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EXPLORING THE USE OF A COMMERCIAL GAME ENGINE
FOR THE DEVELOPMENT OF EDUCATIONAL SOFTWARE

by

HUSSAIN ALAFAIREET

A THESIS

Presented to the Faculty of the Graduate School of the
MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Approved by

Jennifer Leopold, Advisor
Richard Hall
Daniel Tauritz

ABSTRACT

Three-dimensional visualization and simulation environments are becoming increasingly important in both industrial and educational environments. However, developing these simulations can be a difficult and expensive task. Herein we explore the use of a commercial game engine to develop a 3-D, interactive computer game designed to teach players about the anatomy of a frog. The goal of this project is threefold: 1) to develop high-fidelity virtual reality educational software with a limited budget and limited personnel, 2) to define a software development process by which similar simulations can be developed, and 3) to explore the benefits that these simulations provide to secondary education. To this end, the *Frog Explorer* software development process will be reviewed, including discussion of the use of frog anatomy information, as well as the use of the Quake III game engine tools and features. Positive and negative results from two user-testing studies will be reported, with a focus on the game's usability and utility as an educational tool.

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1. INTRODUCTION

1.1. PROJECT GOALS

Three-dimensional visualization and simulation environments are becoming increasingly important in both industrial and educational environments. Such simulations have an infinite number of uses, from battlefield simulations to architectural design. However, developing these simulations can be a difficult and expensive task. Even before a simulation itself can be created, the underlying software responsible for generating and governing the simulation, commonly known as a *three-dimensional graphics engine*, must be created. These engines govern every aspect of the resulting simulations, from the overall environments and objects contained within, to the views and world interactions of the user, and even the rules of physics that ensure a realistic virtual world (an important consideration for scientific and educational simulations). The development of an engine is a notoriously difficult task. Even commercial teams with experience in such development can take years to fully develop an engine. The engine must be completed before the simulation itself can be developed, which is a substantial software development project in itself. As a result, it is not feasible for most educational and non-commercial entities to develop three-dimensional simulations from the ground up.

There exists a category of three-dimensional simulations outside of the educational, industrial, or military spheres of endeavor. Instead, these simulations are the three-dimensional games found in the commercial video game industry. These games are designed to provide an immersive experience, and often incorporate realistic visual, audio, and physical features. In addition, the developers of these games understand the simulation development problems outlined above. Commercial game engines are often designed to be reusable, and many game companies even license their engines for use in other commercial projects. In addition to this re-usability, many of the resulting three-dimensional games allow players to, within certain restrictions, generate user content and even modify the game itself.

Commercial three-dimensional engines are a potentially useful tool for the creation of simulations in the educational and non-profit spheres of endeavor. By

avoiding the creation of an engine from the ground up, simulation designers can instead focus on developing the simulation itself, with a significant reduction in time, effort, and financial costs. The challenge then focuses on comprehension of the capabilities and limitations of the three-dimensional engine, and developing a simulation within those limitations.

The focus of this project is the development of *Frog Explorer*, an educational game designed for middle-school students. In *Frog Explorer*, players explore a three-dimensional environment designed to be an accurate representation of the interior of a frog head. The goal of this project is threefold: 1) to develop high-fidelity virtual reality educational software with a limited budget and limited personnel, 2) to define a software development process by which similar simulations can be developed, and 3) to prove that these simulations provide a benefit to secondary education.

1.2. PROJECT BACKGROUND

The initial design of this project grew out of the MorphologyNet visualization project carried out between the Missouri University of Science and Technology's Biological Sciences and Computer Science departments [20]. The MorphologyNet viewer is a 3-D visualization program used to view a surface reconstruction of a specimen from histological and/or CT data.

One application that evolved from the MorphologyNet project was the idea of an educational game. For example, middle school students could explore the interior of a frog's head, gaining knowledge and insight into the biological workings of living organisms, and exercising their spatial reasoning skills. The game could be further expanded with the use of quizzes and world interactions, allowing for knowledge retention and problem-solving skill development. Eventually, the game could be placed within a kiosk at natural history museums, or even sent to middle school computer labs around the country.

One option was to develop the *Frog Explorer* game using an existing graphics API to generate the visuals, and a custom game engine to handle all other asset generation and behind-the-scenes calculations. But instead of building a game engine and associated development tools, this project re-used these components from an existing

commercial video game project. As discussed earlier, many commercial computer games, especially those from the first-person shooter (FPS) genre, allow users to generate their own content and modifications for the games, with certain provisions. The most common of these provisions is that the user-generated content cannot be commercially marketed. The *QUAKE III ARENA* game engine acted as a full development environment for this project, allowing personnel to spend more time and resources developing the game, as opposed to developing the underlying tools and technology. The enormous savings in time and effort through the use of a game engine contributed significantly to the success of the project.

1.3. SUMMARY OF INTRODUCTION

The goal of this chapter was to introduce the *Frog Explorer* development project by giving a general explanation of the project and its objectives. It also provided a description of the project's history prior to the work presented in this thesis. In subsequent chapters, the function, development, and evaluation of the *Frog Explorer* educational game will be discussed.

2. RELATED LITERATURE

This chapter will cover background information related to the *Frog Explorer* development project. It will cover the history of computer games in education, as well as examples of game engine use in simulation projects. The material covered in this chapter will provide a proper foundation for the development methodology covered in later chapters.

2.1. USE OF GAMES IN EDUCATION

Terrapin Logo [5] is a computer-based learning tool developed by Seymour Papert with a MIT development team in the 1970s. In *Logo*, students guide a virtual turtle around the screen in various paths. The turtle can be commanded to move straight, turn, and walk in a semi-circle. The turtle can also be commanded to mark its path as it moves along, which allows students to “draw” various designs using the turtle's path. In this way, primary and secondary school students using the tool will learn about geometry and logical thinking. While not strictly a game, *Logo* does demonstrate a design principle that educational games adhere to: the use of a virtual environment to impart knowledge in a subtle, intuitive manner.

Where in the World is Carmen Sandiego? [6] is a well-known and influential educational game, released in 1985 by Broderbund Software. In *Carmen Sandiego*, the player assumes the role of a chief detective tasked with finding and apprehending a world-class thief named Carmen Sandiego [9]. The player uses clues that Sandiego left behind to chase her all around the world. The clues are hints that require the player's knowledge of the geography and history related to the area Sandiego has escaped to in order to follow her. *Where in the World is Carmen Sandiego?* has proven to be one of the more popular and enduring educational computer games, spawning a line of sequel games, as well as two television shows [9] [7].

The Oregon Trail is also a well-known educational computer game. *The Oregon Trail* acts as a very simple computer simulation of pioneers traveling on the Oregon Trail during the 1800s. These pioneers traveled by wagon along the Oregon Trail from Missouri to Oregon in order to settle areas in the Pacific Northwest [24]. The game was

originally created in 1971 by three education majors, Don Rawitsch, Paul Dillenberger, and Bill Heinemann at Carleton College in Minnesota [11]. In 1974, Rawitsch joined the Minnesota Educational Computing Consortium (MECC), a state-funded organization that developed educational software. *The Oregon Trail* was further developed by the MECC, and was released to the public on floppy disk in 1985 [16]. The game proved popular among elementary school students, and has since had eight versions released.

In *The Oregon Trail*, the player takes on the role of the head of a pioneer family journeying to the Pacific Northwest along the Oregon Trail. Game play consists of a series of screens depicting the trials and tribulations the player encounters, played out against the backdrop of a map screen depicting the family's progress along the trail. Players must make a number of decisions as the journey progresses. Examples of these decisions include deciding whether or not to ford a river based on the current and depth, deciding whether or not to examine an abandoned wagon, and deciding if it is advisable to stop the wagon in order to let a sick family member recover. The player must also deal with the numerous difficulties that arise on the journey, often as a direct result of the player's choices. These difficulties include the loss of supplies due to fording a river, or the death of a family member due to dysentery [16]. The game continues until the player's family has reached the end of the trail, or until the player's entire family has perished due to the many dangers present along the trail.

