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# Computer Science

Studying Anatomy of Organisms through  
Virtual Reality

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## **Abstract**

Understanding anatomy is important for research in life sciences. Over the years new methods have been developed that can be used to enhance the learning process, such as Virtual Reality (VR). VR allows users to examine, and interact with anatomical structures in a three-dimensional space, providing a more immersive and intuitive learning experience. In this research project, the effectiveness of VR in studying anatomy is investigated. A VR environment has been programmed that visualizes anatomy of a zebrafish embryo. The VR environment is divided into two parts: the usage of games and the visualization of an ontology. User evaluations have been conducted to test the usability of the VR program for studying the anatomical parts. Results have been collected during the evaluations through observations and a questionnaire. By using familiar controls, repeating certain functionalities, and incorporating gamification, VR can be used to effectively visualize anatomy ontologies and study anatomy.

**Keywords:** Virtual Reality, Zebrafish, Anatomy, Ontology, Visualization.





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# 1 Introduction

## 1.1 Context Zebrafish

Zebrafish are a small type of freshwater fish that are native to South Asia. Adult zebrafish reach a length ranging from about 2 to 4 centimeters [CE13] [Ge18]. The name of these fish is derived from the horizontal stripes that run along the sides the of zebrafish's body [Bur16]. Due to the many valuable characteristics these fish have, they are commonly used for scientific research. They make useful model organisms for studying the development of vertebrates [NIH22]. These fish have many genes that have the same or similar functions as genes found in humans. This means that these fish can be used to study human diseases caused by genetics. Moreover, zebrafish are used as model organisms for studying developmental genetics [Ge18]. By using zebrafish as model organisms, it is possible to gain more knowledge in the function of certain genes in humans, in how certain genes contribute to the development of humans, and in human diseases and treatments. However, having similar genetics is not the only reason why zebrafish are useful to model organisms for scientific research. Zebrafish have a short generation time and can produce hundreds of offspring per week. Furthermore, zebrafish are easy to maintain and cheap to work with. Another interesting characteristic of zebrafish is that the fertilization and development of their eggs occurs externally and that zebrafish embryos are transparent. This makes it easier for researchers to study early development [Bur16] [NIH22] [SZ12].

Zebrafish have multiple different organs and body parts. Anatomy can be grouped together in an ontology. An ontology is a way to give a clear overview of the relationship between entities. In this case, an ontology gives an overview of how anatomical parts of a zebrafish are related to each other. For example, the yolk and the hatching gland of a zebrafish embryo are both parts of the embryonic tissue.

## 1.2 Virtual Reality Visualization

Virtual Reality (VR) is a computer-generated three-dimensional (3D) environment that allows users to explore and interact with the surroundings in the virtual environment by using a Virtual Reality headset (and controllers) [She22]. Virtual Reality can be used for many purposes, from marketing to educational purposes. By using VR in marketing, you can give users an immersive experience with your brand and highlight the benefits of your product [SP18] [She22].

For this research, the focus mainly lies on the possible educational value of using VR. Earlier studies have shown that Virtual Reality can have different benefits in the field of education. It seems that using VR can motivate students to study and learn new material [LB20] [TCT22] [PM18]. Moreover, VR can provide a simulated controlled learning environment. This allows students to engage in activities and experiences that may not be possible or safe in the physical world. Through VR, students can practice complex procedures without the risk of injury, damage, or the need for animal sacrifices. Usually, practical assignments such as performing cadaveric dissection are mandatory. VR provides an ecologically friendly approach to dissection, due to the limited availability of real-life cadavers and their disposable use. Additionally, VR provides a personalized learning experience. Students can learn at their own pace and tailor their learning experience to their own interests and needs. This could potentially allow students to engage with the material in a way that leads to a

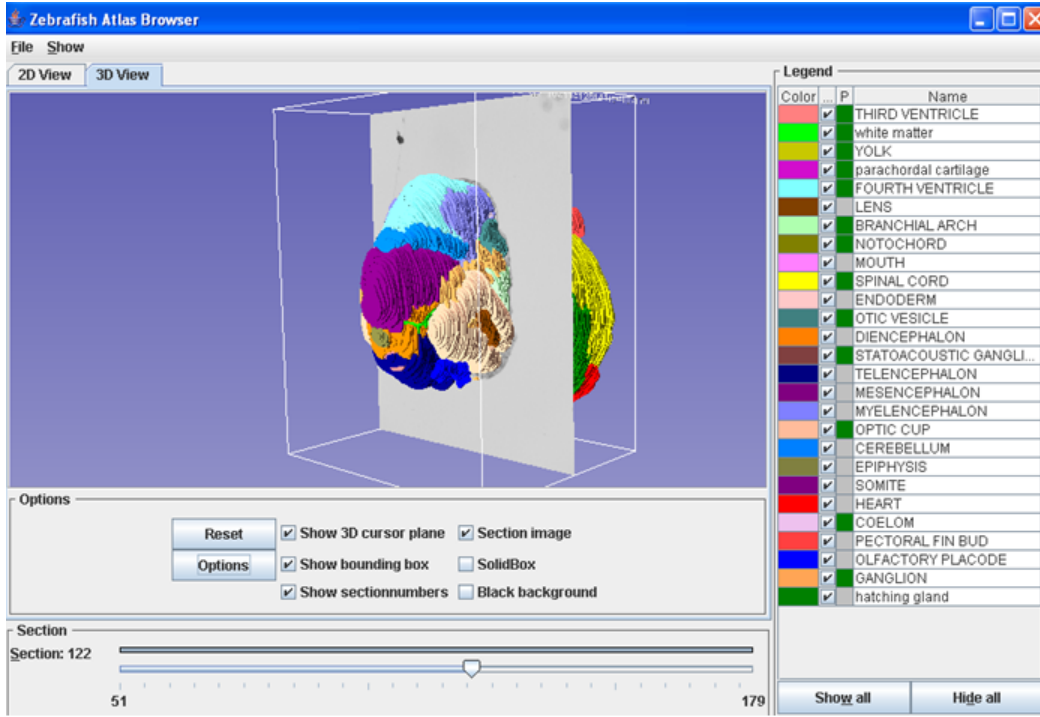


Figure 1: Visualization of a 3D 45-hours-old zebrafish embryo model in Atlas Browser

better understanding of the subject matter.

### 1.3 Related Work and Motivation

An understanding of human anatomy is essential in medical careers. It helps healthcare professionals in diagnosing and treating medical conditions and diseases [Tur07] [STGA15]. Furthermore, anatomy helps researchers and healthcare professionals to understand how different parts and organs of organisms function. Knowledge about the different systems and organs in a living organism's body allows for a better understanding of how these organs work together to carry out essential functions. Therefore, it is important that anatomy is studied carefully so that a proper understanding of an organism's body gets formed. Zebrafish make an ideal model for molecular and genetic research, due to their well-characterized genomic features and suitability for experimental manipulation. 2D and 3D visualizations of different stages of zebrafish have been made. With the use of a 3D reconstruction program called TDR-3dbase, 3D models from a series of aligned section images by drawing contours of structures can be generated [IaLc]. This program can also display the section images and give a 2D or 3D visualization of the input. Moreover, people from the Imaging and Bioinformatics Group at Leiden Institute of Advanced Computer Science (LIACS) created a 3D atlas of zebrafish development [IaLb]. Figure 1 shows a 3D visualization of a model of a 48-hours-old zebrafish.

In earlier studies, 3D models of zebrafish were displayed on a 2D screen. One drawback of this 2D visualization is the challenge encountered by individuals in accurately perceiving the depth and spatial relations of the different parts of the organism. Moreover, some anatomical parts can be

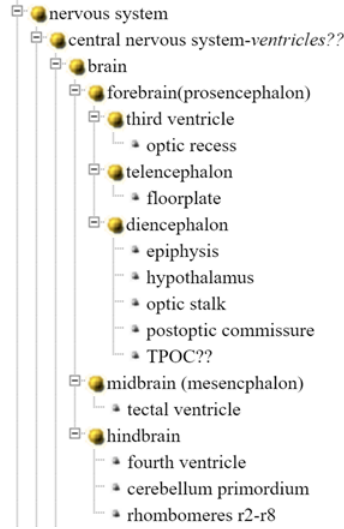


Figure 2: Part of an ontology visualization of a zebrafish's nervous system (Bio-imaging LIACS) [LaLa].

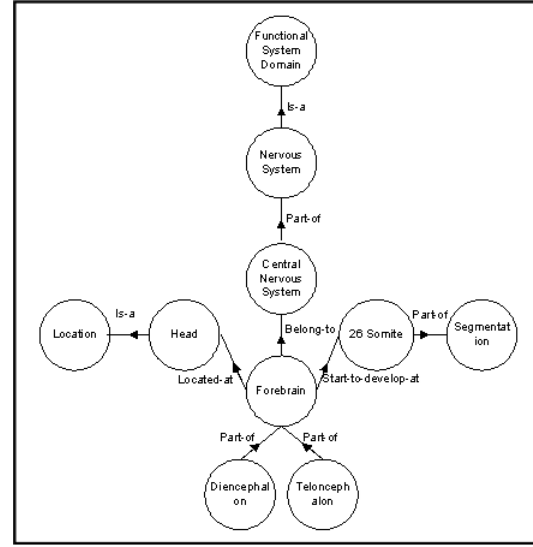


Figure 3: Example image of zebrafish ontology. Belmamoune & Verbeek 2007

difficult to see or can be hidden as a result of the projection on a 2D screen. For this research, a 3D model of a 48-hours-old zebrafish (zf1848) has been visualized in Virtual Reality. VR allows users to interact with their environment, and it also allows for 3D visualization in an actual 3D space. This can provide a more immersive experience and a more intuitive way of interacting with the environment. Therefore, this research investigates the effectiveness of VR in visualizing and studying zebrafish anatomy.

Other work about Anatomy in VR reality exists. A software was developed by S.G. Izard, J.A. Juanes Méndez, and P.R. Palomera for studying human anatomy. They created an interactive Virtual Reality that can be used to study the human skull and tried to illustrate its teaching potential [IMP17]. S. Chen Et Al., have conducted research to compare using VR as a teaching method for anatomy of a human skull, with other traditional teaching methods [CZA20]. Both researches focus on the educational benefits VR can have on studying anatomy. However, both studies do not contain ontology visualization.

There exist tools to view zebrafish anatomy ontology, such as images (figure 2) and 2D digital visualizations (figure 3) where the relations between different parts of a zebrafish are shown. As far as literature goes, 3D visualizations of ontologies in an actual 3D space do not seem to exist. Therefore, this Virtual Reality has been created that visualizes zebrafish anatomy ontology.

## 1.4 Goal and Research Questions

This research aims to investigate the impact of virtual reality games on the study of zebrafish anatomy and evaluate the efficacy of visualization techniques employed for ontology visualization. This led to the following two research questions:

1. **How can Virtual Reality effectively be used to visualize an anatomy ontology and study it?**
2. **What influence do Virtual Reality games have on studying anatomy of organisms or parts of organisms?**

## 1.5 Thesis overview

This bachelor thesis researches how zebrafish ontology can be visualized in an effective way by using VR, and what the effect is of playing VR games to study zebrafish anatomy. This research is done under the supervision of Prof. Dr. Ir. F.J. Verbeek, and Feibo Duan MSc. In order to investigate the effectiveness of VR in visualizing and studying zebrafish anatomy, the VR program has been split into two parts. One part of the program shows an ontology visualization of zebrafish anatomy. The other part contains three different games that can be used to study zebrafish anatomy. Since the bachelor thesis is made by two people, the implementation of the VR program was split in two as well. Both students cooperated on each topic of the program. However, in the later stages of the development, Yanna primarily focused on ontology visualization and implementation while in the meantime Nikki mainly focused on the game aspect of the program.

In this thesis, the materials that were used to create the Virtual Reality program, are discussed first (section 2). This section gives more information on the used hardware and software, packages, 3D model, and data. After that, the design of the ontology visualization, the quiz, the scavenger hunt, the puzzle games, and the technical controls are explained (section 3) leading to their implementations explained in section 4. In section 5 the user analysis and evaluations of the research are deliberated, alongside the usability requirements for evaluating the program and for answering the research questions. The results that were obtained from conducting user evaluations are discussed in section 6. Conclusions are drawn from the results in section 7. At the end of this thesis (section 7.10), possible future developments are mentioned and elaborated upon.

## 2 Materials

This research required a couple of essential materials. A Virtual Reality hardware set was needed in order to test and utilize the program made for this research. Furthermore, a real-time development platform was used to build the program. Moreover, anatomy 3D objects need to be available for the visualization of anatomical hierarchies. Lastly, a data set is necessary that includes the ontology information of the same anatomical parts that the 3D objects represent. This section will discuss the specific materials that were used for this research.

### 2.1 Hardware and Software

The HTC VIVE Pro VR gear was used for this research. This kit contained a VR headset, two controllers, a battery, a wireless adapter, and two base stations. For the program to cooperate with the VIVE set, the PC needed to meet specific system requirements. These requirements are shown in the table in figure 4 [corb].

Component	Recommended system requirements	Minimum system requirements
<b>Processor</b>	Intel Core i5-4590/AMD FX 8350 equivalent or better	Intel Core i5-4590/AMD FX 8350 equivalent or better
<b>GPU</b>	NVIDIA GeForce GTX 1060, AMD Radeon RX 480 equivalent or better	NVIDIA GeForce GTX 970, AMD Radeon R9 290 equivalent or better
<b>Memory</b>	4 GB RAM or more	4 GB RAM or more
<b>Video output</b>	HDMI 1.4, DisplayPort 1.2 or newer	HDMI 1.4, DisplayPort 1.2 or newer
<b>USB port</b>	1x USB 2.0 or newer	1x USB 2.0 or newer
<b>Operating system</b>	Windows 7 SP1, Windows 8.1 or later, Windows 10	Windows 7 SP1, Windows 8.1 or later, Windows 10

Figure 4: PC system requirements necessary to operate VIVE technologies [cora]

For the VR tools to work properly, a set-up of the playing area had to be created. It was advised to place the two base stations diagonally with a height of two meters and a maximum distance of five meters between both base stations [cora]. However, for this research, the advised setup was slightly modified to make it suitable for the room that it was held in. The two base stations control the playing field and needed to be placed optimally to get the best view of the player. Each base station was placed about one and a half meters above the ground. The two base stations were positioned diagonally across each other with a distance of approximately seven meters between them. The base stations have a degree field of view of 120 degrees. For an optimal result, the angles of the base stations were adjusted to let them face the desired playing area.

Moreover, the VR devices need to be connected to the PC on which the VR program is executed. This connection is regulated by the SteamVR software that was installed on the PC.



## 2.2 Packages

To use the SteamVR connection of the PC in the Unity program, the SteamVR package was used, imported from the Unity Asset Store [Sto]. This package included some necessary functions to acquire the VR information in Unity in order to make the VR system accessible in the program. It also contained a few standard interaction scripts to apply the inputs coming from the controllers and the headset in the VR environment.

Furthermore, the Newtonsoft Json package was used to retrieve the data information from a Json file and make it compatible with unity [par17].

Lastly, TextMeshPro is used to display text in the UI [Doc21].

## 2.3 Object Files

This research used a visualization of the anatomical structures of a 48-hours-old zebrafish embryo. Therefore, objects were obtained that constructed the anatomy of this embryo. These models were all stored in an OBJ format. In total, 35 anatomical parts pertained to an object file. The attained parts are listed below:

- |                                     |                            |                             |
|-------------------------------------|----------------------------|-----------------------------|
| 1. yolk                             | 12. pectoral fin bud       | 24. hatching gland          |
| 2. yolk extension                   | 13. otic vesicle           | 25. fourth ventricle        |
| 3. white matter                     | 14. optic nerve            | 26. epiphysis (epithalamus) |
| 4. vein                             | 15. optic cup              | 27. endoderm                |
| 5. third ventricle                  | 16. olfactory placode      | 28. ectoderm                |
| 6. telencephalon                    | 17. notochord              | 29. dorsal fin              |
| 7. statoacoustic ganglion           | 18. myelencephalon         | 30. dorsal aorta            |
| 8. spinal cord                      | 19. mouth                  | 31. diencephalon            |
| 9. somite                           | 20. mesencephalon          | 32. coelom                  |
| 10. prechordal cartilage            | 21. lens                   | 33. cerebellum              |
| 11. precartilage of pectoral girdle | 22. lateral line neuromast | 34. branchial arch          |
|                                     | 23. heart                  | 35. axial vein              |

The information of these object files was stored in an XML file. To obtain the object file for each part, an XML file was used that links every separate part of the zebrafish to its corresponding PNG files. Each part is made out of layers of images. By uploading this XML file to TDR, it was possible to export OBJ files that could be imported into Unity. However, the contours of some parts consisted of tiny overlaps. This caused a systematical error when the program was trying to build a 3D reconstruction for these parts. Therefore, the contours of each of the parts that caused this error had to be adjusted manually within this application. New contours were drawn carefully,

to make sure that no intersections were present. Subsequently, these contours were saved in the XML file by overwriting the intersecting contours. After doing so, the 3D reconstruction of the entire embryo could be acquired.

The color of the objects was defined in the XML file as well, however, Unity is unable to read these color definitions. In Unity, an additional file is necessary alongside an OBJ file that describes how a program should apply textures and colors to that object. Therefore, a Python code created by Feibo Duan(Msc) was used that creates an MTL file from the XML file. This file satisfies the requirements needed for Unity to process the color information.

## 2.4 Data

A MySQL database was used to attain the necessary ontology information, mentioned in the table “zf\_anat\_terms\_rel”. To acquire the ontology information within this database, a query was written that selected the names of the parents and the children within this table. A new table was created containing this information. The coded query is presented in the appendix section 1. The derived table was converted to a JSON file to make the data accessible in Unity. This data set consisted of the information of a fully developed zebrafish. Hence, including more anatomical parts than an embryo in stage 48h. To guarantee that the data set contained only the parts that an object file is available of, the data set had to be filtered during the preprocessing phase. In addition, the names of the 3D objects differed from their equivalent part mentioned in the data set. This had to be adjusted during the preprocessing stage as well, in order to make sure that the object files could be linked to their corresponding part in the ontology.

## 2.5 Preprocessing

The JSON data set obtained from the MySQL database had to be modified to make it compatible with the zebrafish embryo objects. Firstly, all 35 objects had to exist in the ontology data set as an entity. Two holdbacks were introduced when utilizing this data set for the 3D model of the zebrafish embryo in stage 48h. The first problem concerned the dissimilarity between the names of the parts in the 3D model and the entities in the ontology. Some anatomical parts had an existing entity in the ontology but were named differently. Therefore, these parts could not be linked to their corresponding entity without any preprocessing beforehand. To solve this problem, the names of these objects were changed manually to the way they were defined within the ontology data set such that they would match their entity. In addition, other anatomical parts were not present in the ontology. These parts were added as a new entity to the ontology, in a way that it was related to an already existing entity. All the implemented adjustments are listed in table 1.

