021), 297.

[19] Ramiro Serrano-Vergel, Pedro Morillo, Sergio Casas-Yrurzum, and Carolina Cruz-Neira. 2023. Exploring the Suitability of Using Virtual Reality and Augmented Reality for Anatomy Training. *IEEE Transactions on Human-Machine Systems* 53, 2 (2023), 378–389. https://doi.org/10.1109/THMS.2023.3235250

[20] Vinicius Souza, Anderson Maciel, Luciana Nedel, Regis Kopper, Klaus Loges, and Eliane Schlemmer. 2020. The effect of virtual reality on knowledge transfer and retention in collaborative group-based learning for neuroanatomy students. In *2020 22nd Symposium on Virtual and Augmented Reality (SVR)*. IEEE, 92–101.

[21] Wenge Xu, Hai-Ning Liang, Qiuyu He, Xiang Li, Kangyou Yu, Yuzheng Chen, et al. 2020. Results and guidelines from a repeated-measures design experiment comparing standing and seated full-body gesture-based immersive virtual reality exergames: Within-subjects evaluation. *JMIR serious games* 8, 3 (2020), e17972.

[22] Robert K Yin. 2015. *Qualitative research from start to finish*. Guilford publications.