The Oregon Trail remains an influential educational game to this day. The map screen and the game's text introduce players to basic historical and geographic information about the Oregon Trail during its heyday. The tasks the player must accomplish help develop the player's planning and decision-making skills. These aspects of the game create a lasting, nostalgic impression that has elevated *The Oregon Trail* to the status of a cultural icon [16]. *The Oregon Trail* was also influential in the area of commercial educational game production. Through the sale of its multiple editions, *The Oregon Trail* was one of the first games marketed commercially, creating interest in educational games as a commercial endeavor.

There is one particular category of educational games that deserves special mention. This category of games is known as “edutainment” [2]. These games are so categorized because they are created for the commercial entertainment market, but through their particular subject matter and/or software design, they contain a significant level of educational value.

A good example of the edutainment category is *Civilization*, the first game of the popular *Civilization* series of computer games. *Civilization* is a turn-based game in which the player takes on the role of the ruler of a civilization. The player develops his or her civilization over the course of 6,000 simulated years of human history, beginning with the founding of the first cities, up to the near-future space colonization of Alpha Centauri. Of course, the player is not alone on this virtual Earth. Other nation-states, controlled by computer opponents, compete with the player for control. The game can end under a number of conditions: if the simulated calendar runs out in 2020, if the player’s civilization is completely conquered by another civilization, if the player conquers all other civilizations, or if a civilization successfully sends a colony ship to Alpha Centauri.

The main educational value of *Civilization* is found in the game play factors of civilization development that are present in the game. These factors are representative of real-world civilization development. The best example of these factors is city management. As with real-world civilizations, the cities make up the core of the player’s nation-state, with the populations of these cities collecting local resources [8]. Food is used to maintain and increase the population, while resources like lumber and metals are used to create industry goods that either can be used locally or traded to other locations. Since the resource collection rate is limited, players must strike a balance between luxury goods that keep the population happy, and useful goods that actually improve the state of the civilization. A second educational factor in *Civilization* is the need for technological and scientific development. History is replete with examples where a civilization’s technological prowess allowed it to dominate others. The Spanish conquistador Cortez, for example, was able to dominate an Aztec population many times the number of his own force through the use of firearms and artillery. So it is with the player in *Civilization*. A player that neglects technological and scientific development faces

military defeat or economic dominance from other civilizations [8]. A final educational factor within *Civilization* is the means by which the player interacts with other civilizations. Just as in the real world, the player has a number of ways to interact with other nation-states. The player can choose the peaceful paths of trade and diplomacy, or the antagonistic paths of espionage and outright warfare. The three factors of city management, scientific development, and nation-state interaction have a strong basis in history. With these gameplay factors, *Civilization* provides a level of education value that most commercial computer games lack.

A second example of the edutainment genre is *SimCity*, the first game of the *SimCity* series of computer games, and the originator of the system simulation or “God Game” gaming genre. In *SimCity*, the player takes on the role of a city planner, and oversees the development of a simulated city. Viewing the city from an overhead perspective, the player can make various adjustments to the city, such as zoning off land for specific purposes, creating buildings for the population to live, work, and play in, and setting up utility services [3]. As one would expect from a system simulation, the population and resources of the city react to the players’ decisions, so the player must constantly make adjustments in order to keep the population happy and the city's coffers full. The player must also contend with disasters, both natural and man-made, and repair the resulting damage.

The original version of *SimCity* was designed by now-renowned game designers Will Wright and Jeff Braun in 1985, for the Commodore 64 game system. The game was published on the Macintosh and Amiga by Broderbund Software in 1989, and achieved mainstream success after a story in Newsweek magazine [3]. *SimCity* proved to be so successful that it spawned four direct sequel games, as well as the popular “The Sims” spin-off series of “people simulator” computer games. The game also stirred up immense interest in realistic simulations. Wright and Baum were contacted by multiple government agencies, including the U.S. Central Intelligence Agency and the Department of Defense, with requests to create other simulations. Educators also took interest in *SimCity*, using the program as a teaching tool in some 10,000 classrooms [12]. *SimCity*'s real-world use as an educational tool is yet another example of the potential value that commercial video games have in educational endeavors.

2.2. USE OF GAME ENGINES FOR SIMULATIONS

CaveUT [22] is a projection-based virtual reality simulator developed at the University of Pittsburgh, utilizing game engine technology to streamline the simulation development process. CaveUT currently is used by a number of academic project groups to develop and use high-fidelity 3-D simulations. As the name suggests, CaveUT consists of a virtual reality “cave” formed by two intersecting walls. Digital projectors display screen output from multiple PCs merged together to create a seamless virtual environment. CaveUT supports stereographic imaging for a more immersive 3-D experience, as well as real-time spatial tracking to facilitate user-environment interactions. The initial development of the CAVE project began in the 1990s, and utilized both pre-built graphic libraries such as OpenGL, as well as custom graphic libraries. However, despite significant effort and financial investment, these tools only resulted in primitive graphics, limited networking capabilities, and poor overall performance. To compensate for these difficulties, a new version of CAVE was developed in 1997 and used Quake, the first game in the Quake series. The current iteration of the project, termed CaveUT, was developed in 2000 using Quake III's FPS contemporary, *Unreal Tournament*. The use of a game engine proved to be a great benefit, as it provided an excellent architecture for the multiple-PC environment CAVE requires. Using *Unreal Tournament*, each PC can maintain its own complete copy of the virtual environment, and can perform its own graphics and physics computations, resulting in a distributed workload. CaveUT's development history is an excellent argument for our development process, showcasing the difficulty in developing simulations from the ground up, as well as showcasing the utility of game engines in a simulation project.

SIEVE (Spatial Information Exploration and Visualization) [23] is a visualization project that demonstrates one of the classic uses of 3-D simulation: representation of complex data in an intuitive, visual format. *SIEVE* was created within the context of Geographic Information Systems (GIS); that is, information systems designed to model environmental processes. A significant problem with GIS is the tendency to present models and conclusions only in the form of graphs, tables, and 2-D maps. These types of presentation are acceptable for experts in geography and geology, but are not appropriate

for farmers, city planners, and other non-experts who could benefit from understanding this data. SIEVE integrates GIS, 3-D models, and a game engine into a cohesive visualization package. SIEVE goes even further, by creating a collaborative environment where multiple participants can view, alter, and hold discussions on a geographic visualization. The designers of SIEVE chose to use the *Torque Game Engine*, a FPS game engine, and make this choice in accordance with several design considerations. First of all, the license for this engine allowed the designers direct access to the engine's source code. This access allowed for more extensive customization than typical virtual reality development tools would normally allow. Second of all, the engine is multi-platform by nature, which greatly simplified the software development process. Finally, TGE provided a complete set of tools. In addition to the graphics rendering and animation capabilities, TGE provides user chat functionality, networking capability, and a customizable user interface. As the designers had a limited number of staff to create SIEVE, the feature set that TGE provided was what made the project feasible.