The second complication that arose from the data set, was related to the difference between the size of the data set and the number of anatomical objects. Originally, the data set contained 1090 unique entities, while only 35 entities corresponded to a game object. Consequently, not all entities that were included in the data set were needed since they did not appear in the involved zebrafish model. The required entities were selected solely on whether they were related to one of the 35 objects or another entity that was somehow related to them. A Python code was implemented to read and filter the JSON data set, mentioned in the appendix 2, to discard all parts that did not

have an available OBJ file or did not have any relations to a part with an OBJ file. An overview of these steps is given in figure 5.

Original Object Name	Object Name Adjustment	Ontology Adjustment
yolk	-	yolk->extra embryonic tissue
yolk extension	-	yolk extension ->yolk
white matter	brain	-
vein	-	-
third ventricle	-	-
telencephalon	forebrain	-
statoacoustic ganglion	statoacoustic (VIII) ganglion	-
spinal cord	-	-
somite	-	-
prechordal cartilage	prechordal plate	-
precartilage of pectoral girdle	pectoral fin	-
pectoral fin bud	-	-
otic vesicle	otic placode	-
optic nerve	eye	-
optic cup	-	optic cup->eye
olfactory placode	-	olfactory placode->vestibuloauditory system
notochord	axial mesoderm	-
myelencephalon	rhombomere	-
mouth	-	-
mesencephalon	midbrain	-
lens	-	lens->optic cup
lateral line neuromast	lateral line system	anterior lateral line system->lateral line system posterior lateral line system->lateral line sustem
heart	-	-
hatching gland	-	hatching gland->extra embryonic tissue
fourth ventricle	-	-
epiphysis	-	-
endoderm	-	-
ectoderm	-	-
dorsal fin	-	dorsal fin skeleton->dorsal fin
dorsal aorta	-	-
diencephalon	-	-
coelom	-	coelom->mesoderm
cerebellum	-	-
branchial arch	pharyngeal arch	-
axial vein	-	axial vein->vein

Table 1: All adjustments made to the object files and the ontology data set. The first column lists all the anatomical parts by their original name. The second column indicates the name to which the part was adjusted. The third column specifies the ontology relation that was added to the data file. The arrow (->) means that the left-hand side is part of the right-hand side. A dash (-) indicates that no changes were made.

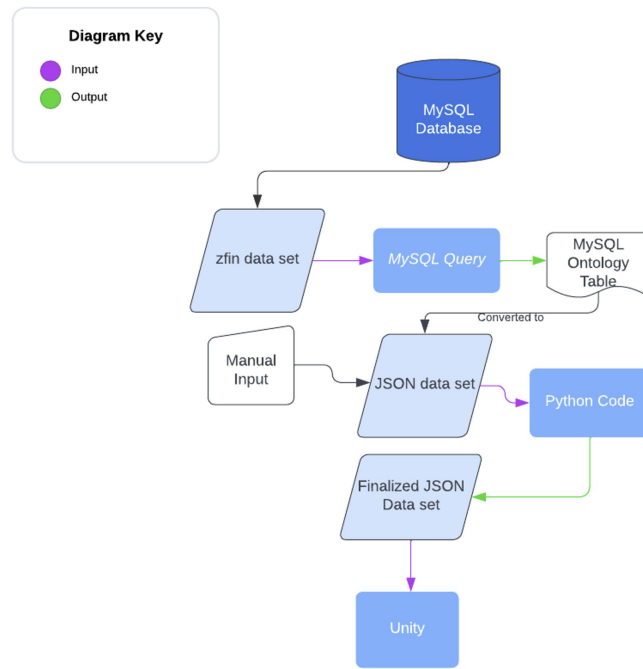


Figure 5: Flowchart of the preprocessing steps that the ontology data file undertook. The zfin data set was imported from the MySQL Database and adjusted by several queries. The output table was then converted to a JSON data file and imported into Python to filter the data set to get the desired information.



## 3 Design

It is important that the user understands the intentions implemented in the program. Several design choices are employed to facilitate the user’s comprehension of the underlying intentions. Both research questions require unique design strategies to achieve their objectives. These employed design methods are deliberated in the first two subsections. In general, all scenes make use of the same standard VR controls alongside additional controls tailored exclusively for the specific requirements of that particular scene. The thoughts behind these technological controls are explained in the last subsection.

### 3.1 Ontology Visualization

In order to answer the first research question on how VR can be used to effectively study anatomy, it is imperative to present anatomical information in a visually interpretable manner. To try to achieve this objective, an ontology is utilized to provide a clear depiction of the anatomical hierarchies. Anatomical ontologies are used to describe and classify the structure of living organisms in a consistent and standardized way. The data set used for this exclusively comprised information pertaining to entities that shared the relation “is part of”, which indicates that one entity is a component of the other. Besides giving an informative overview, the main function of the ontology is to find out where certain parts are located in the zebrafish model.

In section 1.3, several already existing works get discussed that illustrate 2D anatomical ontologies. Figure 2 gives an example of a coherent ontology in a 2D visualization where each entity is presented by its full name. However, in 3D spaces, using text meshes to present entities can lead to multiple problems. The size constraint of a text is crucial, as excessive length can lead to undesirable overlap between entities, making it harder to distinguish one from the other. When the font size gets too small on the other hand, the legibility of texts in a VR space can be significantly compromised, making it harder for the user to read. As a solution, entities in the ontology visualization for this research got depicted by spherical objects. To prevent overlapping text, the name of an entity only appears when you point towards it with the right VR controller.

Furthermore, the 2D ontology in figure 2 starts off at the root, where the terms are shown that do not have a parent entity. For each new layer in the ontology, tabs are used to clarify which entities belong to the same layer. All entities that share the same parent are directly connected with each other by a line that is coming from the parent object. This ontology representation can get long as a consequence of the sequential listing of entities beneath each other. On a 2D screen, this may not interfere with the user experience since it is possible to scroll through the ontology. In a 3D VR environment, however, scrolling through the ontology can go less efficiently due to the delayed and uncontrollable responses of a VR controller. This is partly due to the fact that you need to steady your hands while using the controllers, and the given inputs need time to be processed.

Placing the entities in segments beneath each other leads to another problem in 3D spaces. When the data set contains a lot of information, the ontology gets too big which only augments the problem that certain entities will not be easily reachable. Therefore, for the 3D ontology in this research, an alternative way to visualize ontology anatomy was composed. To try to make each entity easily reachable with the VR controllers from one position, the entities are oriented in circles. This method makes sure that there are no entities located in corners that have a greater distance to the middle point of the ontology than others. All entities in the same circle have the same distance

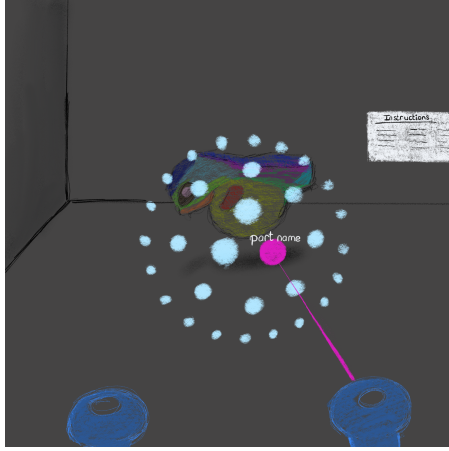


Figure 6: Entity object lights up with a fluorescent fuchsia color when it is hit by the laser pointer.) [IaLa].

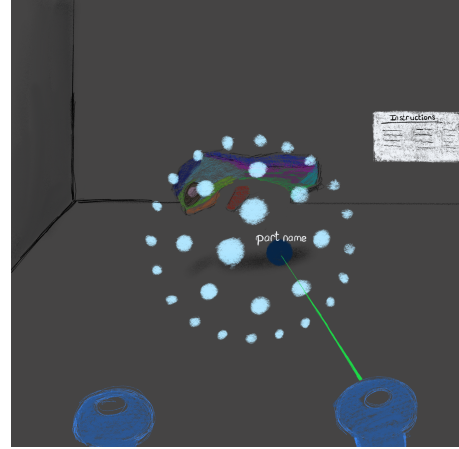


Figure 7: Entity object becomes dark blue when its corresponding anatomical part has been turned off.

to the middle point of the ontology. The number of required depends on how many entities are displayed simultaneously. Unlike in figure 2, not all entities are displayed at once. The visualization of the ontology starts with the root. This shows all entity objects that are not a component of any other objects. In order to see another layer in the ontology, the user needs to interact with it. When they selected an entity, all objects that were on the same layer as this entity disappear and a new layer shows up. This new layer includes all child objects that were a part of this selected entity. Furthermore, the scale of an entity is contingent upon the circle in which it is located. As the distance between an entity and the outermost circle increases, the size of the entity diminishes. This makes it possible to fit more entities in the ontology to make this visualization also compatible with bigger data sets. However, it reduces the ease of finding a specific entity. Therefore, scrolling is possible, which rotates the circles and moves each entity one step aside.

Besides design ideas that were inspired by web-based designs, some additional features were included to enhance the VR experience. Color coding was used to indicate different meanings. All entities are light blue if they are visible in the ontology. An entity is highlighted in pink when the user points at it. This is the same pink color as the laser pointer, to indicate the correlation between the pointing action and its result. When pointing at an entity, the corresponding parts in the anatomical model can be turned on or off. Toggling it off, changes the color of the entity to dark blue, to specify that its parts have been disabled and are currently not visible in the anatomy model. Toggling it back on switches the color back to light blue and enables the corresponding anatomical parts. In figure 6 and 7 an illustration is given of the aforementioned color design choices. Furthermore, instruction boards are placed in the environment. By adapting this approach, users are able to read information regarding the controls or current scene when they need to.

## 3.2 Game Interface

The second part of this thesis focuses on the creation of three games that can be used to study zebrafish anatomy. A quiz game, a scavenger hunt, and a puzzle were created. The design and controls for all the scenes were kept as consistent as possible. By striving for optimal consistency, it is aimed to enhance users' navigational experience and facilitate interaction with their virtual surroundings.

### 3.2.1 The Quiz Game

Multiple design choices were implemented for the quiz game. The idea of the quiz was to create a 3D user interface (3D UI) that enabled users to interactively answer multiple-choice questions about the names of different zebrafish parts by getting to choose between four different options for each question. The design choice of using multiple choice questions for the quiz was made to allow for quick testing and practice of recalling information from memory. The 3D UI also displayed the user's current question number and score, which could potentially motivate a user to improve their anatomy knowledge by wanting to increase their score.

Moreover, color-coding was used for the design of the quiz. Next to the 3D UI, a 3D zebrafish model was placed. The colors of the objects in this model were set to gray. However, the color of one randomly chosen part got set to bright green for which the user had to assign the correct name. When a new question got asked, a new part got randomly chosen to light up in bright green. Another color-coding decision that was made was to clearly indicate which object a user has pointed at. This was done by letting the gray parts light up with bright purple when the user pointed at them. Since some parts of the zebrafish model could be (partially) hidden behind other parts, users were enabled to delete objects from the model.

To indicate whether a user selected the correct answer, a correct or incorrect screen gets displayed. On these screens, the correct answer gets shown and the obtained points for answering that question. Each correct answer adds 3 points to the user's score, while each incorrect answer subtracts 1 point from the score.

Figure 8 shows an example of how the quiz works. The first image (figure 8.1) shows that when a user points at a part in the model, the color of that part turns purple. In 8.2 the user has clicked on the object they were pointing at, to delete that part. A similar occurrence is illustrated in figure 8.3 and figure 8.4 with a different zebrafish part. Figure 8.5 and figure 8.6 show that the user interacts with the 3D UI to select an answer.



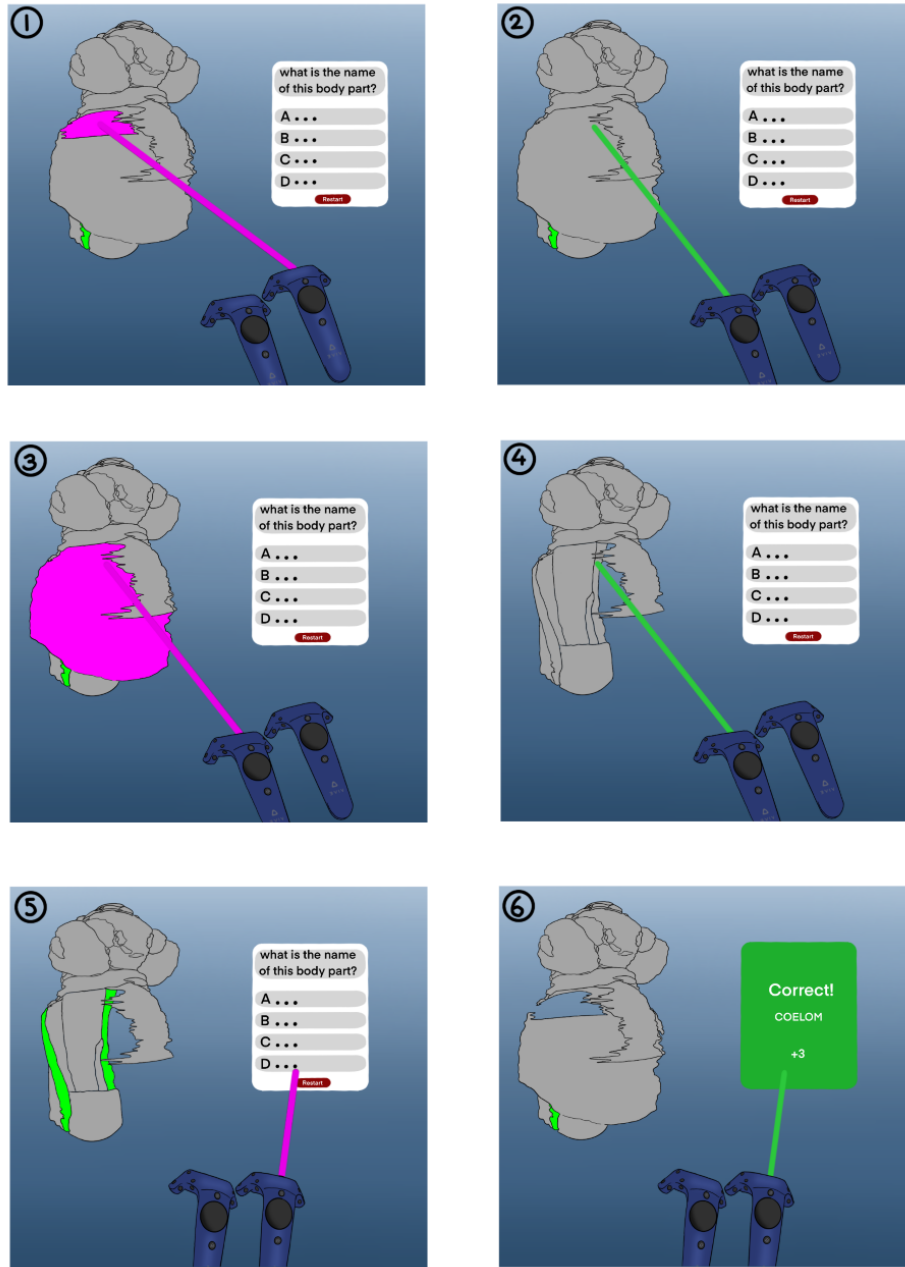


Figure 8: Design sketch of the implemented quiz game. The sketch also shows the interaction between the user’s right controller and the game elements. The goal of the quiz is to assign the correct name to the green part of the zebrafish model. An object in the model lights up in bright purple when a user points at it, and users can delete objects from the model by clicking on them. Users can interact with the 3D UI by clicking on answers.

### 3.2.2 The Scavenger Hunt Game

During the scavenger hunt, the name of an anatomical part was displayed on a 3D UI screen. This screen also displayed the current question number and the user’s score. The goal was for the user to

find the corresponding part in the zebrafish model located next to the screen. Since certain parts could be hidden behind other parts, users were able to delete parts of the model in the same way as during the quiz game (section 3.2.1). When the user pointed at a part, it would light up in bright purple. They could then choose to delete the part or select it as their answer to the question. Again, to indicate whether a user selected the correct answer, a correct or incorrect screen gets displayed.

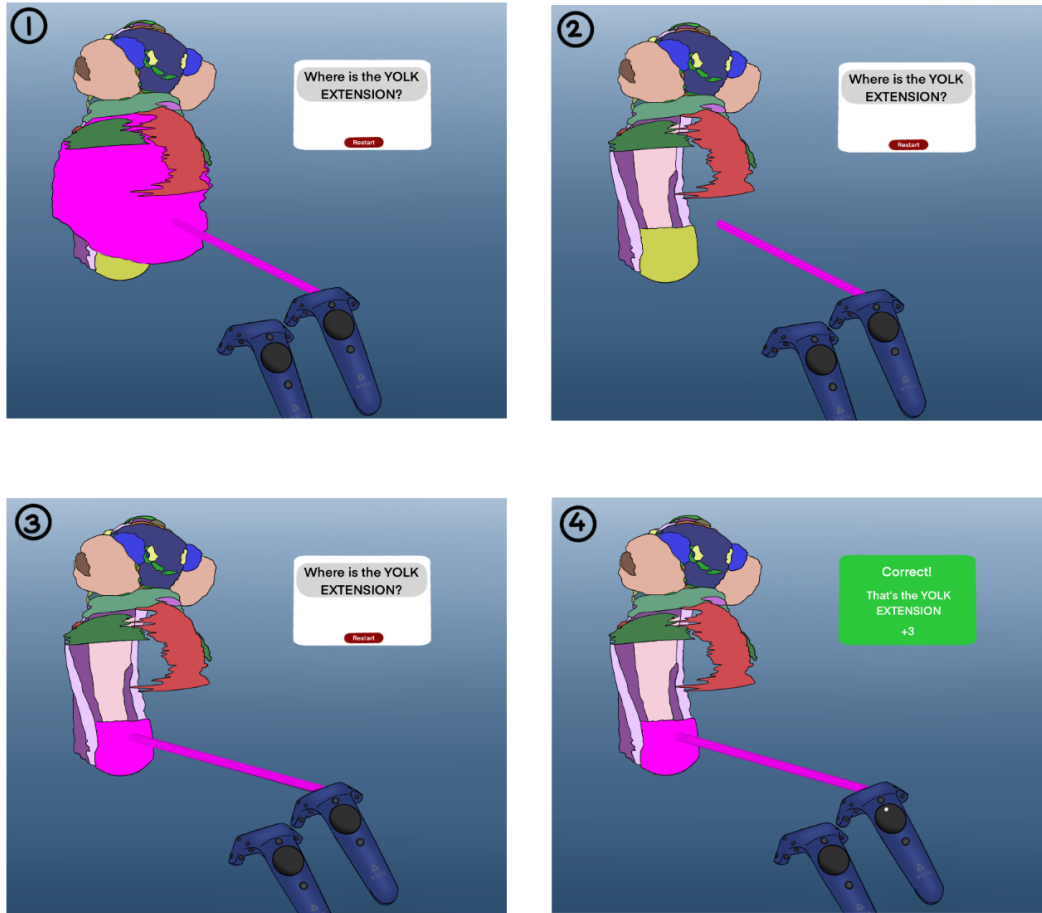


Figure 9: Design sketch of the implemented scavenger hunt game. The sketch also shows the interaction between the user's right controller and the game elements. The goal of the scavenger hunt is to find the part of the zebrafish that is being displayed on the 3D UI. An object of the model lights up in bright purple when a user points at it. Subsequently, users have the option to either delete the mentioned part or select it as their chosen answer.