Another example of game engine use involves a particularly interesting simulation project involving urban search and rescue robots [15]. These robots are designed to handle urban disaster situations that are extremely hazardous to human beings. The U.S. National Institute of Standards and Technology (NIST) developed a standardized set of three arenas to test and evaluate the capabilities of urban search and rescue robots. The Yellow Arena is designed to test a robot's sensing capabilities with an office environment that contains mirrors, large windows, and low-light areas. The Red Arena tests a robot's locomotive capabilities with a large rubble pile. The Orange Arena tests both sensing and locomotive capabilities with a multiple arena containing both rubble obstacles and reflective objects. While these arenas are excellent tools for testing the capabilities of rescue robots, their usefulness is limited by their geographical location. The expense of maintaining these arenas is significant, so they only exist in a few locations around the world. Robot designers can therefore only test their creations in the arenas on an occasional basis, reducing the rate at which improvements can be made. Designers at the University of Pittsburgh have developed a software simulation of the NIST arenas, using the FPS game *Unreal Tournament 2003*. UT 2003 has several features that the designers used to simplify the development of the simulation. Like

many FPS games, UT 2003 implements “bots”, computer-driven opponents the player can fight with or against. UT 2003 has a tertiary modification called *Gamebots*, which allows these bots to be controlled over a TCP/IP connection through the use of standardized commands and custom scripts. The designers used these bots to simulate the sensors and behaviors of a semi-autonomous robot. The second feature that the designers took advantage of was the physics engine. As discussed earlier, an important characteristic of a rescue robot is its ability to move through a cluttered environment, so it is important that the physics of both the robot and the environmental obstacles be modeled accurately in a simulation. UT 2003 utilizes a robust physics engine called *Karma*. This engine allowed the designers to model the vehicles chassis and arm manipulators of the robot, as well as the behavior of dynamic objects in the environment, without having to calculate and build all of the physical reactions from scratch. This project is an example of a game engine providing tools for simulation construction beyond simply the graphics; network communication and realistic physics simulation are also provided.

An additional example of game engine usage can be found in a visualization project conducted by the University of Missouri-Rolla in 2004 [21]. The project was run in conjunction with the U.S. Department of Defense (DOD), and involved the simulation of obscurant battlefield smoke. The DOD is naturally interested in modeling and simulation, as these methods can replace experiments and training exercises, providing a reduction in costs, as well as an increase in safety. One simulation area of interest is in the simulation of battlefield smoke, and the understanding of how such smoke can influence the visibility of the battlefield. To this end, several battlefield smoke simulation programs have been created. While these programs handle the mathematics and physics reactions, they only display their results in terms of numeric data entries, charts, and graphs. The lack of a visualization component limits the effectiveness of the simulation programs, making the resulting interpretation difficult, and preventing the results from being directly useful in a training program. The primary goal of the project was to connect the data-centric simulation results of two inter-connected simulation programs, known as COMBIC and SSPM, to a visualization component. This component would be capable of taking the simulation results and building a

three-dimensional representation of the simulated battlefield and smoke. The secondary goal of the project was to build this visualization component using a game engine, showing that with this approach, a visualization component could be built with minimal resources and personnel. The game engine platform used for this project was 3DGameStudio, a game development platform for the Windows operating system. 3DGameStudio was chosen because it provides a complete development package, with every design component the developers needed. It contained a 3-D engine, a map editor to easily create the battlefield environment, a model editor to create the objects populating the environment, a scripting engine used to define and control events within the environment, and a plug-in system that would allow the developers to add any custom capabilities the developers might need.

The developers were successful at crafting a visualization component for the COMBIC and SSPM using the 3DGameStudio platform. This visualization component takes the form of a 3-D interactive scenario displaying a 3-D battlefield. Users view the environment from one of four perspectives: the view from a soldier's perspective, the view from the perspective of an armored vehicle, the view from a vehicle emitting smoke, and the view from a floating free-form camera. The user can manipulate each one of these views. In the case of a soldier and vehicles, the user can move the on-screen avatar around the battlefield scene. The free-form camera can be moved in three dimensions as if it were floating freely in the air, such as from a helicopter.

The development of the visualization component described above parallels the *Frog Explorer* project in a number of ways. Like *Frog Explorer*, the goal of the smoke simulation project was to develop a high-fidelity three-dimensional interactive visualization, using minimal resources and personnel. Like *Frog Explorer*, the virtual environment was not arbitrarily designed, but was based on scientific data. And like *Frog Explorer*, the obscurant cloud project used a game engine to minimize the cost, and carefully selected the game engine according to a set of design criteria. With such similarities, the success of the obscurant smoke project is a strong example supporting the *Frog Explorer* development procedure.

The Virtual Environment and Object Modeling (VeNoM) labs of Missouri University of Science and Technology (formerly, the University of Missouri-Rolla) has been involved in a virtual reality project held in conjunction with the U.S. Army's Maneuver Support Center and funded by the Army's Tank-automotive and Armaments Command. The goal of this project was to develop a "First Responder Simulation and Training Environment" (FiRSTE), a virtual training environment [17]. This environment would be used to train first-response emergency personnel in the performance of their duties during the aftermath of a chemical weapon attack. The FiRSTE system can simulate the dispersion of a chemical agent throughout a virtual environment, and can also simulate the operation of a real-world chemical sensor. Thus, emergency personnel training with this system can go through the motions of a chemical agent search as if they were truly at the site of a chemical weapon attack.

Like the other projects described in this chapter, FiRSTE uses a game engine to display the virtual environment, in this case, the Half-Life first-person shooter. Unlike the other projects, however, this project uses the game engine within the context of a full virtual reality system, complete with a head-mounted display, and a treadmill-based scene navigation system. The game engine is interfaced with several custom hardware and software modules. In addition to the head-mounted display and treadmill, the game engine interacts with a custom software module that simulates the dispersal of the chemical agent, a custom software module that simulates the operation of the chemical sensor, and the underlying simulation architecture software that unifies all other components into a unified whole. The use of the Half-Life engine in this project is noteworthy, as it shows that a game engine is a useful tool even in complex settings where interfacing with customized software and hardware modules is necessary.

2.3. USE OF SIMPLIFIED GAME DEVELOPMENT SOFTWARE

A possible alternative to the use of a game engine as a development platform is the use of simplified programming tools. These tools are primarily designed to be educational in nature, allowing individuals with little programming background to create graphics-based computer programs without worrying about the intricacies of syntax. The tools can be powerful, but also can be limited in capability, especially for the experienced

programmer. The rationale for investigating the use of these programming tools was an attempt to lower the complexity of the design tools used to create *Frog Explorer*. The software tools typically used to create virtual environments are notoriously complex and difficult to use. These tools require users to view and manipulate the virtual environment from multiple viewpoints simultaneously, understand and memorize a wide variety of complex commands, and may even require mathematical knowledge and advanced computer programming skills. It was therefore a worthwhile endeavor to examine the ranks of simplified programming tools, in an attempt to find a development environment that would allow the creation of a virtual environment without the complexity normally associated with such a task.

The primary candidate among the simplified programming tools reviewed for this project was the *Alice* visual programming language [25]. *Alice* was originally developed in 1997 at the University of Virginia [10], with continuing development at Carnegie Mellon University. *Alice* has a simplified development environment that computer novices can use to create virtual environments. It is particularly notable among simplified programming languages for its ability to generate fully 3-D environments without the complexity of standard 3-D programming tools. The most striking feature of *Alice* is the code editor. This editor allows users to script events in their virtual environments through drag-and-drop building blocks. The building blocks correspond to various aspects of imperative programming, such as variables, methods, loops, and conditional statements. The user drags a building block into a sequence, which results in the creation of a Java code fragment behind the scenes. The editor has error checking that prevents the user from creating a sequence that will result in syntax errors. The editor also facilitates the creation of scripts that respond to keyboard and mouse input, allowing *Alice* programmers to create actual games, as opposed to non-interactive 3-D sequences. This type of editor drastically reduces the knowledge required to create an application, as the user does not need to know the formal syntax of the underlying programming language to build code fragments. The *Alice* interface contains other features necessary for the design of 3-D virtual environments [18]. For example, the interface contains an object tree to track the relationships between objects in the virtual environment. It also contains a view-port that allows the designer to place objects into

the virtual environment, and then observe the environment from the same perspective as the end-user. *Alice* uses a combination of Java and Java 3-D to generate the virtual environment, and uses the Python scripting language to create the scripts generated by the code editor sequences. Once the virtual environment has been completed, Alice can export it into a .jar file, which can then be embedded into a Web page.