In figure 9 an example is given of the scavenger hunt. Figure 9.1 and figure 9.2 show that users can delete objects in the zebrafish model. Figure 9.3 and figure 9.4 show that a user can select an answer in the zebrafish model.

### 3.2.3 The Puzzle Game

The puzzle game allowed the user to study the anatomical parts of an organism in a visual and interactive way by completing a puzzle. Contrary to the other games, a puzzle could help users develop spatial awareness and visualization skills, which could be useful for understanding and remembering the relationships between different anatomical parts. The puzzle was presented by a silhouette of the zebrafish model, this gave basic guidelines of where a piece belonged. When a puzzle piece had been picked up, a small text appeared that indicated which piece the user was holding. To maintain consistency between all the scenes, the color of the puzzle objects became bright purple when the user pointed at them. Analogously, this effect applies when pointing at parts in the silhouette.

Figure 10 gives an example of the puzzle. In figure 10.2 a user points at a zebrafish part and decides to pick it up. Figure 10.3 and figure 10.4 show that the user places the “yolk extension” in the correct location of the zebrafish silhouette.

## 3.3 Technical Design

The functional design aspects are based on the standard controller layout that has been used by bigger game branches such as Nintendo, Playstation or Xbox. Generally, the left hand operates orientation actions such as moving the playable character or editing the camera view. The right hand is required for executing more precise tasks such as item acquisition. Moreover, according to Fitt’s law, the time to perform an action caused by a certain target depends on the distance to this target and the size of the target. For this reason, the thumb and index finger are primarily used to perform the actions with the gamepads, because these fingers are within reach of the buttons on the controller. The other fingers are limited in their options and are mostly used to hold the gamepad in a comfortable way [Dot17].

To gain familiarity with the controls, the functional design for the VR program adhered to the standard layout scheme. The user has access to two VR controllers. The left controller is solely designated for navigating within the VR environment, while the right controller can be used to perform actions. In each scene, it is made possible to walk around by hovering over the left trackpad, with the left thumb. If the user presses the trackpad, the sprinting option is enabled, and the player moves faster. The right controller has two main buttons that can be used. Firstly, the trigger button is especially used to perform primary actions that need to be done to complete an assignment, or for interacting with a UI screen. For instance, in the ontology scene, the main assignment is for the user to discover the location of various anatomical parts in the reconstructed model. Therefore, the trigger button is used to toggle anatomy parts on or off when pointing at an entity. In the quiz, the assignment given to the user is to answer the question. The trigger button can be used to complete the assignment by disabling certain parts in the model to get a better view of the highlighted part. In addition, the right answer in the UI screen can be selected with the trigger button. Similar to the puzzle game, operating the trigger button can destroy the targeted anatomical object. There is no UI screen in this scene, therefore a different button should be applied to select the right answer in order to complete the game.

In the puzzle game, the trigger button is used to pick up pieces and place them in the puzzle

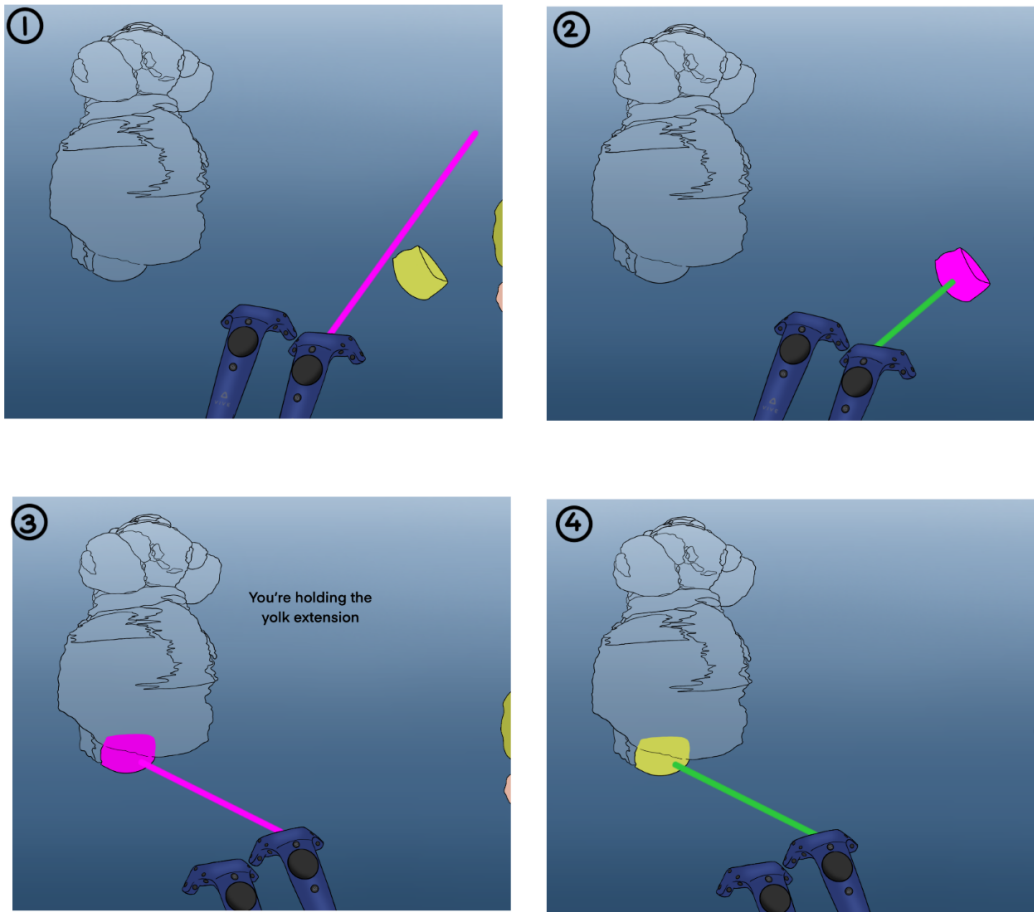


Figure 10: Design sketch of the implemented puzzle game. The sketch also shows the interaction between the user's right controller and the game elements. The goal of the puzzle is to place parts of the zebrafish model in the correct location in the silhouette. A puzzle piece or a part of the silhouette lights up in bright purple when a user points at it. When a piece is being held, the name of that part gets displayed in the 3D space.

silhouette. Lastly, the trigger button is used to select a scene in the menu.

The trackpad is only used in the ontology scene and the scavenger hunt. In the ontology scene, the right-hand trackpad is used to search for entities. When you point towards an entity, you can view its children by pressing on the right side of the trackpad. If you want to see the previous layer again, you press on the left side. Scrolling through the ontology is possible by using the upper and bottom parts of the trackpad. Pressing upwards moves each entity in the ontology layer one place to the right and downwards moves them to the left. In the scavenger hunt, the trackpad is used to answer the question. Since the trigger button is already used to destroy objects, selecting answers should go through a different control. Hence, when the user directs their pointer towards an object, they are required to press the upper part of the trackpad to designate that particular object as their chosen answer.



## 4 Implementation

The design layout deliberated in section 3 was used as a guideline for the implementation of the four specified scenes. Pictures of the ultimate version of the scenes are shown in figures 11 to 14. Additionally, a QR code is added to the appendix that can be scanned to access a video showcasing the final version of the program (figure 23).

The four scenes are each implemented in a separate scene in Unity. For each scene, fundamental game objects have been created that control the functions in the scene. These functions are formulated in scripts that can be added as a component to game objects. Besides scripts that are self-implemented for this research, there exist standard scripts that are created by Unity and scripts that are used from the packages mentioned in section 2. Some scripts incorporate variables that require inputs in order to execute their functions. This section will discuss the important game objects and their components in each scene.

Each scene contains a player game object and a camera rig object. The purpose of these objects is important for all scenes and the implementation remains the same. The player object allows walking around through the game environment. It includes the walking script that is linked to the camera object to keep the player and camera object in sync. The character controller component from the UnityEngine is added to this game object too, to make it possible to perform movement actions without a rigid body. This component needs to be assigned to the controller variable set in the walking component [Doc23].

The camera rig contains the camera object and the controller objects. Therefore, it takes care of the VR camera view and the input of its controllers. The object for the camera rig holds a few components, two of which are self-implemented. The script *move camera* makes sure that the camera aligns with the player object, and that it moves through the environment as a consequence of the walking action. The second self-implemented script in this game object is *Go To Menu* and manages the action to return to the menu screen during the game. The other scripts are conducted from the SteamVR package. The SteamVRPlayArea component monitors the playing field that had been calibrated. The camera rig contains the game object for the right and left-hand controllers. These objects are in charge of the inputs that are given by the user through the VR controllers. The script for the laser pointer is attached to the right controller. When the laser pointer is aimed at certain objects, the material of these objects gets changed in order to change their appearance. A brief overview of the important functionalities in each scene is given in the appendix in figures 24, 25, 26, and 27. Other game objects are specifically created for their corresponding scene and are discussed in more detail in the upcoming subsections.

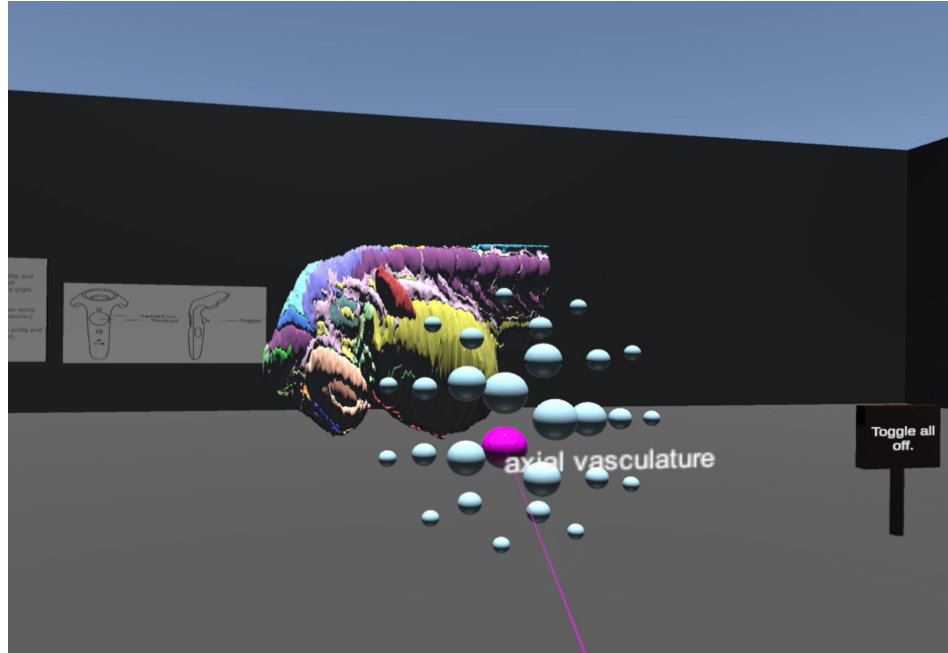


Figure 11: Screenshot that is taken from the Ontology Scene in the final VR implementation. The ontology visualization is shown in the middle. Each sphere represents one anatomical part. The zebrafish embryo model can be seen behind the ontology. The pink laser pointer indicates the direction the user is pointing in, marking a sphere a similar color when pointing at it.

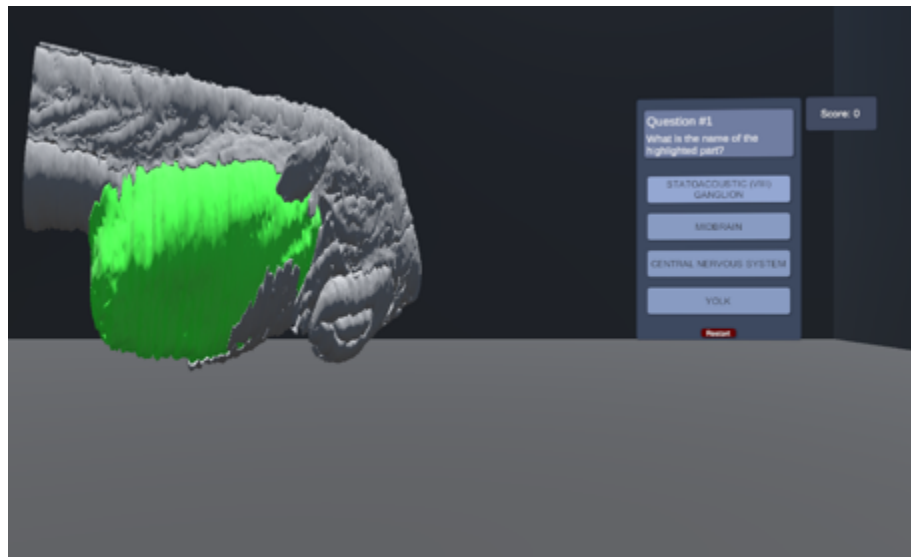


Figure 12: Final version of the quiz game scene. The zebrafish model is shown on the left side of the figure. The user needs to give the name of the anatomical part that is highlighted in green. On the right, the UI screen is placed that displays the multiple-choice answers to the question.

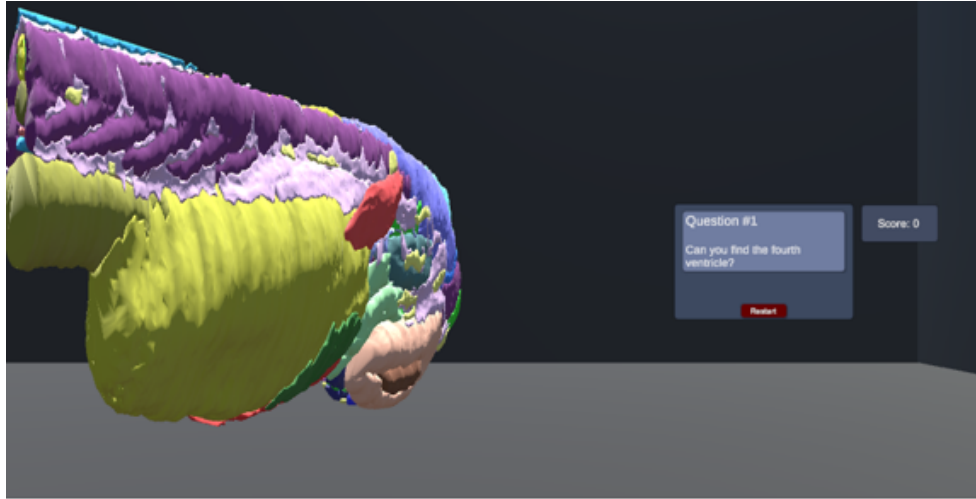


Figure 13: Final version of the scavenger hunt game scene. The anatomical structure of the zebrafish is shown on the left. The question can be seen on the UI screen on the right side of the figure. The user needs to find the anatomical part that is revealed on the UI screen.

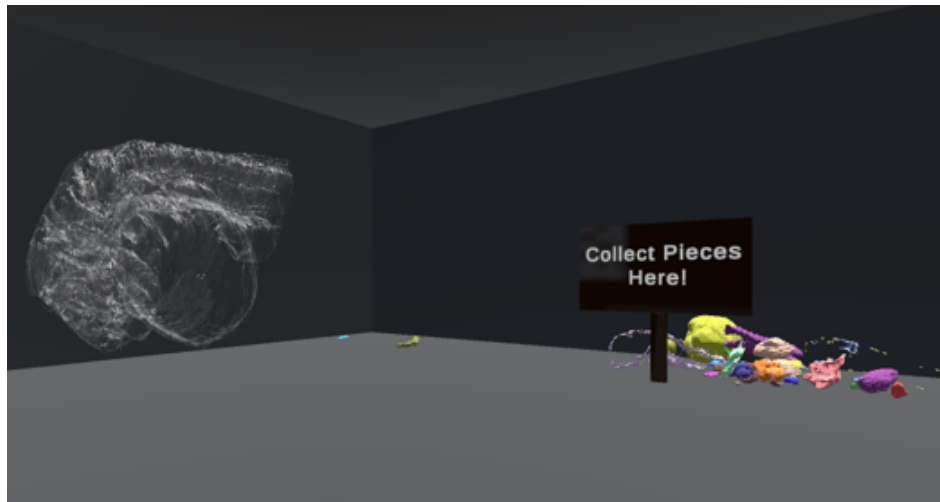


Figure 14: Final version of the puzzle game scene. A silhouette of the zebrafish embryo model can be seen on the left side of the figure. The puzzle pieces lay on the floor on the right side of the figure.



## 4.1 Ontology Implementation

First of all, in the ontology scene (the main scene), there are two important game objects with fundamental components, in addition to the player and camera rig: *Scene Handler* and *Data Handler*. The flowchart illustrated in figure 24, gives an overview of the fundamental parts of the main scene.

Scene Handler handles all the interaction inputs that the computer program retrieves from the user and links them to the consequences of the actions that it leads to. The connection between the action input and its consequences is controlled by the script named *SceneHandler*. This is managed by the variables *laser pointer* and *show ontology*. The LaserPointer script held by the right controller game object is assigned to the laser pointer variable. This component handles the user's actions and keeps track of the direction the user is pointing in. When the pointer is aimed at a certain location, it can unlock actions assigned to the controller. The variable shows ontology handles the interaction with the ontology visualization. When the laser pointer is aimed at an entity object in the ontology, this script enables the possibility to view the next layer in the ontology, as described in section 3. The script ShowOntology is a part of the game object Data Handler. Therefore, this game object needs to be assigned to the corresponding variable of Scene Handler. The other written script that Scene Handler contains is *ToggleAll*. This script simply determines if the user has activated the toggle on/off option and performs the required action.