Alice was an attractive potential development platform for *Frog Explorer*, due to its ability to create virtual environments without the complexity of standard 3-D design tools. However, *Alice* was created to be an educational tool to teach programming, not a tool to create production-level applications. As such, several of its design features make it less suitable for the creation of an immersive 3-D game than a traditional game engine. The virtual environments produced by the *Alice* tool-set are quite small in relation to the player's viewpoint. Such a small environment would have difficulty in conveying the impression of actually being inside a frog head. The user's ability to view the virtual environment during the design process consists of a single view-port without a discrete coordinate system. This single view-port system is adequate for novice users, but does not provide the capability to observe and manipulate a particularly complex virtual environment. The drag-and-drop paradigm of the code editor is again, simple for the novice to use, but cumbersome for the experienced programmer. Finally, the fidelity of the graphics produced by the Java components of *Alice* is significantly less advanced than those of even 10-year old FPS game engines. As a result, the environments produced by *Alice* would be much less immersive than those produced by a FPS game engine.

2.4. SUMMARY OF RELATED LITERATURE

This chapter provided a survey of related literature, including existing educational computer games, as well as contemporary uses of game engines in academic environments. Chapter 3 will cover the use of the *Frog Explorer* game from the perspective of the user.

3. USER INTERFACE AND VIRTUAL ENVIRONMENT

This chapter will describe the functionality of *Frog Explorer* from the perspective of the user. The system requirements, startup sequence, user interface, and user controls will be discussed, as well as the structure and layout of the virtual environment.

3.1. PROGRAM SETUP AND SYSTEM REQUIREMENTS

The system requirements for *Frog Explorer* are the same as the system requirements for Quake III Arena. The minimum system requirements for the Windows version of Quake III Arena are [1]:

- a Pentium 233 MHz processor,
- an 8 megabyte video card fully compatible with the OpenGL graphics API,
- a Windows 95/98 operating system installed,
- a quad-speed CD-ROM drive,
- a sound card 100% compatible with Microsoft's DirectX audio components, and
- a Microsoft-compatible mouse and keyboard.

All of these system requirements are easily exceeded by even contemporary low-end PC hardware. Despite the game's age, Quake III Arena is compatible with both Windows XP and Windows Vista.

The setup process for *Frog Explorer* is relatively simple, even without an actual installer. First, Quake III is installed to C:\quake3 on the base C system drive. Second, the Quake III 1.32 point release is installed to patch Quake III to the last version. This version is compatible with modification projects that necessitate changing the source code, and is therefore necessary for the game. Third, the customized assets, maps, models and source code, are placed within the quake3 directory. Each type of asset (maps, models, and source code) is placed in its own folder, and then all three custom asset folders are placed within a global modification directory. This modification directory is then placed in the base quake3 directory. The global modification directory gives easy access to the custom assets created for the game, while maintaining separation between custom game files and original game files.

The final step in the setup process is the creation of a customized Quake III shortcut. The command line for this shortcut is augmented with a set of command switches that Quake III will recognize. These switches enable Quake III to allow custom content, and to load the customized virtual environment immediately upon program execution. An example of this customized shortcut is the following:

C:\quake3\quake3.exe +set vm_game 0 +set vm_cgame 0 +set vm_ui 0 +set sv_pure 0 +set fs_game mymod +map froghead. The *C:\quake3\quake3.exe* portion is the default command line, and runs the Quake III executable. The *+set vm_game 0* portion of the shortcut instructs Quake III to allow the use of a custom game.qvm file. Quake Virtual Machine (QVM) files are compiled code files that govern certain functions within Quake III. The game.qvm file governs all aspects of Quake III related to the behavior of the server version (Quake III has a client-server architecture in order to support games with multiple players). Normally, Quake III will not allow the use of custom .qvm files; by setting the *vm_game* flag to 0, Quake III will allow the use of a custom server code file. The *+set vm_cgame 0* and *+set vm_ui 0* perform the same function for the cgame.qvm and ui.qvm files, which govern the client version and user interface functions respectively. The *+set sv_pure 0* function instructs Quake III to allow for an “impure” server. A “pure” server is a server that only allows game assets provided with the original Quake III installation to be used. Since *Frog Explorer* acts as both a client and a server, the *sv_pure* switch is used to instruct the program that it should allow the use of custom game assets. This switch acts as a prerequisite to the three previous switches, as well as allowing the use of custom models and textures. The *fs_game mymod* switch informs Quake III of the directory for the custom .qvm files, models, and textures which are stored within the base quake3 directory. In this example, Quake III searches the *mymod* folder for all custom game assets. The final switch is the *+ map froghead* switch. This switch instructs Quake III to load a particular virtual environment, named *froghead*, immediately upon program execution, instead of forcing the user to select the environment and associated game option from Quake III’s initial menu. This switch is used to load the player directly into the virtual frog head environment, circumventing the display of the Quake III options menu. Once this shortcut is created, a simple double-click will take the user to the starting location within the game.

All of the setup steps after the installation of Quake III and its point release have been automated with a customized installation program. Once Quake III and the point release have been installed, the *Frog Explorer* installation will place all custom assets in the correct directory structure, and will create a customized desktop shortcut and Start Menu shortcuts.

3.2. USER INTERFACE AND CONTROLS

The user interface is simple, with a lack of on-screen elements. This simplicity was deliberately engineered for three reasons. First and foremost, a simple, unobtrusive user interface avoids underscoring the fact that *Frog Explorer* is a game, and instead adds to the immersive feeling of being inside a frog head. Secondly, the target audience for this game is younger users who may or may not have experience in computer games. A simpler user interface will aid in the acclimation process for new players from this audience. Finally, a simpler interface is easier for system designers to maintain.

Upon entering the game, the player views the environment from a first person perspective, with none of the typical on-screen user interface elements such as navigation maps and compasses. The only user interface component utilized is a targeting crosshair, placed in the very center of the player's view. In a standard FPS game, this crosshair is used by the player to aim his or her weapon. The player manipulates the view to place the crosshair on a target, and the following shot will travel in the direction in which the crosshair is pointing. In *Frog Explorer*, the crosshair defines the center of the player's viewpoint, acting as a means by which the player can orient himself/herself. Figure 3.1 shows an example of the user interface

Similar to the user interface, the controls also have been kept simple. *Frog Explorer* employs the standard "W-A-S-D" control scheme that FPS games traditionally use. In this scheme, the left-hand manipulates the location of the player's virtual avatar, and the right-hand manipulates the view of the avatar with the mouse. Pressing the W key moves the avatar forward in respect to the player's view, pressing S moves the player backward, and pressing A or D sidesteps the player left and right, respectively. In a similar fashion, moving the mouse up, down, left, or right moves the player's viewpoint in the corresponding direction. The WASD control scheme is a widely-used control

navigation scheme in computer games, and worked very well during *Frog Explorer's* user testing (which will be discussed in Chapter 5).



Figure 3.1: User interface example with crosshair.

3.3. STRUCTURE AND LAYOUT

The overall layout of the virtual frog head is a hub structure. Each area of interest within the frog head (eyes, ears, mouth, etc.) is modeled as a specific room, with a large central room (the brain) acting as common access to most of the other rooms. The reasoning behind this layout is two-fold. First, a common hub allows for easier,

procedural navigation. Second, this structure is consistent with frog anatomy, as the eyes, ears, and nasal cavities truly are accessible from the brain.

3.3.1. **The Brain.** In the game the brain is a flattened sphere several times as large as the eye, ear, and nasal cavity rooms. A thin circular sheet the diameter of the widest portion of the brain is suspended halfway between the top and the bottom of the brain. This sheet acts as the “floor”, giving players a stable surface upon which to traverse the room. At the same height as the floor, six tunnels are built into the walls of the brain, equidistant around the circumference of the sphere. Each of these tunnels leads to one of the eye, ear, or nasal cavity rooms. The visible surfaces of the brain are textures with a custom texture resembling the inside surfaces of an actual frog brain, adding to the brain's realistic appearance. An example screen shot of the brain room is shown in Figure 3.2.