Data Handler is in charge of structuring the ontology data. Moreover, this object holds the script *VisualizeOntology*, which controls the visualization information for the ontology. The visualization is implemented with the use of a few mathematical functions. As described in section 3 each layer in the ontology consists of multiple circles. The number of circles that need to be generated depends on the number of entities that should be shown. Each generated circle is assigned to an integer ( $n$ ). Each circle has a maximum capacity ( $C$ ) of entities that it can contain. This maximum is determined by a basic exponential function 1.

$$C = 1 + 2^n \quad (1)$$

This function allows moderate growth in capacity for the first few circles but increases rapidly when more layers are added to fit more entities in the ontology.

Furthermore, for each new circle that is needed, the radius ( $r$ ) slightly increases. The radius of each circle is determined by a simple linear function 2. In this function, the radius of the previous circle is multiplied by the circle number of the new circle.

$$r_n = r_{n-1} * n \quad (2)$$

Similar to the capacity, the scale ( $s$ ) of each entity depends on the circle number too. A quotient function was constructed that qualified for the scale calculation 3. Here, a linear function is divided by a quadratic function.

$$s = \frac{n + 1}{n + a * r^2} \quad (3)$$

The coefficient  $a$  is a parameter that determines the speed at which the scale decreases per circle layer, the larger the value, the faster the scale decreases. This function was appropriate to determine the scaling due to its slope starting off decreasing swiftly towards the inflection point. Afterward, it slowly continues to decline toward its horizontal asymptote at the y-axis. This ensures that the scale can never be equal to zero since  $n$  will always be greater than zero.

The circle-oriented visualization design facilitated an easy and straightforward approach. The circles are easily computed with the use of the unit circle theories and polar coordinates. The coordinates of the unique entities are determined by the basic trigonometric functions, and this automatically puts the entities in a circled position. Each entity is given a unique polar coordinate that includes the angle it makes with the positive x-axis and the distance to the center of the circle (the radius). In the created code, the angle of an entity depends on the entity capacity of the circle in which it is located. The formula that was designed for calculating the angle uses a specific integer that each entity has been given. This integer is referred to as the child number ( $i$ ). Using the child number, the angle of each child increases slightly, compared to the child before them. Once the code starts running, each entity object within a circle receives a unique number, between one and the entity capacity of their circle. Hence, each entity is located at a different spot and there are no interceptions.

$$\alpha = i * \frac{2\pi}{C} \quad (4)$$

After the polar coordinates of an entity have been determined, the rectangular coordinates can be computed by the standard trigonometric functions [5](#) [6](#).

$$x_i = S_z + (r * \cos \alpha) \quad (5)$$

$$y_i = S_y + (r * \sin \alpha) \quad (6)$$

The starting position ( $S$ ) that is mentioned in these equations refers to another variable specified in the component VisualizeOntology. This variable requires the coordinates of a game object, to initialize the center of the ontology circles. An empty game object was created and attached to this variable. Consequently, the y and z values of these coordinates were used for the starting position. Furthermore, the shape and material of the entities were declared in VisualizeOntology. Any material file can be used to assign to the entity material variable, and the ontology entity variable accepts all mesh files. Lastly, the zebrafish anatomy objects were assigned to the anatomy objects variable, to let the code access the object files.

## 4.2 Games

The implementation for the games used the same arrangement as in the main scene. Besides the player and camera rig objects, additional objects are constructed that handle other functions specifically for each scene.

The flowchart in figure [25](#) gives a clear overview of all the required game objects in the quiz Scene, and the connections between certain objects. For the quiz Scene, one additional object was set up that controlled the information for the quizzes. It first selects a random object from the anatomical parts with the use of the *RandomGameObjects* script and then displays the name of this object

on the quiz interface screen through *QuizTextControl*. The player's input is processed through the script. Similar to the *SceneHandler* component mentioned in the main scene, *QuizHandler* keeps track of the input mechanisms employed by a user. Therefore, the right-hand controller in the camera rig needs to be attached to the *QuizHandler* component. Subsequently, through laser pointer detection, actions can be executed. There are two types of translations that the input signal can lead to. Selecting an answer when pointing at the UI screen, activates a function in the component *AnswerCheck* that evaluates the given answer. It compares the name of the random game object that got selected, with the name of the answer that was targeted. The second event type is called when the input is signaled while aiming at the anatomy objects, which dissolves the selected object. The scavenger hunt scene applied similar methods as in the quiz Scene. It required one additional game object named *QuizManager*. This object contained a few different functionalities that were specifically built for this game. The Handler component is once again in charge of the input signals coming from the user. First, a random game object is selected that needs to be found during the hunt. The name is then displayed in the UI screen, via the *Hunt* component. When the user has selected an answer, a signal is sent from *Hunt Select* to the Hunt Handler to compare the name of the random object with the selected object. Eventually, *HuntEvaluation* keeps track of the score, and notifies the user about if the given answer was correct.

Lastly, the puzzle scene required a few additional game objects. The Handler game object functioned slightly differently than the handler components in other scenes. Similar to the other scenes, *PuzzleHandler* receives and analyses the input from the VR controllers. However, unlike other scenes, it transmits these inputs to a different component that is held by the right controller object. This component performs the direct actions caused by the input and is assigned to the *piece interaction* variable in *PuzzleHandler*. Moreover, *PuzzleHandler* required instructions on where to place the puzzle pieces. This is determined by another variable that is adjustable in the Unity scene. It receives the location of the inserted empty game object, which is placed at the desired location for the puzzle pieces in the environment. These puzzle pieces are provided with *RigidBody* functionalities, meaning that the gravity forces apply to these objects. Once the scene is loaded, the pieces collapse on the ground, so that the puzzle pieces are no longer in their correct position. During the discharge of the puzzle, a wall is blocking the pieces to keep them near the requested location. This wall is another game object set in the scene, surrounding the game object that the piece location variable got assigned to. The last noticeable variable added to *PuzzleHandler* is another material that is given to the puzzle silhouette mentioned in section [3.2.3](#).

## 5 Methodology

### 5.1 User Analysis

The target user group for this VR program was biology students between the ages of 16 and 35. This group represented students who are pursuing or are likely to pursue higher education in biology or biology-related fields, and who may have some familiarity with technology. The users could be motivated to use the VR program in order to gain a deeper understanding of zebrafish anatomy for coursework or personal interest. This target user group was likely to have some knowledge of biology and may have previously studied zebrafish anatomy. However, the VR program could also be useful for users who are new to zebrafish anatomy.

A potential problem for the mentioned user group could be the fact that they also need to understand how the VR program and its controls work. Therefore, an age range was specified for this user group since most people of the younger generations have grown up with technology. This might result in it being easier for them to learn how certain technology works [Pil21], such as the created VR program. However, if a user is not familiar with technology, they could still learn how the VR program works, but it could take them a little longer to get used to all the controls.

### 5.2 User Evaluations

To evaluate the zebrafish anatomy ontology visualization in VR, 10 people tested the VR program. They had to perform multiple tasks, which can be found in the Appendix (A) figure 29, to let them interact with the ontology and the zebrafish model. Usability attributes were measured based on these tasks while using the VR program. Additionally, they were asked to provide feedback and score the program through a questionnaire. Moreover, they completed the System Usability Scale (SUS) questionnaire [Bro95] to evaluate the usability of the VR program. This questionnaire contained 10 statements that the users had to rank from 1 to 5 based on how much they agreed with the statement (figure 33).

The user evaluations were also conducted to assess the usability of the VR program for studying anatomical parts of zebrafish. The participants were divided into two groups: an experimental group and a control group. Both groups consisted of eight people where four people had a biology background and four people did not have a biology background. Most participants fell in the age range of the target user group. However, two of them were older. The control group was asked to use a website [LaLd] to study zebrafish anatomy, while the experimental group used the created VR program.

The experimental group used the VR program to play three games: a scavenger hunt where they had to find two anatomy parts, a puzzle in which they had to place three zebrafish parts in the correct locations, and a quiz where they had to answer ten multiple choice questions. The questions for the scavenger hunt and quiz were randomly generated. In the puzzle, the user could choose which three parts they wanted to place.

The control group was assigned the task of individually looking at twelve randomly chosen parts. These parts were selected with a simple Python code that randomly printed object names from a list of all the zebrafish model objects. The users in the control group were also asked to select three

parts that they wanted to view. An example can be seen in figure 30.

In summary, both groups got the chance to study twelve random parts of zebrafish anatomy and three parts of their own choosing.

Both groups completed a pre-test and a post-test to assess their knowledge of zebrafish anatomy before and after playing the VR games or using the website. This was done to take prior knowledge of the participants into account. The test for the experimental group consisted of an image of a zebrafish with 35 numbered parts, and they were asked to identify the corresponding parts. The names of all the parts were listed, and the users could fill in the ones that they knew. The control group had a similar test, but the model they viewed on the website only had 33 numbered parts since the model was slightly different. The tasks and the tests for both groups can be found in the Appendix (A: figures 29, 30, 31, and 32).

The experimental group consisted of the same aforementioned participants as during the evaluation for the ontology visualization. However, two of these users did not get to participate in the pre-test and post-test due to problems with the VR hardware or due to time constraints. Moreover, to make sure that the tests of the VR users did not get influenced by the ontology visualization part of the program, the VR participants first had to take the pre-test, then play the VR games, and afterward take the post-test, before getting to experience the ontology visualization part of the program.

Following the results of both tests, a two-sample t-test with  $\alpha = 0.05$  is held. With this significance test, it can be determined if the number of learned anatomical parts is significantly different between both groups. For this test, the following null hypothesis and alternative hypothesis are formulated:

- $H_0 : \mu_1 = \mu_2$
- $H_a : \mu_1 > \mu_2$

Here,  $\mu_1$  refers to the average number of learned parts by the VR group and  $\mu_2$  to the control group.

### 5.3 Usability Specifications

Different usability attributes were established for the usability specification to evaluate the usability of the VR program. Figure 15 shows the usability specification that was set for this research. The following attributes were measured:

- *Learnability*: How easy it is for users to understand different parts of the VR program.
- *Functionality*: How well the VR program functions.
- *Familiarity*: How self-evident it is to go from one scene to another scene in the VR program.
- *Usability*: How easily and efficiently the VR program can be used based on results from the SUS-questionnaire.
- *Satisfaction*: How the users are satisfied with the overall experience.
- *Clarity*: How clear the VR program is for users.

Usability Attributes	Usability Metrics	Metric Unit	Worst Possible Score	Worst Acceptable Score	Target Score	Best Possible Score
<b>Learnability</b>	mastered functions	<i>% of functions learned</i>	0	50	75	100
	time to learn interacting with ontology	<i>seconds</i>	3600	600	180	0
	time to learn interacting with the quiz	<i>seconds</i>	3600	600	180	0
	time to learn interacting with the scav. hunt	<i>seconds</i>	3600	600	180	0
	time to learn interaction with the puzzle	<i>seconds</i>	3600	600	180	0
<b>Functionality</b>	time for the ontology scene to load	<i>seconds</i>	$\infty$	60	5	1
	time for the quiz scene to load	<i>seconds</i>	$\infty$	60	5	1
	time for the scav. hunt scene to load	<i>seconds</i>	$\infty$	60	5	1
	time for the puzzle scene to load	<i>seconds</i>	$\infty$	60	5	1
	how many errors occur during one session	<i># of errors</i>	$\infty$	2	1	0
<b>Familiarity</b>	how many tries to select a scene	<i># pressed buttons</i>	$\infty$	5	2	1
	how many tries to get to the menu	<i># pressed buttons</i>	$\infty$	5	2	1
	predicting actions	<i># tasks user took without help</i>	0	9	12	18
<b>Usability</b>	questionnaire	SUS-score	0	60	70	100
<b>Satisfaction (overall)</b>	questionnaire	<i>score from 1 to 10</i>	1	5.5	7.5	10
<b>Clarity (overall)</b>	questionnaire	<i>score from 1 to 10</i>	1	5.5	7.5	10
<b>Educational Value (overall)</b>	questionnaire	<i>score from 1 to 10</i>	1	5.5	7.5	10
<b>Educational Value (Scavenger Hunt)</b>	questionnaire	<i>score from 1 to 10</i>	1	5.5	7.5	10
<b>Educational Value (Puzzle)</b>	questionnaire	<i>score from 1 to 10</i>	1	5.5	7.5	10
<b>Educational Value (Quiz)</b>	questionnaire	<i>score from 1 to 10</i>	1	5.5	7.5	10
<b>Educational Value (Visualization)</b>	questionnaire	<i>score from 1 to 10</i>	1	5.5	7.5	10

Figure 15: Usability specification with the worst possible scores, the worst acceptable scores, the best possible scores, and the target scores for each usability attribute and metric. The usability metric column shows what was measured (or how it was measured) to evaluate the usability attribute. The metric unit column shows what metric unit was used to measure the usability metric

- *Educational Value*: How well different scenes in the VR program help users learn zebrafish anatomy.

How many functions a user could perform eventually after using the VR program, were counted to measure the learnability of the program. There are a total of 11 functions that could be mastered while using the VR:

- |                                   |  |
|-----------------------------------|--|
| 1. Walking                        | 7. Selecting answers in the quiz       |
| 2. Sprinting                      | 8. Deleting certain parts in the model |
| 3. Going to the menu              | 9. Selecting parts in the model        |
| 4. Scrolling through the ontology | 10. Picking up puzzle pieces           |
| 5. Folding/Unfolding the ontology | 11. Placing puzzle pieces              |
| 6. Toggling zebrafish parts       |  |

Additionally, to assess the learnability, the time it took users to learn interacting with the games and the ontology, was also recorded. This was timed from the moment the users were done reading instructions until the point where users could interact with the environment in these scenes without asking for help or making mistakes. This way, the timing was solely focused on the introduction of unique functions per game, particularly considering that users had to navigate through the environment before encountering the instructional signs.

The functionality was measured by recording the time it took for the different scenes to load after selecting them in the menu. Also, the number of errors that occurred in the VR program during the evaluation was tracked. To evaluate the familiarity of the VR program, the number of tasks (figure 29) a user could perform during the user evaluations without any additional help from an evaluator was counted. For familiarity, the number of tries to go to the menu or select a scene for the first time was also counted. The usability, satisfaction, clarity, and educational value were determined through questionnaire scores.

For every usability attribute, a worst acceptable score and a target score were specified. The worst acceptable scores for usability attributes were set to determine the lowest level of usability for each attribute that is considered acceptable for the program. The target scores that are listed in figure 15, show the goal for the usability of the program for each attribute. Moreover, the worst possible scores, and best possible scores can be seen in this figure.



## 6 Results

As discussed earlier, multiple attributes were recorded to evaluate the VR program and answer the research questions. In this section, the measured results will be discussed.

### 6.1 System Usability Scale

To assess the usability of the program, users were asked to complete a SUS questionnaire. The answers of the participants for every statement are listed in figure 16. Based on these results, the SUS score for each participant was calculated and the average score was taken. This resulted in an average score of approximately 74. The highest possible SUS score is 100, and 74 is above average. For the last statement in the questionnaire (figure 33), the biggest difference between the answers of the respondents occurs. Some of the users did not feel like they needed to learn a lot of things before being able to use the system, while others did. All of the users reported that they found the various functions in the VR were integrated well. The highest SUS score that was obtained from all the respondents was an average score of 82.5, and the lowest score was an average score of 65.

	respondent 1	respondent 2	respondent 3	respondent 4	respondent 5	respondent 6	respondent 7	respondent 8	respondent 9
Statement 1	2	4	4	2	2	4	3	3	4
Statement 2	2	2	2	1	2	2	1	2	3
Statement 3	4	4	4	5	4	3	4	3	4
Statement 4	3	2	3	1	1	3	1	1	2
Statement 5	4	4	5	4	4	4	4	4	4
Statement 6	1	1	1	1	1	2	1	1	1
Statement 7	4	5	5	4	5	4	4	2	5
Statement 8	1	2	2	1	3	2	2	2	2
Statement 9	4	3	3	3	4	3	3	4	4
Statement 10	2	3	4	1	2	3	2	1	1
SUS score	72.5	75	72.5	82.5	75	65	77.5	72.5	80
Average SUS score = 73.75									

Figure 16: Results of the SUS questionnaire for every respondent that used the VR program and filled in the SUS questionnaire. The average SUS score is equal to 73.75 and is highlighted in green. The SUS score for every respondent is highlighted in purple, with 82.5 being the highest obtained SUS score, and 65 being the lowest.

### 6.2 Usability Attributes

Most usability attributes that were set for this research had to be measured while participants performed the user evaluations. The results can be seen in figure 17. The green color indicates that a participant came from a biology background. On the other hand, the blue color indicates that the participant came from a non-biology background. The learnability, functionality, and familiarity were measured. Overall, it can be seen that for learnability, it took users the longest to learn how to interact with the ontology visualization. In section 5.3, it was explained that users could learn a total of 11 functions during using the VR program. Six out of eight participants mastered all the functions by the time they were done using the VR. For familiarity, a large difference was observed in the number of tasks users could accomplish unassisted. The number of reported errors while measuring the functionality of the program, is high (5 errors) for the first evaluation. The loading



time for the various scenes was similar throughout the evaluations (1 - 3 seconds). Moreover, there is a difference between the familiarity of pressing buttons to get to the menu or a different scene for the users.

Usability Attributes	Usability Metrics	Metric Unit	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	Average
Learnability	mastered functions	% of functions learned	82	100	100	100	100	100	100	73	94.3
	time to learn interacting with ontology	seconds	408	31	62	149	173	151	63	102	142.4
	time to learn interacting with the quiz	seconds	83	22	5	25	20	35	21	44	31.9
	time to learn interacting with the scav. hunt	seconds	58	31	40	69	23	94	49	137	62.6
	time to learn interacting with the puzzle	seconds	5	34	35	38	19	7	30	30	24.8
Functionality	time for the ontology scene to load	seconds	2	1	2	2	1	2	2	1	1.6
	time for the quiz scene to load	seconds	2	2	2	1	1	1	3	2	1.8
	time for the scav. hunt scene to load	seconds	3	2	2	2	1	1	2	2	1.9
	time for the puzzle scene to load	seconds	2	2	1	2	1	2	1	1	1.5
	how many errors occur during one session	# of errors	5	1	1	1	0	0	0	0	1.0
Familiarity	how many tries to select a scene	# pressed buttons	1	5	1	3	1	4	1	1	2.1
	how many tries to get to the menu	# pressed buttons	3	1	4	1	1	1	1	2	1.8
	predicting actions	# tasks user took without help	7	12	15	14	12	6	8	4	9.8

Figure 17: Results of the usability attributes measured during the user evaluations. The noticeable worst and best measurements are encircled with red (worst) and blue (best). The blue background color means the user did not have a biology-related background, while the green background color means that the user did have a background in biology. The averages are highlighted in purple. User 1 had a lot of difficulty learning how to interact with the ontology visualization and also experienced a lot of functionality errors while using the VR. User 8 had the most trouble performing tasks on their own without asking for help.