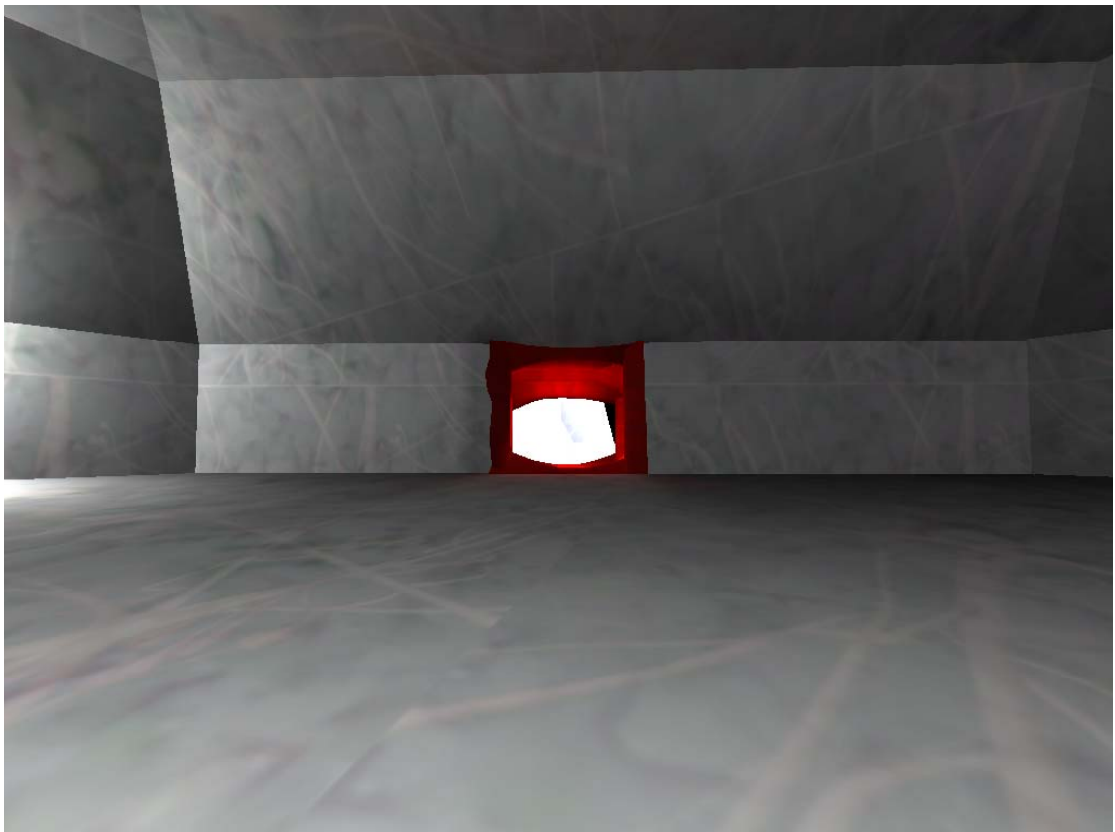


Figure 3.2: The brain area, with a connecting tunnel to the eye.

3.3.2. The Ear. Two identical ear structures exist in the virtual frog head. Each ear consists of two identically sized spheres several times smaller than the brain. These spheres are placed touching each other, and connected to each other through openings cut where the two spheres touch. As with the brain, this structure is representative of frog anatomy. Again, each ear is textured for a realistic appearance. The ear chamber closest to the brain contains a representation of the semicircular canals, an organ in the ear that helps maintain a frog's sense of balance. This object is shown in Figure 3.3.

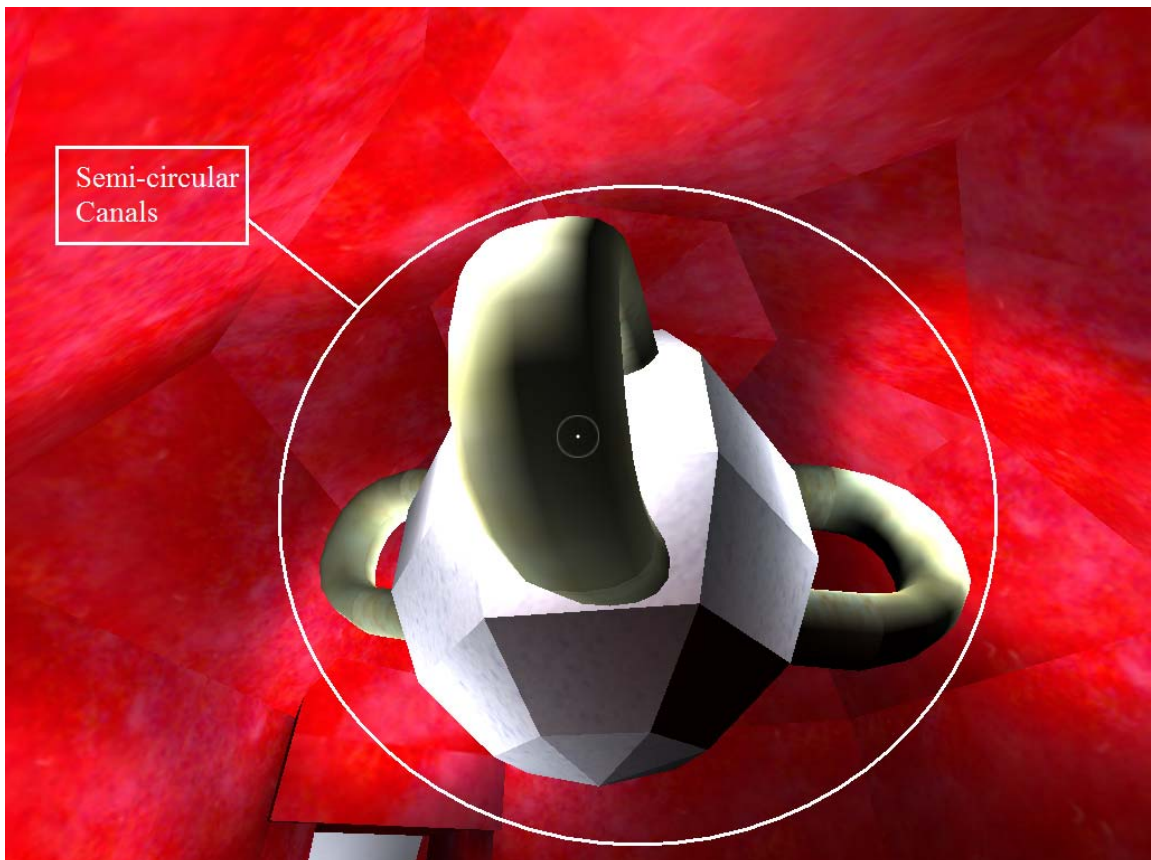


Figure 3.3: First ear chamber with semicircular canals.

The second ear chamber also contains significant objects. The first object is the ear bone, which runs along the width of the chamber above the player. The ear bone is shown in Figure 3.4. The second object is an invisible trigger running along the floor of the chamber. When touched by the player, the trigger plays a .wav file of a bullfrog croaking. Because this chamber would be closest to the exterior of the ear in a real frog, it is reasonable to assume that a person who was somehow inside the frog's ear would be able to hear the frog croaking from this position.

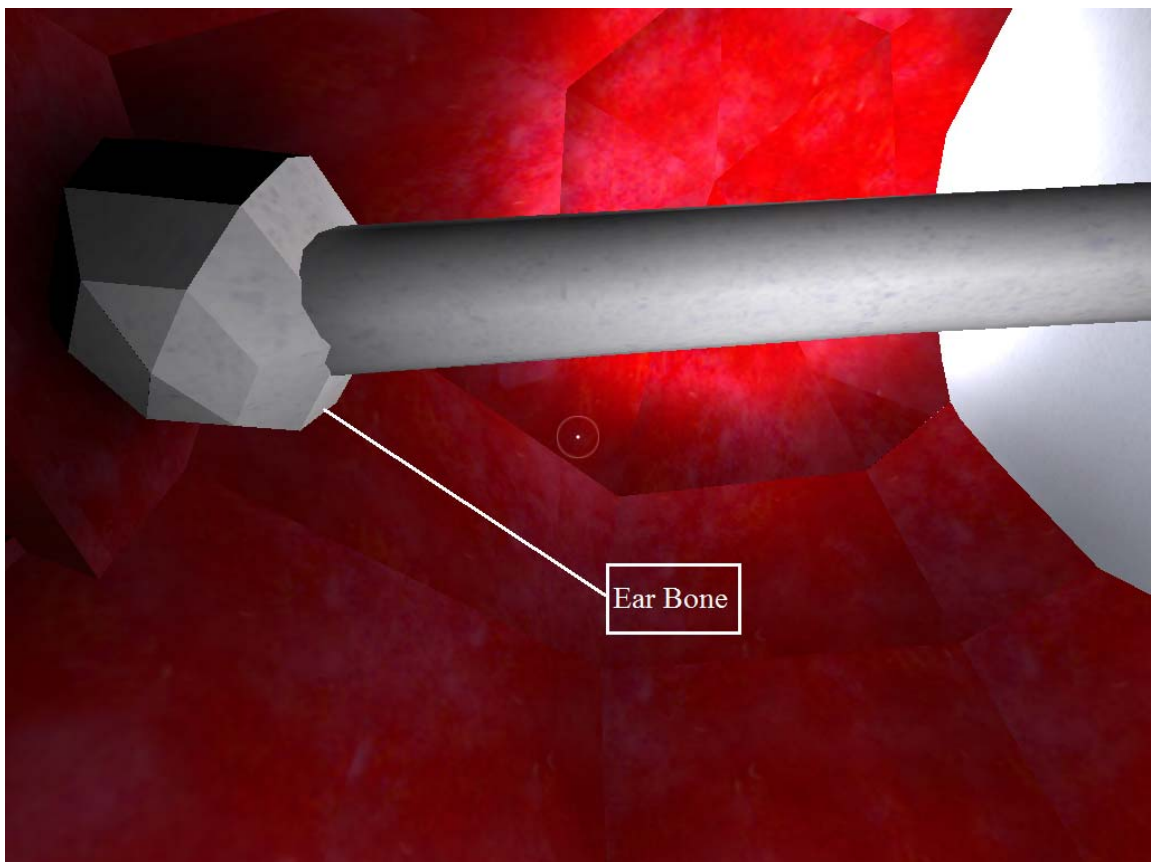


Figure 3.4: Second ear chamber with ear bone.

3.3.3. The Eye. Two identical eye structures exist in the virtual frog head. Each eye is a single sphere of the same size as a single ear chamber. The eye contains texturing, as well as a pupil and iris structure along the front wall of the eye. Positional lighting gives the appearance that light from the outside of the eye is pouring in from the pupil, again consistent with the anatomy of the eye. Figure 3.5 shows the pupil, iris, and positional lighting.

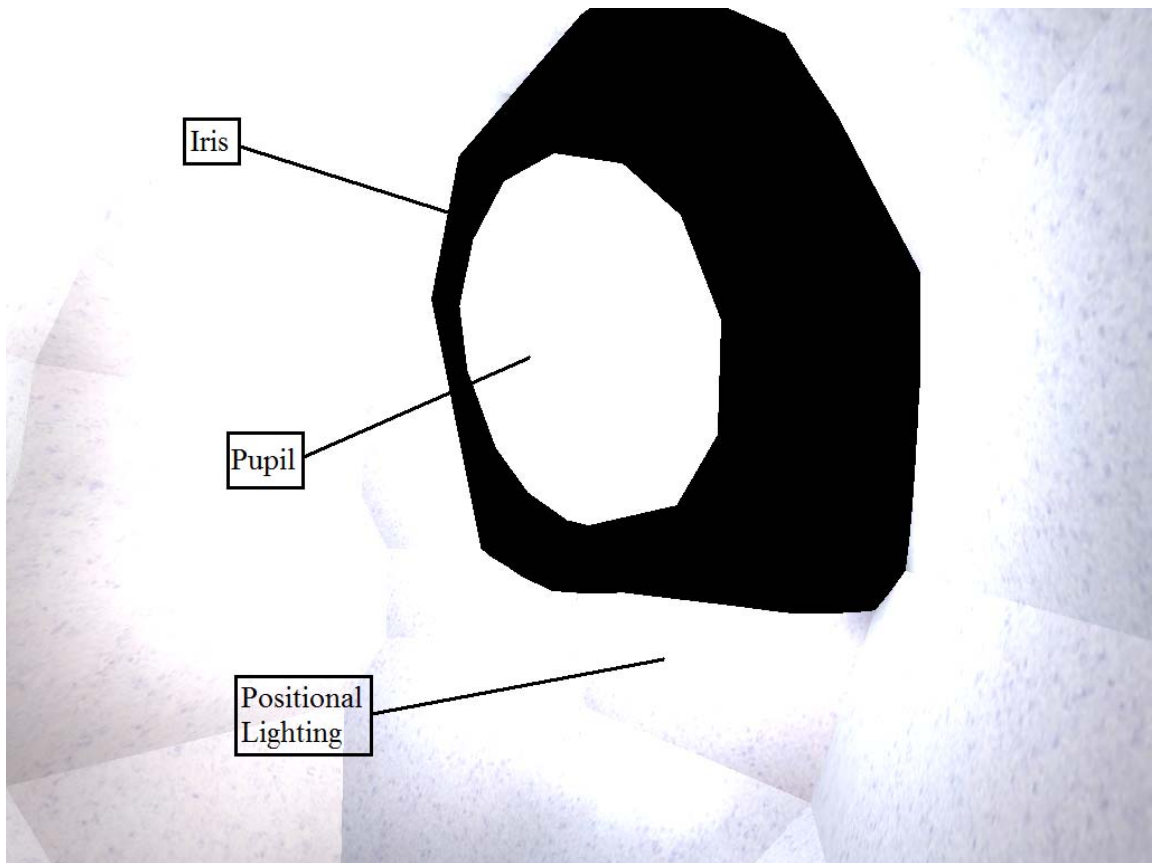


Figure 3.5: Eye chamber with iris, pupil, and positional lighting.

3.3.4. The Nasal Cavity. As with the eyes and ear, there are two identical nasal cavities attached to the brain. Each nasal cavity is a spherical room approximately the same size as the eye chamber. In addition to the custom texturing, the nasal cavity has several distinctive features. The walls are covered with special “patch” objects shaped in such a manner as to give the nasal cavity the appearance of being covered in soft, puffy flesh, just as in a real nose. In addition, a textured circular sheet is placed against the “front” wall to give the appearance of a nose hole, and the nasal cavity is filled with volumetric fog to represent the particles of outside material that are used during the smelling process.

The nasal cavities contain one additional feature of note. From the biological perspective, the nasal cavities are the only areas in the virtual frog head with a direct physical connection to the mouth. Accordingly, the nasal cavity contains a passage to the mouth. Since the mouth is positioned some distance below the nose, the passage takes the form of a trapdoor built into the floor of the nasal cavity. To avoid any usability issues that might arise from the traversal of a downward tunnel, a different traversal method is used. Quake III has a system of teleportation functionality. The designer can designate an object as a teleportation object. Touching this object will automatically move the player directly to a pre-determined location. A teleportation object is located directly below the trapdoor in the nasal cavity. Players fall “into” the teleportation object, and are then transported directly to the mouth.

All significant features of the nasal cavity, including the soft tissue, fog, nasal cavity, and trapdoor, are shown in Figure 3.6.

3.3.5. The Mouth. The final area in the game is the mouth. The mouth takes the form of a high-ceilinged room several times larger than the eye, ear, and nose rooms. The walls and ceiling are appropriately curved to give the appearance of a mouth interior. Teeth-shaped objects are embedded into the ceiling, and custom textures are used with particularly great effect to create a realistic appearance. Figure 3.7 shows the teeth and custom texturing. A teleportation object is placed on the floor at the back of the mouth, allowing players to move back to the nasal cavity.