Figure 18 shows the usability requirements that were set, and the average of the corresponding usability attributes that were recorded. This also includes the attributes that were previously discussed above. It can be seen that, for almost every attribute, the average scores were better than the target scores that were aimed for. The average number of tries to select a scene is slightly worse than the target score. The same can be observed for the average educational value for the scavenger hunt obtained from the questionnaire. All of the scores are better than the worst acceptable score.

Usability Attributes	Usability Metrics	Metric Unit	Average Score	Target Score	Worst Possible Score	Worst Acceptable Score	Best Possible Score
Learnability	mastered functions	% of functions learned	94.3	75	0	50	100
	time to learn interacting with ontology	seconds	142.4	180	3600	600	0
	time to learn interacting with the quiz	seconds	31.9	180	3600	600	0
	time to learn interacting with the scav. hunt	seconds	62.6	180	3600	600	0
	time to learn interacting with the puzzle	seconds	24.8	180	3600	600	0
Funtionality	time for the ontology scene to load	seconds	1.6	5	$\infty$	60	1
	time for the quiz scene to load	seconds	1.8	5	$\infty$	60	1
	time for the scav. hunt scene to load	seconds	1.9	5	$\infty$	60	1
	time for the puzzle scene to load	seconds	1.5	5	$\infty$	60	1
	how many errors occur during one session	# of errors	1.0	1	$\infty$	2	0
Familiarity	how many tries to select a scene	# pressed buttons	2.1	2	$\infty$	5	1
	how many tries to get to the menu	# pressed buttons	1.8	2	$\infty$	5	1
	predicting actions	# tasks user took without help	9.8	12	0	9	18
Usability	questionnaire	SUS-score	74	70	0	60	100
Satisfaction (overall)	questionnaire	score from 1 to 10	7.7	7.5	1	5.5	10
Clarity (overall)	questionnaire	score from 1 to 10	8.0	7.5	1	5.5	10
Educational Value (overall)	questionnaire	score from 1 to 10	7.9	7.5	1	5.5	10
Educational Value (Scavenger Hunt)	questionnaire	score from 1 to 10	7.4	7.5	1	5.5	10
Educational Value (Puzzle)	questionnaire	score from 1 to 10	8.1	7.5	1	5.5	10
Educational Value (Quiz)	questionnaire	score from 1 to 10	8.6	7.5	1	5.5	10
Educational Value (Visualization)	questionnaire	score from 1 to 10	8.3	7.5	1	5.5	10

Figure 18: Average results of the measurements of the usability attributes. The target scores, the worst possible scores, the worst acceptable scores, and the best possible scores for each usability attribute and metric are also displayed. The usability metric column shows what was measured (or how it was measured) to evaluate the usability attribute. The metric unit column shows what metric unit was used to measure the usability metric. Almost all of the average scores are better or the same as the target scores that were aimed at. However, the questionnaire score regarding the educational value of the scavenger hunt game lies 0.1 under the target score. Furthermore, the number of tasks a user could perform without help was lower than the target score.

## 6.3 Questionnaire Scores

After performing the user test, every participant was asked to fill in a questionnaire. The questions and responses can be seen in figures 34, 35, 36, and 37. In total, there were ten user testers that tested out the VR program. Nine out of the ten users filled in the questionnaire.

To measure the satisfaction and clarity regarding the VR program, users were asked to rate using the overall VR program and to rate the clarity of the VR program on a scale from 1 to 10. The satisfaction got an average score of approximately 7.7, while the clarity got a score of approximately 8.0 (figure 18). Additionally, participants were asked to rate using the VR program as an educational tool. The educational value of the VR in general obtained an average score of approximately 7.9 (figure 18). The educational value of different aspects of the VR program has also been scored. The scavenger hunt, the puzzle, and the quiz got average scores of around 7.4, 8.1, and 8.6, respectively. The scavenger hunt game scored the lowest on educational value. In figure 35, it can be seen that one of the participants gave the educational value of the scavenger hunt a 4 while the other scores were all a six or above. Moreover, the educational value of the ontology visualization scored 8.3 on average (figure 18).

Questions about the ontology visualization were asked to obtain further insights regarding the ontology visualization scene of the VR (figure 36). All the participants gave at least a sufficient score for how suitable the visualization was for viewing zebrafish ontology. The average score of the suitability of the ontology visualization is 7.7. The average score for how easy it was for the participants to find certain parts within the ontology is 7.8.

Additional questions were asked to assess the influence of using VR games for studying anatomy (figure 37). For every game, the participants were asked to give a score between 1 and 10, to evaluate how well the games helped them remember different parts of the zebrafish. It was also asked how likely it is for the participants to use VR as a study tool for an exam. The given scores vary a lot for the questions that were asked. One of the participants responded with a score of 1 for every question, meaning that they did not feel like they learned anything at all. The answers vary the most for the scavenger hunt and the least for the puzzle.

## 6.4 Questionnaire Open-Response

Multiple open-response questions have been asked through the questionnaire. The questions and the most relevant corresponding answers are listed below.

### 6.4.1 Were there any controls that you did not find intuitive to use during the three games? If yes, which one(s)?

Eight users responded to this specific question. Four out of nine questionnaire respondents reported that there were not any controls that they did not find intuitive. Two respondents expressed difficulties arising from the absence of the hands in the game, leading to challenges in locating specific buttons. Another user reported that it is difficult to understand for someone who has never played games before. However, they also mentioned that the controls were implemented well and that they eventually got used to the controls. Lastly, a user reported that they did not find the

controls for walking around intuitive and that they preferred walking around physically by using their feet.

#### **6.4.2 Do you have any feedback to improve the educational value of the Scavenger Hunt?**

Four respondents provided feedback to improve the educational value of the scavenger hunt game. One mentioned that because they knew nothing beforehand, it was a “big guessing game”. Especially for parts that they needed to guess a lot of different parts for, they would instantly forget which ended up being the correct part. However, they also mentioned that when a person already knows some parts of the zebrafish, the game could be a great tool. This participant did not provide any further feedback.

Another person mentioned that it could be useful to implement a “peek” mechanism in the game. They mention that this could “prevent a user from having to brute-force their way through the game if they get stuck” with the idea that this lessens user frustration and improves the educational value of the game. That same respondent also mentioned rating their memorization progress with a 1 everywhere, since they could not remember any anatomical names after using the program. Additionally, they noted that they do not think this was due to a problem with the program itself. Rather, it had more to do with the names being long and complicated, and them being distracted while using the program due to VR-induced nausea.

#### **6.4.3 Do you have any feedback to improve the educational value of the Puzzle?**

One user reported that some of the puzzle pieces, and the player itself started to fly around during the puzzle game. Another participant mentioned not noticing the indicator that tells the user which part they are holding, and that this should be improved. Someone else suggested sticking the indicator to the controller. Furthermore, it was mentioned that the puzzle worked well, and it was a helpful tool to remember zebrafish parts. Additionally, it was said that the puzzle could serve as a beneficial starting point for students who are not familiar with many anatomical concepts yet. However, it was cautioned that as the zebrafish silhouette is visible, the tool may potentially reveal excessive information over time, when the user has familiarized with the concepts.

#### **6.4.4 Do you have any feedback to improve the educational value of the Quiz?**

A response suggested that having users spell out the name of a highlighted object might be better for memorization, instead of having them choose names from a list of options. Another participant stated that they felt like the quiz helped them memorize parts. However, they state that it might have been the effect of the multiple-choice questions.

#### **6.4.5 Do you have any feedback to improve the visualization?**

Users were asked to provide feedback to improve the ontology visualization. Three participants mentioned that it would be nice to have an image of a zebrafish (embryo) in the scene. This is to get a better idea of what a zebrafish looks like since the 3D model does not exactly look like an actual zebrafish due to different colors, and because the model is abstract. Another respondent suggested

using a visual cue that indicates that a user can go to the next layer in the ontology for a certain part.

Overall, the ontology visualization received positive responses. However, one of the participants mentioned that they were initially confused about what they were looking at when looking at the ontology. Therefore, they mentioned connecting entities in the ontology with lines. There was also a user that mentioned that the names of the parts should be visualized on the entities all the time instead of only when hovering over them.

#### **6.4.6 Do you have any feedback to improve the educational value of the visualization?**

One respondent replied by saying that they think that “learning via a visualization like this is much more fun than learning in a traditional way”. Additionally, they remarked that the different games can be used to learn and then test your progress. Furthermore, one user stated that it was still difficult to recognize certain parts because the objects were not smooth. Therefore, using a better and more detailed model could already help.

#### **6.4.7 Do you have any additional feedback, remarks or suggestions in general?**

Multiple remarks were given regarding the overall VR program. It was mentioned by a user that the only reason they would not use the VR often to study is because it would not be very feasible to do at home, and because of the sensation of nausea induced by VR experiences. Another participant agreed that VR can be a valuable tool for teaching. On the other hand, they do not think that students can easily distinguish different tissue after studying by using this VR program. This is because the model looks different from a real zebrafish embryo. Therefore, they suggest placing a realistic zebrafish model near the abstract model to let people compare.

### **6.5 Test results**

The experimental group and the control group participants had to take a pre-test and a post-test to take prior knowledge into account when examining the influence of using VR games for studying zebrafish anatomy. The results of the pre-tests and post-test were compared for every participant and are shown in figure 19 and figure 20. Again, the green color indicates that a participant came from a biology background, while the blue color indicates that the participant came from a non-biology background. These figures show the number of correct answers that were given during the pre-test and the post-test for every participant. It also shows the difference between the number of correct answers given during the pre-test and post-test. Additionally, the average of the correct answers for both tests and the average of the difference between the correct answers for both tests are shown. For the control group that used a website to study zebrafish anatomy, the average difference is approximately 1.5. For the experimental group that used the VR, the average difference is approximately 3. This means that, on average, the control group learned 1.5 zebrafish part names by using the website as a study tool. The experimental group, on the other hand, learned 3 zebrafish part names by using the VR games as a study tool.

With these results, it was possible to assess whether the VR users were able to memorize more parts than the website users. To compare the significance of the difference between the results for both test groups, a two-sample t-test was performed under the assumption of a normal distribution.

Control Group									
Score	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	average
Pre-test	0	1	1	0	0	0	0	0	0.25
Post-test	2	3	3	2	1	0	2	1	1.75
Difference	2	2	2	2	1	0	2	1	1.5

Figure 19: Results of how many parts were assigned correctly during the pre-test and post-test by the website users in the control group. On average, there is a difference of approximately 1.5 between the correct answers given in the pre-test and the post-test.

Experimental Group									
Score	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	average
Pre-test	0	0	5	0	0	2	5	0	1.5
Post-test	2	4	11	4	4	4	7	0	4.5
Difference	2	4	6	4	4	2	2	0	3

Figure 20: Results of how many parts were assigned correctly during the pre-test and post-test by the VR users in the experimental group. For the experimental group, there is a difference of 3 on average between the correct answers given during the pre-test and the post-test.

The sample size, standard deviation, and mean for both test groups can be seen in figure 21. The estimated standard error (se) is equal to 0.707, and the calculated value for  $t$  is 2.121. These results gave a  $P$ -value equal to 0.031.

	Group1 (VR)	Group2 (Website)
Sample size	8	8
Standard Deviation	1.852	0.756
Mean	3	1.5

Figure 21: The sample sizes, standard deviations, and means of both test groups for performing the two-sampled  $t$ -test. This test was done to determine the significance of the difference between the test results of both evaluation groups. The sample size of both groups is equal to 8. The standard deviation for the experimental group (Group1) is equal to 1.852, and the standard deviation for the control group (Group2) is equal to 0.756. The mean difference of correct answers between the pre-test and post-test for the experimental group is equal to 3. The mean for the control group is equal to 1.5.

Usability Metrics	Metric Unit	User 1	User 2
time to learn interacting with the quiz	<i>seconds</i>	–	11.4 sec
time to learn interacting with scav hunt	<i>seconds</i>	348	134
time to learn interacting with puzzle	<i>seconds</i>	62	91
time for the quiz scene to load	<i>seconds</i>	1	1
time for the scav hunt scene to load	<i>seconds</i>	2	1
time for the puzzle scene to load	<i>seconds</i>	1	2
how many errors occur during one session	<i># of errors</i>	2	–
how many tries to select a scene	<i># pressed buttons</i>	1	1
how many tries to get to the menu	<i># pressed buttons</i>	2	2

Figure 22: Additional results of the usability attributes measured during the user evaluations. These results are not complete and are not taken into account with the overall averages of the usability metrics due to (technical) complications that occurred during the evaluations of both users. The blue color means the user did not have a biology-related background, while the green color means that the user did have a background in biology. During the evaluation of user 2, the VR headset completely stopped working. Therefore, no number of errors could be measured. User 1 had more difficulty learning how to interact with the scavenger hunt than user 2. Overall, this user took the longest out of every evaluator to learn how the scavenger hunt game works.

## 7 Conclusion and Discussion

In section 6, the results of the user evaluations were discussed. As mentioned earlier, ten users participated in testing out the VR program. Before discussing the results and drawing conclusions from them in this section, it is important to note that only nine users filled out the questionnaire. Out of the ten users, only eight users performed both a pre-test and post-test for evaluating the effectiveness of using VR games for studying. Moreover, eight out of ten users were used to measure the usability requirements. This is because, during the user evaluations, one participant experienced nausea while using the VR program, hindering their capability to fully complete the evaluation. In addition, during the user evaluations, one participant experienced hardware problems with the VR headset not connecting to the base station, resulting in an inability to complete the evaluation. These results can be found in figure 22.

The upcoming subsections (7.1 - 7.7) will discuss the results for every usability specification and how they are achieved. Conclusions will be drawn from the results that are being discussed in order to answer the two aforementioned research questions of this paper in section 7.8 and section 7.9:

1. **How can Virtual Reality effectively be used to visualize an anatomy ontology and study it?**
2. **What influence do Virtual Reality games have on studying anatomy of organisms or parts of organisms?**

### 7.1 Learnability

The measurements of all designated learnability metrics in figure 18 score on average better than their worst possible score and have reached their target score. Some metrics are closer to their assigned best possible outcome than others. Looking at the time it took to learn how to handle the various scene specifications, it is notable that the ontology scene took the longest to learn and the quiz and puzzle scenes took the least amount of time. These results imply that overall, the purpose of the latter two scenes is easiest to learn. In each scene, the performance was timed from the moment the user was done reading the newly introduced functions specific to that scene. Ensuring that the timing period exclusively applies to the unique actions in each scene and excludes the actions that are repeatedly used between scenes, such as walking.

According to the results, the scavenger hunt game took on average approximately twice as much time to learn the functions than the other two games. Whereas for the ontology scene, the average user needed nearly two and a half minutes to get familiar with the scene, which is almost six times longer than the average time to understand the puzzle scene. Additionally, the results mentioned in figure 22 imply that out of the three games, the scavenger hunt took the longest to get used to. However, due to the malfunctions during these two evaluations, the total time required to learn the interactions is longer than the aforementioned results, rendering them less reliable as conclusive outcomes. In the end, most users were able to get control of all the implemented functions, resulting in a satisfactory degree of learnability.

Overall, the measured learnability metrics signify the effect of the number of functions and interaction techniques that are implemented in each scene. The puzzle and quiz scenes both require one function in addition to the walking action that is used in each scene. In the scavenger hunt,



one extra function needs to be learned in comparison to the former two game scenes. Lastly, in the ontology scene, the user inquired to learn three new interaction functions. The method needed for the toggle action was through the same button that is required in the other three scenes as well. However, the trackpad button was introduced for the orientation through the ontology, which had not been commonly used in the other scenes. Consequently, this can have an impact on the program's usability since it requires more time to learn a new action. According to the questionnaire results, the ease of learning how to go through the layers was not negatively influenced by this. Another factor that could have an impact on the learnability results is the overwhelming visuals that the scene can include. The game scenes had no complicated visuals to the extent that no visualization choices were made that were expected to be completely unfamiliar to the user. In the ontology scene, however, a new method to visualize a 3D ontology was created, that the users had not seen before. This also adds to the total amount of time it takes for someone to get used to the ontology scene. In the questionnaire, the testers declared that the visualization is suitable for an anatomical ontology, albeit some feedback on how to improve the visualization was given. Some feedback implies that ontology can be ambiguous due to the lack of visual clues that indicate whether an entity contains children. Moreover, the meaning of the ontology can still be unclear since there is no visual aspect that emphasizes the relationship between the entities. Considering the usability specification results for the learnability, it can be concluded that the aimed ease to learn how to use the VR program is reached. Overall, users were able to understand the various implemented functions within the aimed time limit. However, some adjustments to the ontology visualization can be made in order to enhance learnability.

## 7.2 Functionality

The functionality of the VR program was measured by looking at the time it took for each scene to load, and by tracking the number of errors that occurred within the hardware and software during each user evaluation. In figure 17, the results can be seen that were measured during the user evaluations. It is important to note that recording the loading time for each scene, was done with a mobile phone. This means that milliseconds of the time measurements are not accurate, due to recording them manually. For this reason, the time is rounded up to seconds. As can be seen in figure 17, there is no real difference between the time it takes for every scene to load. The time it took for the ontology and puzzle scenes to load for each user tester, ranged from around 1 to 2 seconds. For the quiz and scavenger hunt scenes, this ranged from around 1 to 3 seconds. However, there is a difference between the number of errors that have occurred during a user evaluation session. For the first user, 5 errors occurred. It can also be seen that for the other users, there were fewer or no errors. This is because errors that occurred during user evaluations due to problems with the program itself, were fixed before proceeding with other user evaluations. One of these errors, for example, included suddenly flying in the air during the puzzle game. Moreover, the results mentioned in figure 22 show that the recorded seconds it took for the scenes to load for both users, and the number of errors that occurred for one user (2 errors), were not noticeably different compared to the results of the other evaluations (figure 17) (where for three users 1 error occurred, for four users 0 errors occurred, and for one user 5 errors occurred). However, the second user in figure 22, the user experienced a lot of errors due to problems with the hardware. Therefore, the number of errors could not be tracked since the VR headset stopped working entirely. Figure 18 shows the average measurements compared to the usability requirements that were set.

All of the average scores regarding the loading time for the functionality of the program (ontology scene: 1.6, quiz scene: 1.8 seconds, scavenger hunt: 1.9 seconds, puzzle scene: 1.5 seconds), are better than the set target scores (5 seconds for every scene). The average number of errors that occurred (1 error), is the same as the target score that was set (1 error).

Overall, the obtained usability specification results for the functionality lead to the conclusion that the aimed functionality of the VR program is reached. The average time it took for the ontology, quiz, scavenger hunt, and puzzle scenes to load is 1.6, 1.8, 1.9, and 1.5 seconds, respectively, while the target score for every scene is 5 seconds. However, it is important to take into consideration that problems with the VR hardware are inevitable and that there is always a chance that they occur. Furthermore, the different scenes in this program contained relatively small 3D models and a small data set. Therefore, it cannot be concluded that the loading time of the scenes will stay within an acceptable time range if more data or more complex models are being used for visualization.

### 7.3 Familiarity

The average number of buttons pressed to get to a new scene (on average 2.1 buttons) is slightly above the aimed goal (2 buttons), as shown in figure 18, whereas the average of pressed buttons to show the menu screen (1.8 buttons) meets the target score (2 buttons). These results signify a moderate familiarity with the VR program, and that the system needs some improvements in regard to going to a new menu scene. When looking at the more specific results mentioned in figure 15, it is noted that five out of eight users were able to select a new scene (all in one go) within the aimed number of tries (2 buttons). Other users attempted different buttons (3, 4 or 5 buttons) to select the next scene, leading to an average score that is slightly above the target score of 2 buttons. This implies that the average user is not very familiar with the controls used for selecting scenes in the menu screen, which affects the familiarity with the VR program. However, the user's experience in gaming or VR has a big influence on their performance regarding the familiarity metrics. Throughout the evaluation, it was noticeable that all users were familiar with directing the laser pointer and selecting a scene by means of pointing. These methods are commonly required for menu screens, which is a plausible explanation for these observed results.

Moreover, according to the results, the program still lacks predictability. The provided task list (29) included some instructions that had to be repeated in each scene and required buttons that the user had already interacted with. Therefore, the task list mostly relied on familiarity throughout the whole application. The expectation was that upon the completion of one task, the user would have gained sufficient familiarity with the required controls, enabling them to finish the next task without additional help. However, the average score (9.8 tasks without help) did not reach the target score (12 tasks) and is only a little higher than the worst possible score (9 tasks), implying that the average user did not get familiar with the necessary controls. Looking at the results in figure 17, the number of tasks without additional assistance differs between the users, varying from four tasks up to fifteen. About 50% of the users were able to reach the target score. Hence, it can be concluded that the VR program still needs some improvements in familiarity when it comes to predicting task approaches.

## 7.4 Usability

As stated before, the obtained average SUS score is approximately 74. This score is above average [Sau11] (68), and also slightly above the target score (70) that was aimed at during the usability specifications (figure 18). This implies that the VR program exhibits a favorable level of usability. However, the maximum possible score for the usability is 100. Therefore, the usability can still be improved to create a program that is easier and more efficient.

It is noticeable that the responses of the users were different for the SUS questionnaire statement “I needed to learn a lot of things before I could get going with this system” (figure 16) Some users gave this statement a score of 1, while others provided a score of 2, 3, or even 4. This shows that it was not easy for everyone to immediately work with the VR program. A plausible explanation for this could be the varying levels of prior experience people have with VR and/or games. The main idea of the VR controls, such as walking around in the environment with the left controller, is based on the controls used in games. Therefore, it can be new to users who do not have gaming experience.

The highest given SUS score is equal to 82.5, while the lowest given SUS score is significantly lower (65). The latter score is below average. The user that provided this score gave a neutral score for how confident they felt while using the program, and how many things they needed to learn before understanding the program. Furthermore, they scored the usability a 3 out of 5 on feeling like they needed technical support to use the program, and how easy it was to use this VR. Therefore, the SUS score was lower compared to the other SUS scores. When looking at the results, it can be said that this specific user, thought they had some trouble getting used to interacting with the VR.

The other obtained SUS scores are all above average. This also indicates that the overall usability of the VR program is already quite satisfactory.

## 7.5 Satisfaction

The results shown in figures 18 and 34 indicate that the average user was relatively satisfied with the VR program. The overall satisfaction score of 7.7 on average meets the aimed score (7.5), however, the average is only 0.2 points above its target score. Implementing the feedback received from the questionnaire can enhance satisfaction. One implication indicated that it can be troubling to find a specific entity in the ontology visualization due to the absence of the part names, leading to a less satisfying experience. The advised improvements mentioned in 7.1, might add to the satisfaction degree as well. In addition, other suggestions were given that can help improve satisfaction but are not within the specific field of this research. Such as sitting on a chair while using the application, displaying the control buttons and the user’s hand in the interface, and making the anatomical objects smoother.

## 7.6 Clarity

Users were asked to rate the clarity of the VR program (figure 34). The obtained scores for the clarity are between 7 and 9. Figure 18 shows that the average score for the clarity of the program is 8.0. It can be seen that this average score is higher than the target score (7.5). However, in total, three users rated the clarity of the program with a 7. This is slightly below the goal that was set, but it was still higher than the worst acceptable score (5.5). When looking at the average obtained

score for the clarity, it can be said that the clarity of the overall program is satisfactory according to the respondents of the questionnaire.

It is mentioned that the clarity of the zebrafish anatomy ontology visualization can be improved (section 6.4.5), by including an image of a zebrafish in the visualization scene. This is because, for someone that lacks knowledge about zebrafish anatomy, it is reported that it is difficult to see the resemblance between the model and an actual zebrafish without having a reference. Especially, because the 3D model is abstract and has different colors compared to an actual zebrafish. This can however also be applied to the games. Furthermore, to enhance the clarity of the ontology visualization itself, visual cues can be added to give indications on whether a user can go to the next layer in the ontology for a certain part or not. Moreover, adding names or the first few letters of the names for different zebrafish parts to the entities in the ontology could be helpful for the clarity of the visualization.

## 7.7 Educational Value

According to the results of the questionnaire (figure 35), the overall educational value of the program scores between 7 and 10. The same is true for the educational value of the quiz, the puzzle, and the visualization. However, the distribution of the scores differs. The overall value was scored with mostly sevens, the value of the quiz mainly with eights and nines, the value of the puzzle with sevens and eights, and the value of the visualization mostly received eights. The scavenger hunt, on the other hand, has 8 scores ranging between 6 and 9 and also obtained one score of 4. When comparing the average scores for the overall VR program, and every separate aspect of the program to the usability requirements that were set (figure 18), it can be seen that almost all score higher than the target score (7.5). The overall educational value scores a 7.9 out of 10 on average. The puzzle has an average score of 8.1, the quiz has an average score of 8.6, and the visualization obtained an average score of 8.3. All of these scores are above the goal, meaning that the respondents think that the overall program, the quiz, the puzzle, and the visualization could all be valuable as educational tools to memorize anatomy. The results indicate that the educational values are sufficient. Nonetheless, there are still improvements that can be made. Suggestions for such improvements have been mentioned in sections 6.4.3, 6.4.4, and 6.4.6. The main takeaway for the puzzle is that it would be helpful to place the indicator of which part a user is holding somewhere more noticeable (e.g., stick it to one of the controllers). Apart from that, a respondent mentions that the puzzle is a great tool to start with when studying anatomy. For the quiz, some of the users are hesitant about whether the multiple choice options are the best way to study anatomy. Therefore, they suggest spelling out the names of the highlighted parts. The respondents are optimistic about the educational value of the visualization and believe that it can also be used in combination with the different games for studying and testing anatomy knowledge.

Conversely, the scavenger hunt scores a 7.4 on average for the educational value, which is 0.1 below the target score. This can be explained by the fact that one user gives this game a 4 when it comes to its educational value for studying anatomy. Moreover, one user also gives this game a 6, and none of the participants gave a 10. The average score for the educational value of the scavenger hunt is above the worst acceptable score (5.5). When looking at the feedback provided by respondents for improving the educational value of the scavenger hunt (section 6.4.2), it indicates that the main issue with this game is that users feel like they have to guess their way through the game.

Furthermore, they mention that they think this game can still be valuable if the user has more knowledge about anatomy already, and that it can be improved by implementing a peeking feature with which a user can view the name of a part if they get stuck.

Moreover, during the user evaluations two users mentioned verbally, that it would also be beneficial for the overall VR program to add more information about the different parts and organs apart from the names and ontology. This way, it can be easier to remember certain parts, and it enables users to gain more knowledge about the different parts and organs. Furthermore, additional questions (figure 37) were asked through the questionnaire about how well the user thought the games helped them memorize zebrafish parts, and how likely it would be for them to use this tool for studying anatomy. For the quiz, every participant, except for one, gave a score of 6 or above for how well this game helped them memorize various parts of the zebrafish. For the puzzle, every user, except for one, gave a score of 7 or above. The scavenger hunt received three insufficient scores. One participant provided the quiz, the puzzle, and the scavenger hunt with a score of 1 for how well they helped them memorize. However, this user mentioned gave the following statement: “I rated my memorization progress with a 1 everywhere, since I couldn’t remember any anatomical names after using the app. I should probably stress that I don’t think this was due to a problem with the app itself. Rather, it had more to do with the names just being long and complicated and me being distracted while using the app due to VR-induced nausea”. The variety in opinions about how well the scavenger hunt helped in memorization, leads to it being difficult to draw a conclusion on how effective this particular game is for studying anatomy. The relatively lower scores for this game compared to the other games, can potentially be explained by that most of the user evaluation participants had no prior knowledge about zebrafish anatomy which made this game feel more like a guessing game than an actual study tool. Based on the results of these additional questions and the questions mentioned before, it seems that users are optimistic about the quiz and puzzle in VR for studying. When it comes to how likely it is that someone would use VR as a tool for studying for an exam, the opinions vary a lot. In section 6.4.7 it is mentioned that one participant states that they would not use the VR to study because it would not be very feasible to do at home, and because it made them nauseous. Another participant mentions that they think students will not be able to easily recognize anatomy parts after studying because the used model looks very different from a real zebrafish. The difference in opinions about how likely it would be for them to use this program as a study tool might be explained by the fact that a VR headset is not accessible to everyone which makes it more difficult to study at home. Furthermore, VR can also cause nausea as stated by one of the participants. Thus, for some people, VR could be beneficial for studying, while others feel like it would not be accessible enough to them or it would cause problems such as nausea.

To gain more insights into the specific impact of games aiding users’ memorization of zebrafish anatomy, the control group and the experimental group had to perform a pre-test and a post-test. The results of the pre-test and post-test for both groups can be found in figure 32 and 31. These tables also include the differences between the number of parts each participant assigned correctly before and after using a website or playing VR games to study. It is important to mention that user 8 of the experimental group admitted to not trying to memorize different zebrafish parts because they were busy figuring out interacting with the VR environment, and because they felt dizzy. Another important remark is that both groups consisted of four people with a biology background, and four people without a biology background. Differences in the background could potentially



lead to some participants having more background knowledge about zebrafish anatomy than others. Nevertheless, the examination focused on the difference between the pre-and post-study evaluations with a website or the VR, minimizing its potential influence on the overall outcomes. The average difference for the experimental group is higher than the average difference for the control group. To investigate the significance of the difference between the two groups, a two-sample t-test was performed. Figure 21 shows the sample sizes, the standard deviations, and the means for the experimental group (Group1) and the control group (Group2). As mentioned in the results (section 6.5), the  $P$ -value resulting from the t-test is approximately equal to 0.031. This means that the  $P$ -value is smaller than  $\alpha$  ( $\alpha = 0.05$ ). Using this significance test, relatively strong evidence against the null hypothesis is gained and thus it seems that the VR program had a positive influence on the learning process of users.

## 7.8 Methods for Anatomy Ontology Visualization in VR

Considering the aforementioned conclusions, it can be stated that a relatively effective method has been established to utilize VR to visualize an anatomy ontology. First of all, it is important to attain the seven usability specifications with the VR program. For this research, the learnability of the program is obtained by minimizing the required buttons to use and the variety of functions and visualizations in each scene. The VR hardware is mostly responsible for maintaining the functionality of the program. However, the size of the ontology data set and the anatomical models play an important role in the functionality as well. In this research, the size of both matters was kept relatively small. In order to gain as much familiarity as possible, the implemented controls are kept similar to the standard controls used by bigger game companies, and many principles are operated that are based on commonly used interface designs. Furthermore, some functionalities are repeatedly applied throughout the program to allow the user to recognize certain meanings in aspects across the VR environment. Initially, the purpose of this is to increase the predictability of the system, since a user might be able to predict a function if they have encountered it before. However, according to the results, the application still needs additional features to enhance familiarity. Adding more features could also enhance the user's satisfaction with the system. At this moment, the main focus lies on using the system to learn the anatomical parts, instead of learning complex VR controls. Therefore, satisfaction is maintained by keeping the visualization as simple and straightforward as possible, to allow the user to spend less time figuring out the VR features. This also helps manage the clarity of the program, simple visuals are used to make the system as clear as possible. However, the ontology visualization can use some additional symbols to improve its clarity. Currently, only sphere objects are used to entail entities, and there are no additional features to indicate the hierarchical structure. In the end, the visualization techniques that are used for this research, offer a successful method to study the anatomy of a certain organism. Gamification is used as a learning method to encourage the study process of students. Three games are implemented for this, each of which relies on the previously mentioned specifications.

To answer the first research question “**How can Virtual Reality effectively be used to visualize an anatomy ontology and study it?**”, it can be said that these applied methods lead to an effective way of using VR to study anatomical structures. However, implementing the given feedback by users is an important next step that leads to a more effective way to use VR to visualize anatomy ontologies.

## 7.9 The Effect of VR Games on Studying Anatomy

In consideration of the foregoing discussion and conclusion about the educational value of the VR games, it can be said that VR games seem to have a positive effect on the learning experience of the users for studying zebrafish anatomy. The received responses through the questionnaire show that the overall experience of the users was reasonably positive regarding the educational value of the three VR games. However, especially the scavenger hunt could use some improvements. To answer the research question **“What influence do Virtual Reality games have on studying anatomy of organisms or parts of organisms”**, the result of the significance test also plays a role. The outcome of this two-tailed t-test shows that there is a significant difference in how much users memorized after using the VR instead of using a website.

To come to a definite conclusion, it is preferred to use larger control and experimental groups. This helps prevent reporting false-positive and false-negative results. Furthermore, to derive conclusions specifically intended for the intended user group, it is important to conduct tests on people who align with the characteristics of this particular group. This means that it would be beneficial to test the VR program in a biology-related class and let students use the program to study for a quiz about anatomy. One group could for example study anatomy from a textbook, while the other group gets to use a textbook and the VR program. Moreover, it should be noted that the control group studied a slightly different 3D model than the experimental group. It would have been more reliable to utilize the same 3D models for both test groups.

## 7.10 Future Work

For now, the VR program is only used to visualize anatomy of a zebrafish embryo. However, the program can be further developed to make it usable for anatomy of other organisms as well. The program is created in a way that the visualization and the games can be transposed to other models of organisms without having to make major adjustments to the program. Moreover, information about the function of different parts of the zebrafish embryo is not available in this VR program. To make the program more informative, an option can be added that gives the opportunity to the user to read some facts about a certain part. For example, functions of parts, and when certain parts develop could be added. Furthermore, the feedback given by the users that tested the program can be implemented in the program to enhance positive user experience.

It is hoped that this developed VR program has unlocked a multitude of opportunities for studying anatomy. In the future, it is envisioned that this program could potentially be enhanced to become a highly valuable resource for anatomy education among biology students or students in the field of life sciences.

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## A Appendix



Figure 23: Scan this QR code to view a video of the final version of the VR program.

```
use zfin;

CREATE TABLE IF NOT EXISTS zf_anat_term_id AS
SELECT anat_id, parent_id, anat_name, child_id, rel_id
FROM zf_anat_terms
INNER JOIN zf_anat_terms_rel ON zf_anat_terms.anat_id = zf_anat_terms_rel.
    ↪ parent_id
;

CREATE TABLE IF NOT EXISTS zf_anat_rel AS
SELECT zf_anat_term_id.parent_id, parent_anat_name, zf_anat_term_id.child_id,
    ↪ zf_anat_terms.anat_name, rel_id
FROM zf_anat_terms INNER JOIN zf_anat_term_id ON zf_anat_terms.anat_id =
    ↪ zf_anat_term_id.child_id
;

SELECT * FROM zf_anat_ont;
SELECT * FROM zf_stages;

DROP TABLE IF EXISTS zf_anat_term_id;
DROP TABLE IF EXISTS zf_anat_rel;
DROP TABLE IF EXISTS zf_anat_ont;

CREATE TABLE IF NOT EXISTS zf_anat_term_id AS
SELECT t.anat_id, r.parent_id, t.anat_name AS parent_anat_name, r.child_id, r.
    ↪ rel_id
FROM zf_anat_terms AS t
INNER JOIN zf_anat_terms_rel AS r ON t.anat_id = r.parent_id
;
```

```

CREATE TABLE IF NOT EXISTS zf_anat_rel AS
SELECT r.anat_id, r.parent_id, r.parent_anat_name, r.child_id, t.anat_name AS
    ↪ child_anat_name, r.rel_id
FROM zf_anat_terms AS t
INNER JOIN zf_anat_term_id AS r ON t.anat_id = r.child_id
;

CREATE TABLE IF NOT EXISTS zf_anat_ont AS
SELECT parent_anat_name, child_anat_name, rel_id FROM zf_anat_rel
WHERE rel_id = 'part_of';

SELECT * FROM zf_anat_ont;

```

Listing 1: This code shows a query that is written in MySQL. It generates the table with all parent names and child names that are related to each other.

```

import json
import sys
# Opening JSON file
ontologyfile = open('ZF48_OntologyData.json')
partsfile = open('availableparts.json')

#print(sys.getrecursionlimit())
sys.setrecursionlimit(10000)
# returns JSON object as
# a dictionary
ontologydata = json.load(ontologyfile)
parts = json.load(partsfile)

ontdata = [l for l in ontologydata]
ontparts = [part['ont_name'] for part in parts]
mset = set()

for ont in ontdata:
    mset.add(ont['parent_anat_name'])
    mset.add(ont['child_anat_name'])

def filter_ontology(m_part, m_ontology):
    found_parts = []
    for ont in m_ontology:
        #keep ont line if the parent or the child name matched the part name
        if m_part == ont['parent_anat_name']:
            if ont not in found_parts:
                found_parts.append(ont)
                m_ontology.remove(ont)

```

```

        found_parts.extend(filter_ontology(ont['child_anat_name'],
        ↪ m_ontology))
    elif m_part == ont['child_anat_name']:
        if ont not in found_parts:
            found_parts.append(ont)
            m_ontology.remove(ont)
            found_parts.extend(filter_ontology(ont['parent_anat_name'],
            ↪ m_ontology))
    return found_parts

final_list = []
for mypart in ontparts:
    #find all the relations of the part in the ontology
    mypart_rel = filter_ontology(mypart, ontdata)
    final_list.extend(mypart_rel)

#save new datafile
with open("sample.json", "w") as outfile:
    json.dump(final_list, outfile, indent=2)

```

Listing 2: Python code that filters the data listed in the datafile. It compares the name of each available anatomical game object, loops through the dataset to identify if this object exists. All the lines that include one of the used anatomical parts are stored and imported in a new datafile.