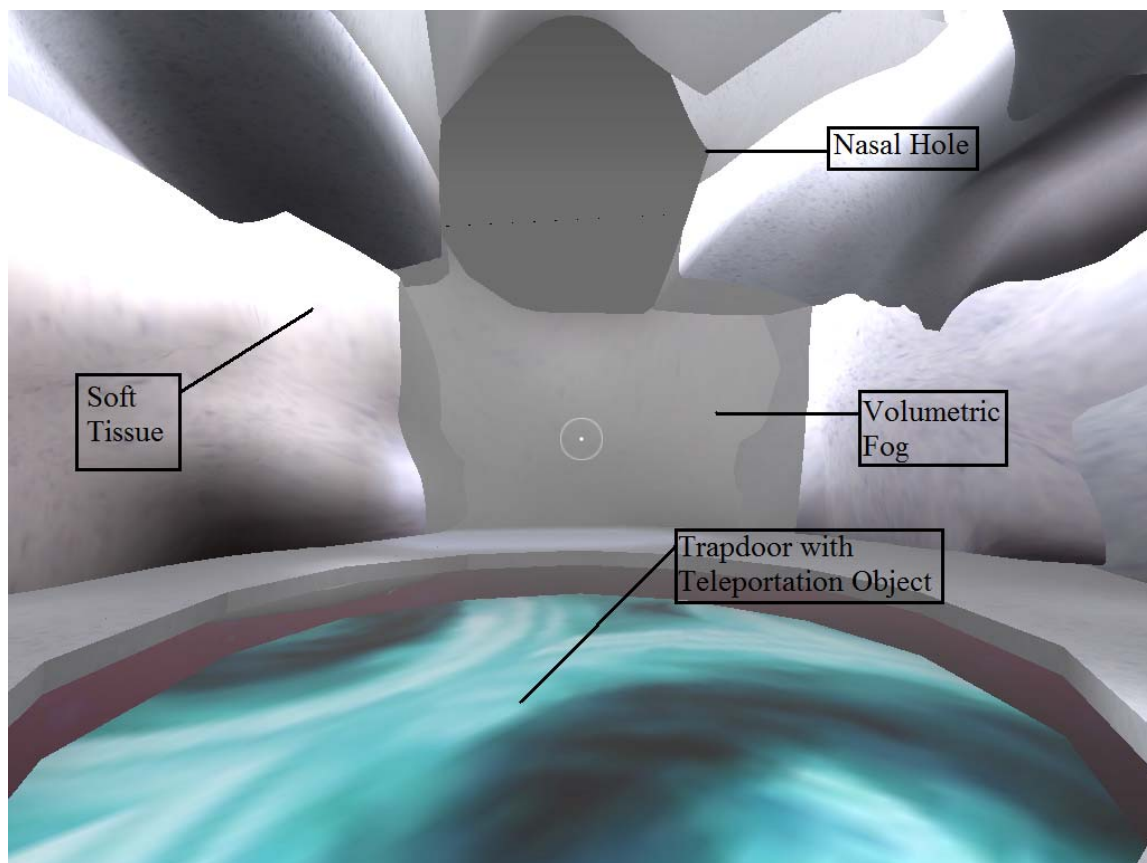


Figure 3.6: Nasal Cavity chamber with multiple features.

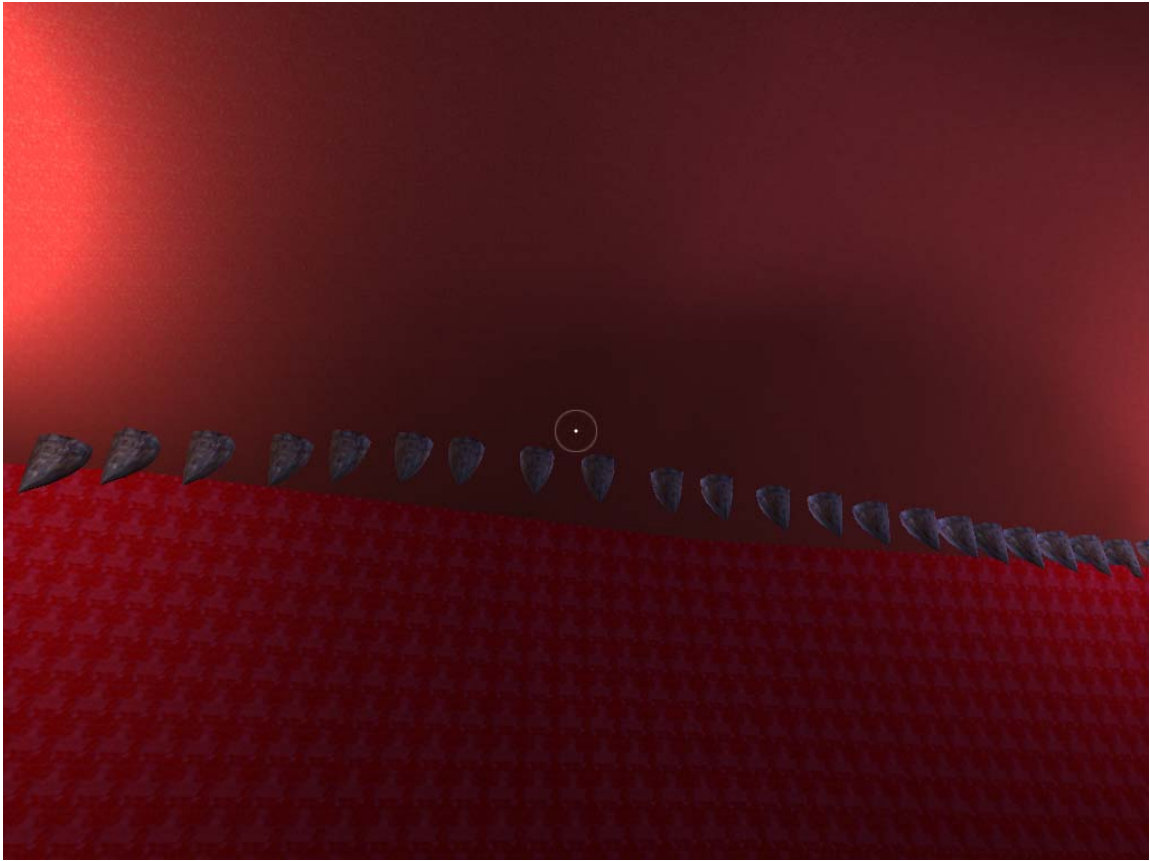


Figure 3.7: Mouth room utilizing custom textures and teeth objects.

3.4. SUMMARY OF USER INTERFACE AND VIRTUAL ENVIRONMENT

This chapter described the *Frog Explorer* experience from the perspective of the user. The system requirements and setup were presented, and the user interface and control scheme were described. The chapter ended with a tour of the virtual environment players explore during the course of the game. Chapter 4 will present the system design process for *Frog Explorer*.

4. SYSTEM DESIGN

This chapter will cover the system design process used during the development of the *Frog Explorer* game. It will begin with a general overview of the development approach, including the selection of a game engine platform, as well as the criteria used to make this selection. It then will cover the specifics of the development process, describing the process by which the game's three-dimensional environment, custom game models, and modified source code were created.