# Main Scene

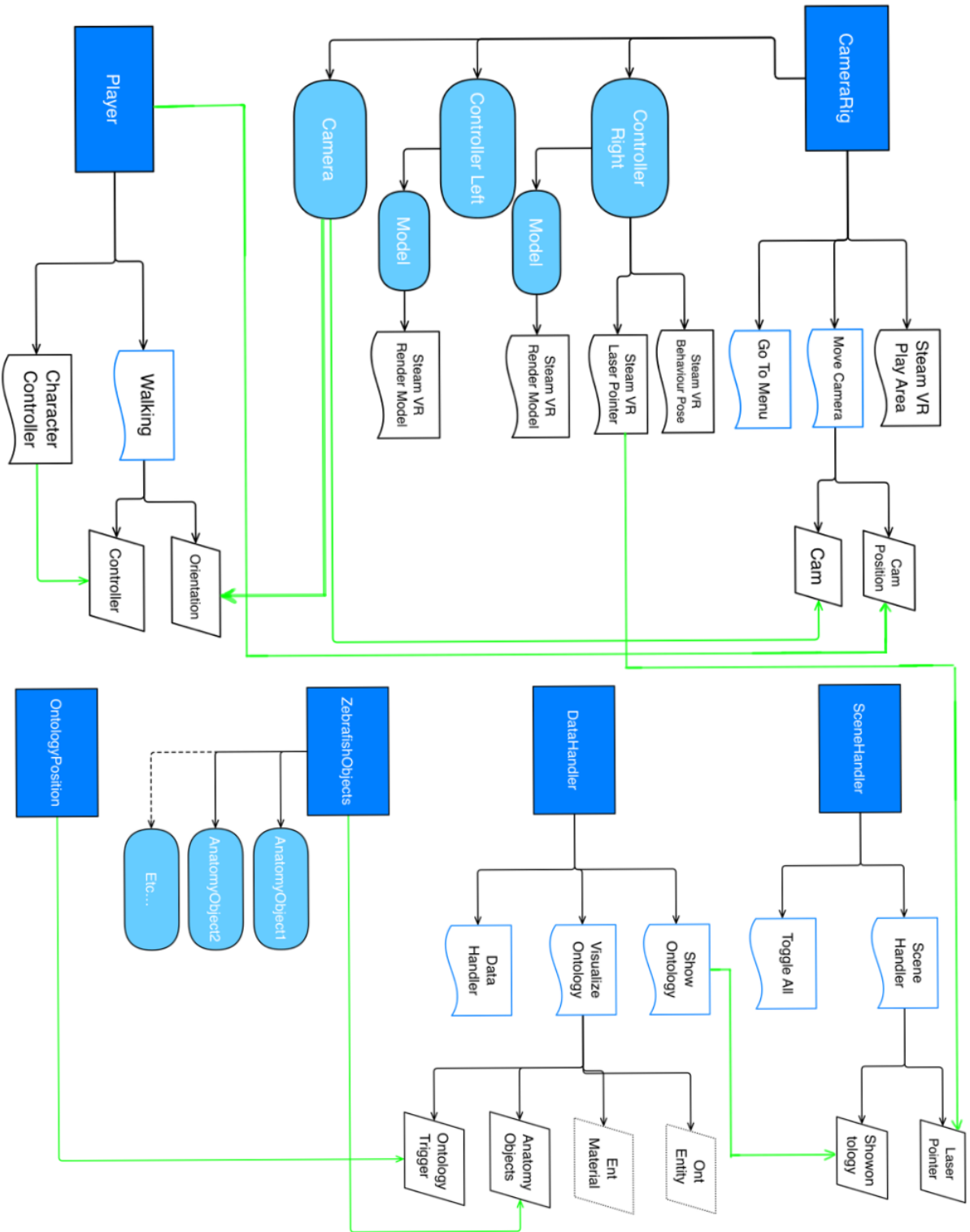


Figure 24: Flowchart of the important functions and assignments done in the Main scene. The meaning of each symbol is mentioned in the legend in figure 28.

# Quiz Scene

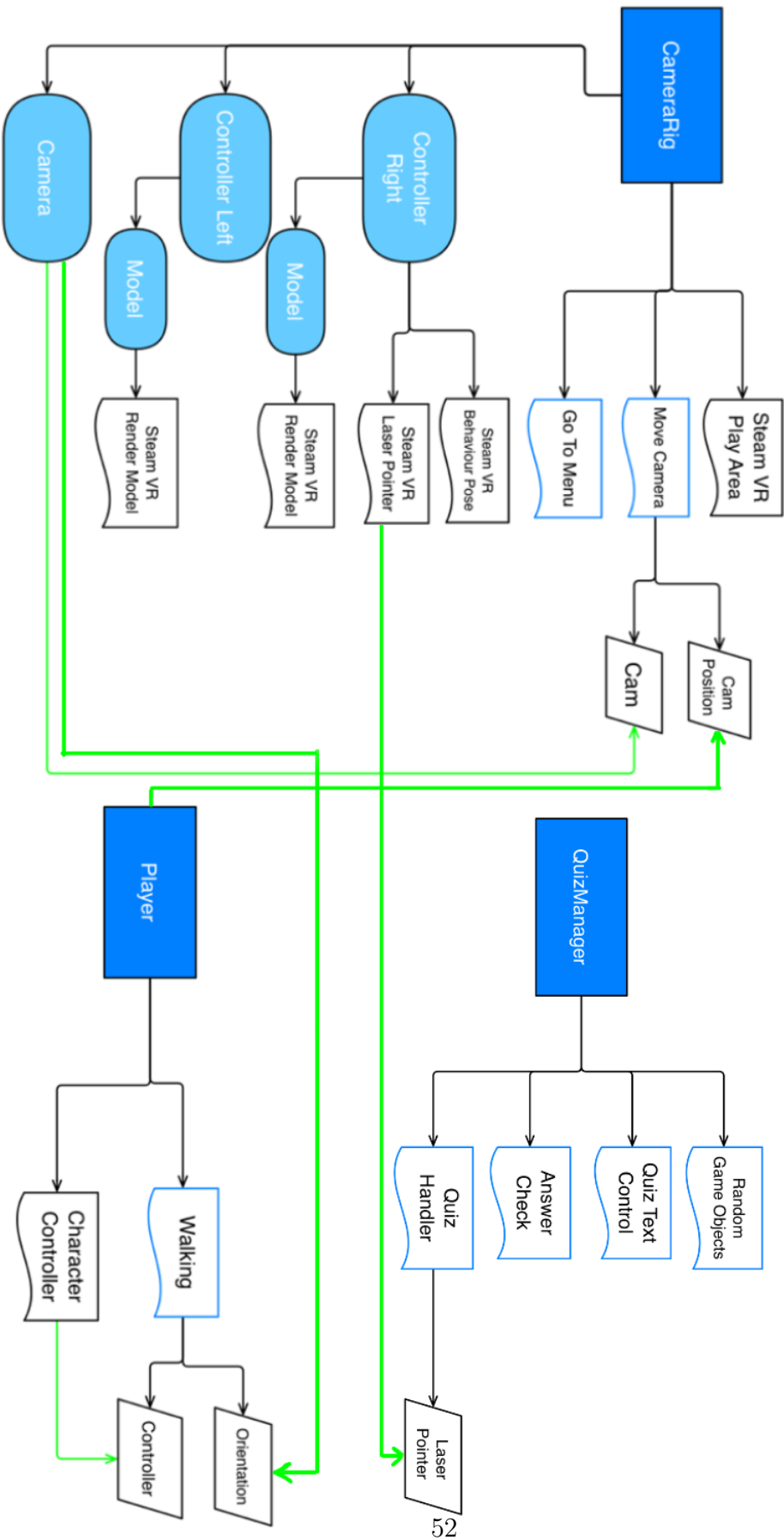


Figure 25: Flowchart of the important functions and assignments that need to be done in the quiz scene. The meaning of each symbol is mentioned in the legend in figure 28.

# Scavenger Hunt Scene

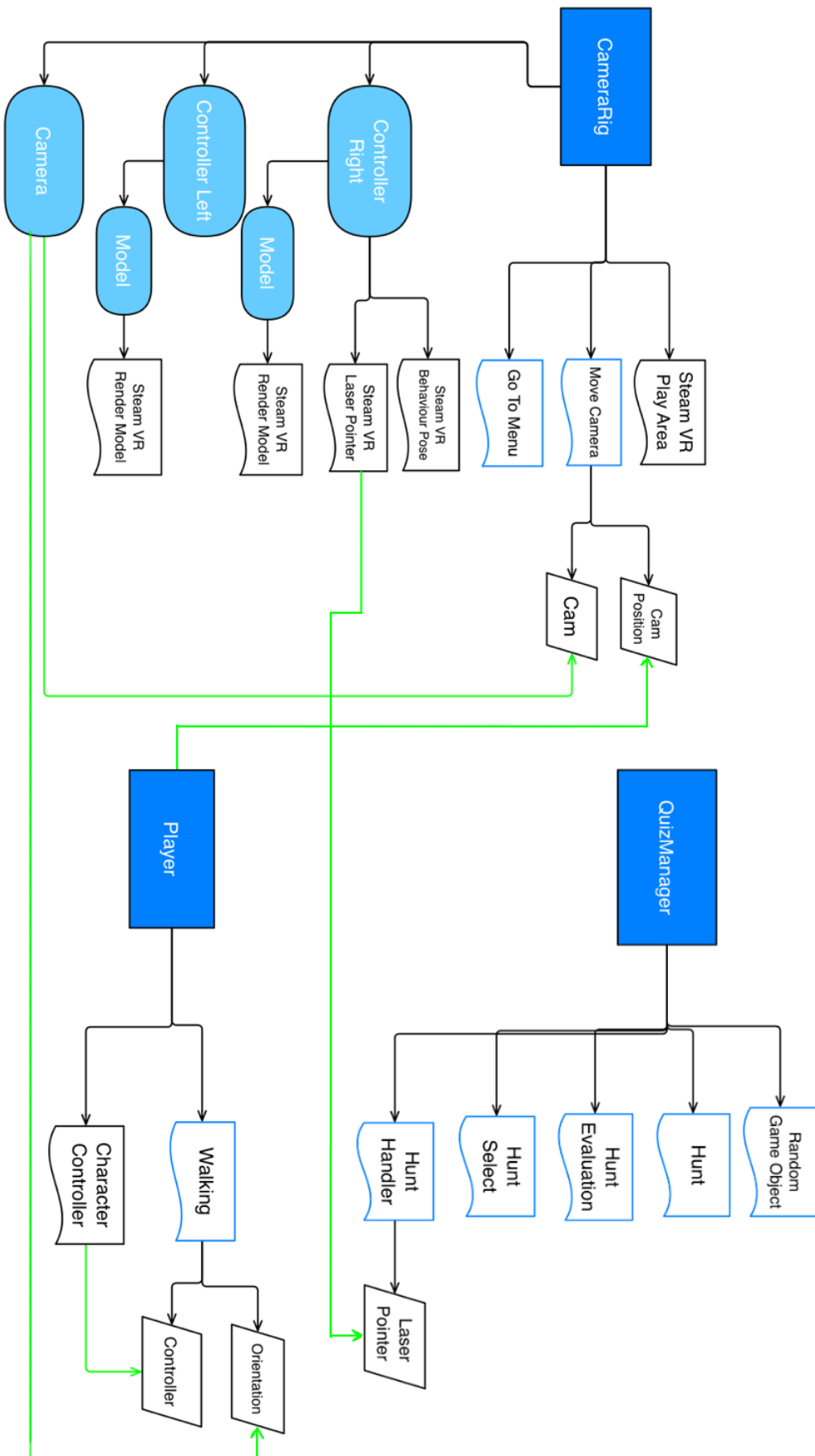


Figure 26: Flowchart of the important functions and assignments for the scavenger hunt scene. The meaning of each symbol is mentioned in the legend in figure 28.



# Puzzle Scene

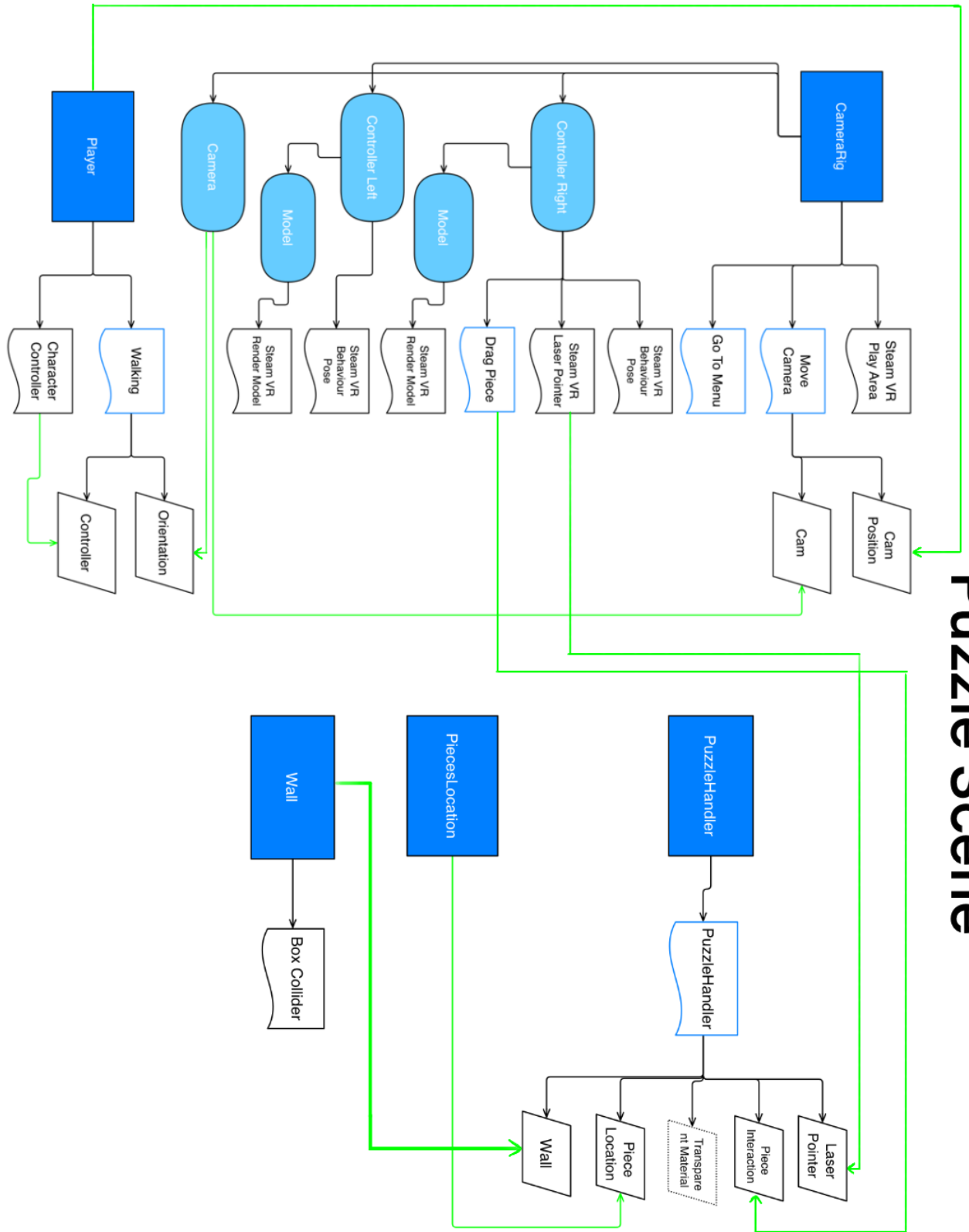


Figure 27: Flowchart of the important functions and assignments in the puzzle scene. The meaning of each symbol is mentioned in the legend in 28.


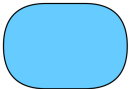






Legend	
	Game Object
	Child Object
	Standard Component
	Self-coded Component
	Assignable Variable From Hierarchy
	Assignable Variable From Assets
	Contains
	Input

Figure 28: Legend for the aforementioned flowcharts.

# User Evaluation Tasks (VR)

The model that is being visualized is a model of a (48-hours-old) zebrafish.

## *Take the pretest.*

### *The Scavenger Hunt:*

1. Navigate towards the Scavenger Hunt scene.
2. Explore your surroundings to figure out the controls and instructions.
3. Walk over to the scavenger hunt game and answer 2 questions.
  - Tip: You can delete parts of the zebrafish to get a better view of certain parts.

### *The Puzzle:*

4. Navigate towards the Puzzle scene.
5. Explore your surroundings to figure out the controls and instructions.
6. Pick up a part of the model and place it in the puzzle. Repeat this 3 times.

### *The Quiz:*

7. Navigate towards the Quiz scene.
8. Explore your surroundings to figure out the controls and instructions.
9. Walk over to the quiz game and answer 10 questions.
  - Tip: You can delete parts of the zebrafish to get a better view of certain parts.

## *Take the post-test.*

### *The visualization/main scene:*

10. Navigate towards the Ontology visualization scene.
11. Explore your surroundings to figure out the controls.
12. Find the **central nervous system** in the ontology.
13. Toggle/turn the **central nervous system** of the zebrafish model off.
14. Find the **coelom** in the **mesoderm** in the ontology.
15. Toggle/Turn the **central nervous system** of the zebrafish model back on.
16. Toggle/turn every part of the zebrafish off **at once**.
17. Select the **embryonic tissue** in the ontology to toggle/turn the corresponding parts of the zebrafish model on.
18. Toggle/turn every part of the zebrafish model back on **at once**.

Figure 29: Tasks the VR participants (experimental group) had to perform for the user evaluations.

# User Evaluation Tasks (Website)

The model that is being visualized is a model of a (48-hours-old) zebrafish.

1. Take the pre-test.
2. Navigate towards the 3D view of the website.
3. Toggle/turn all the zebrafish parts off
4. Find the **MYELENCEPHALON** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
5. Find the **STATOACOUSTIC GANGLION** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
6. Find the **SPINAL CORD** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
7. Find the **CEREBELLUM** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
8. Find the **HEART** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
9. Find the **LATERAL LINE NEUROMAST** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
10. Find the **DIENCEPHALON** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
11. Find the **SPINAL CORD** (again) and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
12. Find the **PECTORAL FIN BUD** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
13. Find the **YOLK EXTENSION** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
14. Find the **YOLK** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
15. Find the **OPTIC CUP** and toggle/turn it on. Take a look at it and toggle/turn it back off when you've seen enough.
16. Choose 3 parts that you are interested in and toggle/turn them on. Take a look at them and continue when you've seen enough.  
\*you can toggle the zebrafish on/off to see where the parts are located.
17. Take the post-test.

Figure 30: Tasks the website users (control group) had to perform for the user evaluations.

## Zebrafish Anatomy Test (VR)

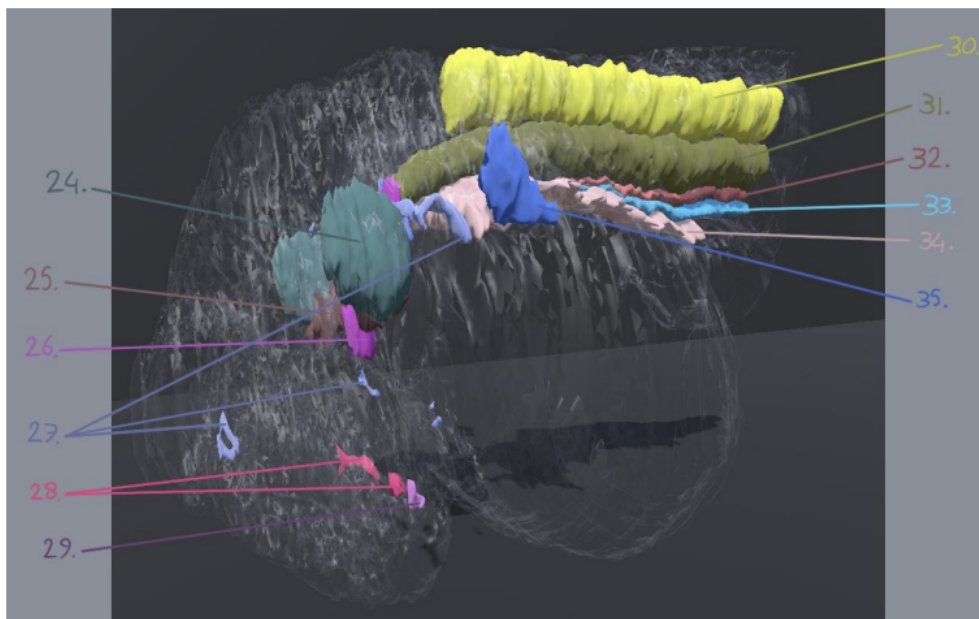
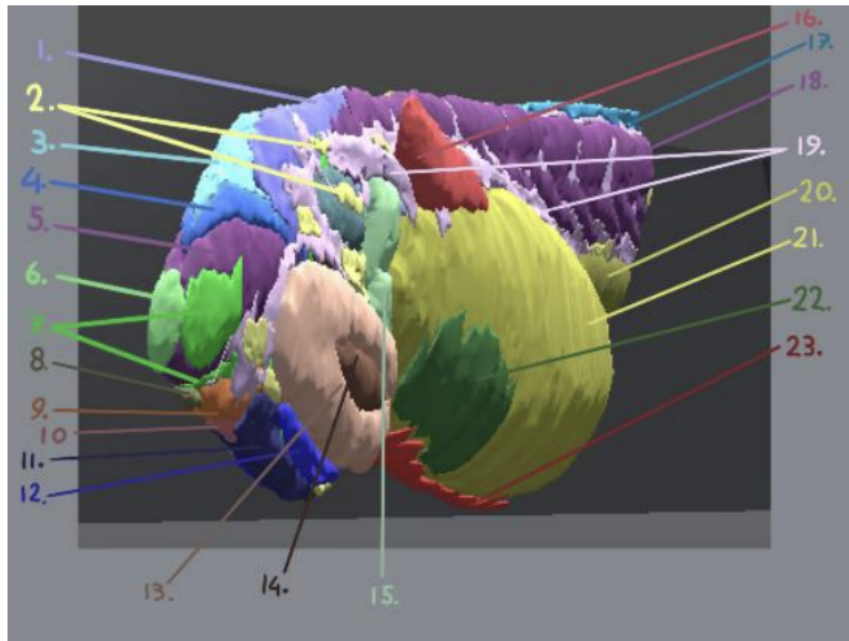


Figure 31: The pre-test and post-test for user evaluations of the VR participants (experimental group).

### Zebrafish Anatomy Test (Website)

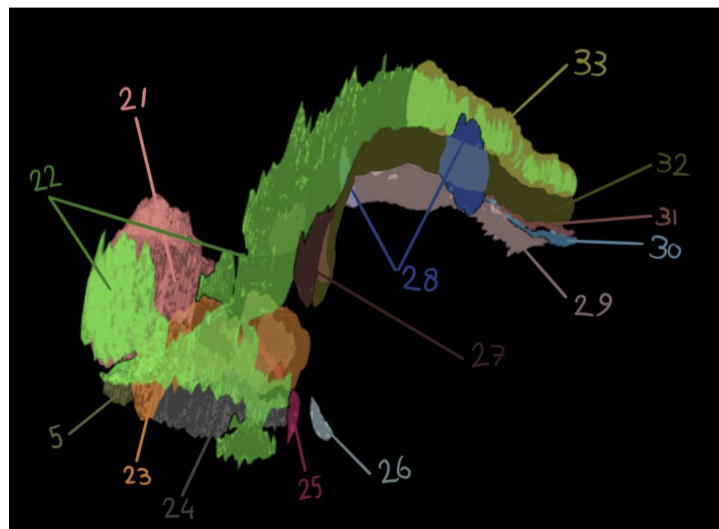
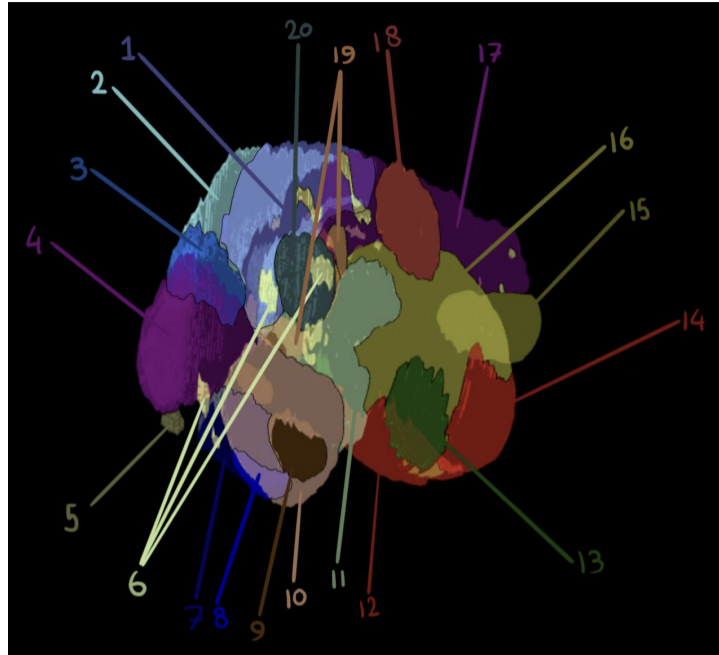


Figure 32: The pre-test and post-test for user evaluations of the website participants (control group).

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
2. I found the system unnecessarily complex	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
3. I thought the system was easy to use	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
5. I found the various functions in this system were well integrated	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
6. I thought there was too much inconsistency in this system	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
8. I found the system very cumbersome to use	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
9. I felt very confident using the system	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	1	2	3	4	5

**J. Brooke. SUS-a quick and dirty usability scale.**

Figure 33: System Usability Scale (SUS) statements that users had to rank based on how much they agreed with a statement.

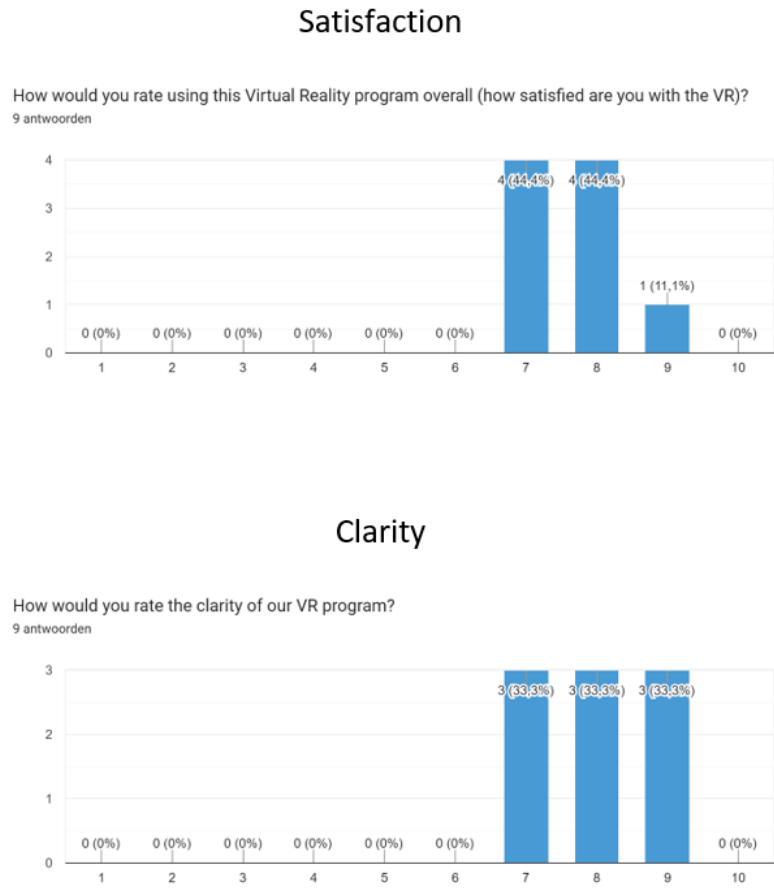


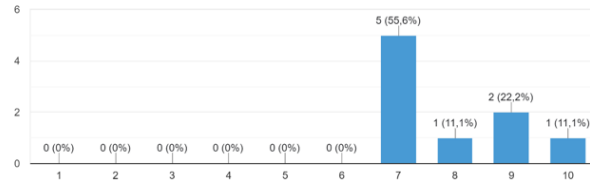
Figure 34: The scores of the questionnaire questions about the satisfaction and clarity of the VR program given by the (9) respondents after participating in a user evaluation. For the satisfaction and clarity, the users gave scores between 7 and 9. Four users rated the satisfaction with a 7 out of 10, or an 8 out of 10. One user gave the satisfaction a score of 9. For the clarity of the program three participants gave a score of 7, three gave a score of 8, and three gave a score of 9.



## Educational Value

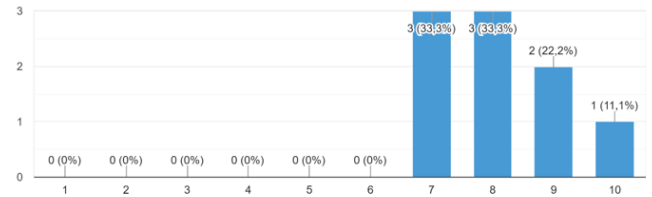
How would you rate using VR as an educational tool in general?

9 antwoorden



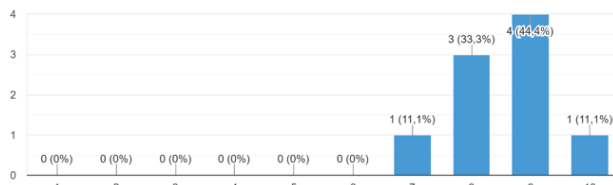
Do you think the Puzzle is valuable as an educational tool for people who want to memorize the anatomy of an organism?

9 antwoorden



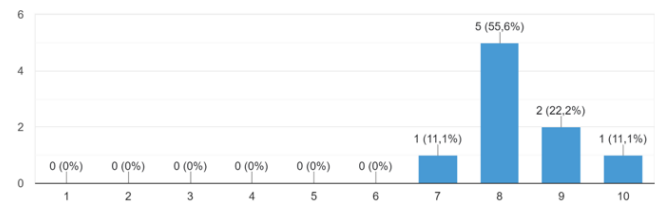
Do you think the Quiz is valuable as an educational tool for people who want to memorize the anatomy of an organism (zebrafish)?

9 antwoorden



Do you think this visualization is a useful tool for studying anatomy of an organism?

9 antwoorden



Do you think the Scavenger Hunt is valuable as an educational tool for people who want to memorize the anatomy of an organism?

9 antwoorden

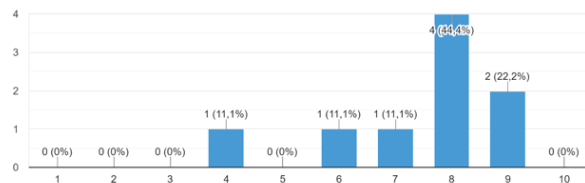
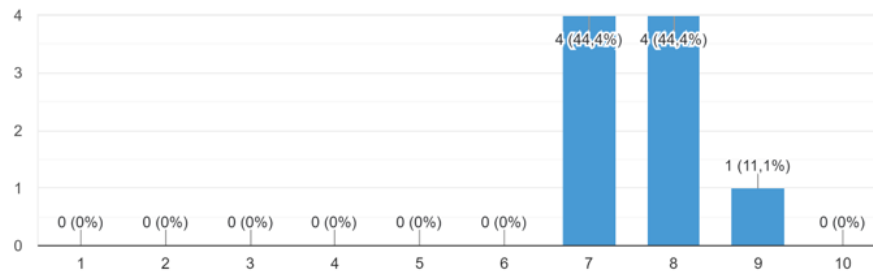


Figure 35: The scores of the questionnaire questions about the educational value of the VR program given by the (9) respondents after participating in a user evaluation. The overall program, the puzzle, the quiz, and the visualization all received scores between 7 and 10 for the educational value. The scavenger hunt scored slightly lower than the other aspects of the VR, and also received one insufficient score.

## Ontology Evaluation

Is the way the visualization is presented suitable for viewing the ontology of an organism (e.g. zebrafish)?

9 antwoorden



How easy was it for you to find certain parts within this ontology by going through the layers?

9 antwoorden

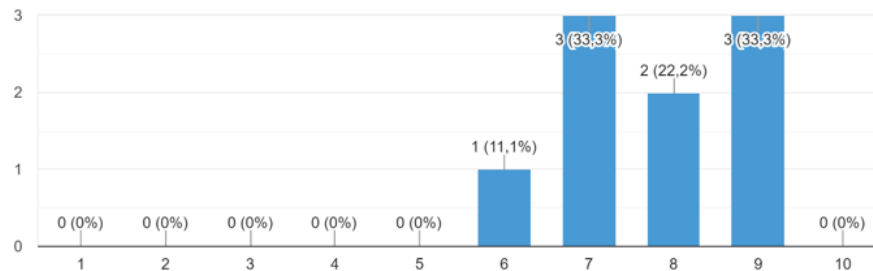
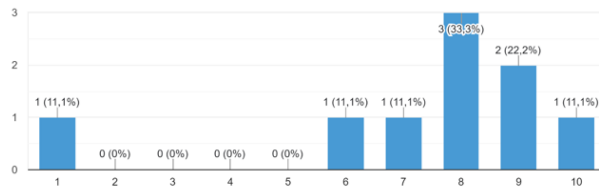


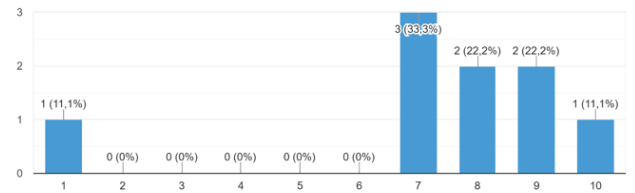
Figure 36: The scores of the questionnaire questions about the ontology visualization of the VR program given by the (9) respondents after participating in a user evaluation. Four users gave the suitability of the visualization a 7. Furthermore, four users gave a score of 8, and one gave a score of 9. Users also rated how easy it was to interact with the ontology. These scores ranged between 6 and 9.

## Additional Questions

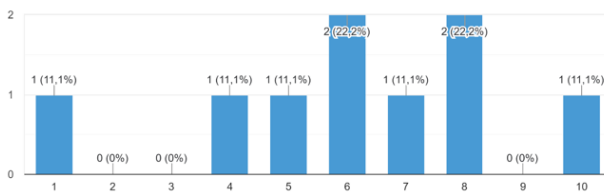
How well did the Quiz help you to memorize various parts of the zebrafish?  
9 antwoorden



How well did the puzzle help you study the various parts of the zebrafish?  
9 antwoorden



How well did the Scavenger Hunt help you memorize the different parts of the zebrafish?  
9 antwoorden



How likely is it that you'll use VR as a tool to study for an exam?  
9 antwoorden

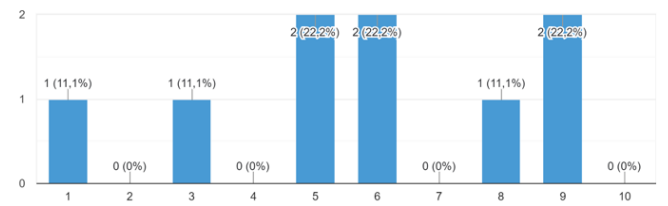


Figure 37: The scores of additional questionnaire questions about the VR program given by the (9) respondents after participating in a user evaluation. Three questions are about how well each game helped users in memorizing various zebrafish parts. One user gave the quiz, scavenger hunt, and puzzle a score of one. Outside of this score, the quiz obtained scores between 6 and 10, and the puzzle received scores between 7 and 10. On the other hand, the scavenger hunt scored two more insufficient scores (4 and 5), and received six scores of a 6 or above. The respondents were also asked how likely it would be for them to use the VR as a studying tool for exams. The given scores have a big variety (ranging between 1 and 9). Four insufficient scores were given, including a 1, and five sufficient scores were obtained.