4.1. OVERALL DEVELOPMENT APPROACH

The first development decision to be made was the selection of which game engine to use. One of the primary goals of the project had always been to make the player feel as if s/he was actually inside a frog. Thus, the idea of using a FPS game engine naturally suggested itself. FPS games naturally lend themselves to player immersion; indeed, that is the primary source of their popularity. In addition, FPS games were among the first games to allow for extensive user modifications, and as such, several FPS game engines were available. After some deliberation, *Quake III Arena* was chosen as the development platform. This decision was due to several important design considerations:

- **System Requirements:** FPS games are among the most graphically complex computer games available today, and modern FPS games are a major impetus in graphics card and CPU upgrading. *Quake III Arena*, however, is several years old, and most modern computers can run it reasonably well.
- **Proven Viability:** *Quake III Arena* is one of the most licensed FPS game engines, with three critically acclaimed FPS shooters, *Return to Castle Wolfenstein*, *Star Wars: Jedi Outcast*, and *Star Trek: Elite Force*, using the engine as the basis for their development. This spoke well of the engine's capabilities.
- **Organic Look-and-Feel:** The 3-D engines behind many FPS games inevitably result in virtual environments with a highly industrial look to them, utilizing square corners and rectangular objects. This look is especially apparent in older FPS games, which utilize fewer polygons in the construction of 3-D objects than

their modern counterparts. It was desirable to use an older game engine as a basis for development, because this would lower the system requirements of the resulting game; however, an older game engine would have a more industrial look to its environments, which was at odds with the need for the game to have curved, organic-appearing surfaces. Quake III Arena, while an older FPS, is an exception to the industrial look problem. While certain elements of Quake III environments still have an industrial look, the underlying engine is far more capable of curved surface generation than its contemporaries. Quake III's balance between system requirements and organic-looking surface generation was an important factor in its selection as the development environment.

- **Modification Tools and Knowledge:** One of the more significant problems in developing FPS modifications is the limit in the support given by the original developers. While some documentation and software tools may be provided by the development teams, programmers must learn how to modify the virtual environment on their own. Quake III Arena has been a popular user modification platform for a number of years, and in those years, a great deal of development knowledge and several useful Quake III-specific software tools have been made available.
- **Modification Limits:** The source code for Quake III Arena has been released under public license, and is free for anyone to use. Access to the source code allowed us to make greater modifications than most FPS games normally allow.
- **Platform Interoperability:** There are versions of Quake III for Windows-, Macintosh-, and Linux-based computers. The executable files produced by the Quake III compilation tools are completely platform-independent. It was therefore possible to create installation files for all three operating systems with a minimal amount of effort.

Once an appropriate game engine had been selected, the next step was the process of learning the development environment, and acquiring the necessary software tools. The development of this project can be split into three different areas: *the maps*, *the models*, and *the programming code*. The *maps* are the overall 3-D environments that Quake III uses. These maps are the major focus of almost any Quake III modification,

and as such, a special editor, *GTKRadiant*, has been developed to create them. *GTKRadiant* was used to develop a Quake III map with the visual appearance of the interior of a frog's head. The ears, eyes, nasal cavities, brain, and mouth are all represented by rooms appropriately shaped and colored, and connected by anatomically accurate tunnels. The *models* are the 3-D objects used to populate a Quake III map. In a normal map, these objects are typically weapons, ammunition boxes, teleportation devices, and other objects appropriate for a science-fiction-themed combat game. This project's custom models are objects appropriate to the anatomical environment, such as internal organs, nerves, and membranes, as well as the objects that players will actually interact with in order to play the game. Quake III Arena uses a custom model format called MD3. The MD3-formatted models were created using a combination of the Lightwave and Milkshape 3D modeling programs. Finally, the *programming code* is the Quake III Arena source code released by Id Software. This code, written in C, governs virtually every aspect of Quake III Arena. It was modified to add extra functionality necessary for the game, as well as to remove any undesirable elements, such as weapons and ammunition.

The development of *Frog Explorer* began with frog head diagrams provided by Dr. Analia Pugener, an amphibian morphologist at the Missouri University of Science and Technology Department of Biological Sciences. These diagrams were used to identify areas of interest, as well as to establish their proper scale and positioning. The eyes, ears, nasal cavities, brain, and mouth were all identified as areas of interest, and each area needed to exist as a room within the virtual environment. Figure 4.1 is an example of these diagrams, detailing the interior structure of a frog's nasal cavity.

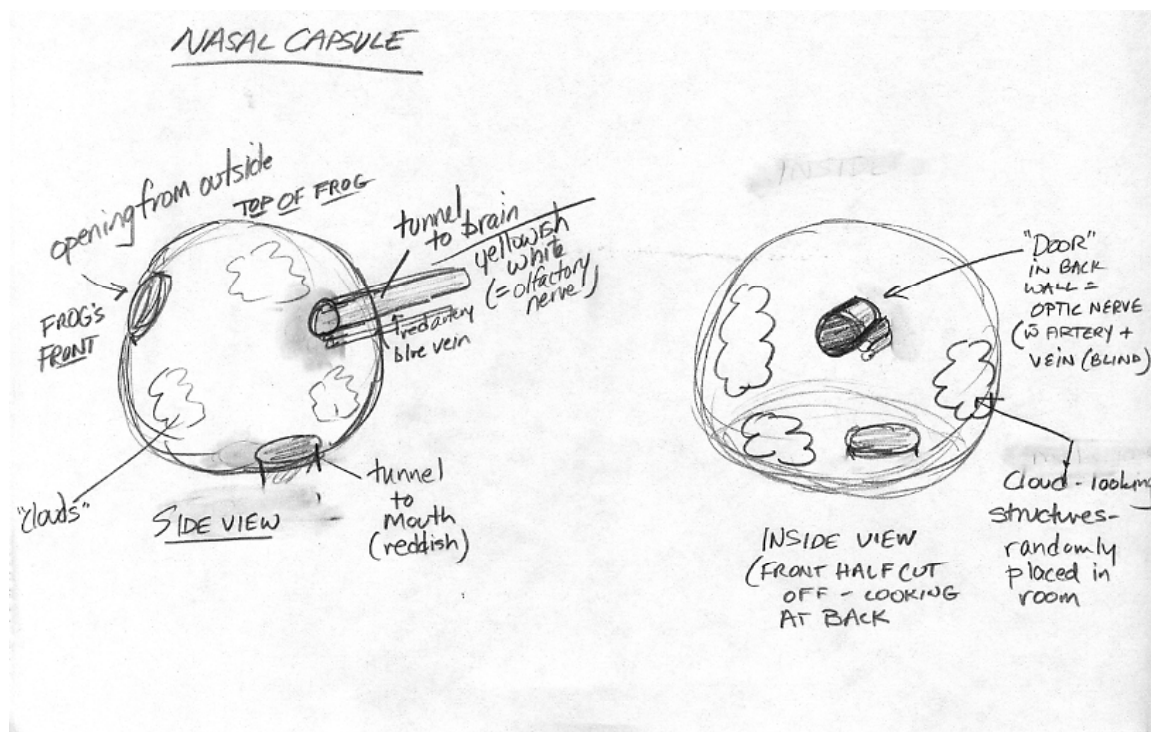


Figure 4.1: Nasal cavity diagram.

Once the diagrams had been analyzed, development began in earnest. For this project, an agile software development life-cycle was used, similar to *Extreme Programming* or *Rapid Application Development*, in which a prototype was developed quickly, submitted for feedback, and further developed in an incremental fashion. Development began with the Quake III map design, using the GTKRadiant editor. In this design, the brain is a large spherical room that acts as a central hub, from which almost all other areas are directly accessible. The starting location for the player is always the brain. Tunnels connect the brain to each of the two eyes, the nasal cavity, and the two ear rooms. Each eye is a spherical room $\frac{1}{5}$ the size of the brain, with a pupil on the front wall of the sphere. An interesting feature of the eye rooms is the light sourcing. Each eye has light-sourcing set up to appear as though light is streaming through the pupil, which is the behavior one would expect in an actual eye. Each of the two nasal cavities is a spherical room the same size as the eyes. Each nasal cavity is covered in "patches"

stretched and distorted to give the appearance that the cavity is covered in soft tissue, which is representative of the actual anatomy. Each nasal cavity also has a connection to the mouth room. Because the mouth room is located directly below the brain, eyes, nasal cavities, and ears structures, tunnels were not used to connect the cavities and the mouth together. Quake III features a teleportation object that can be used to move the player directly between two locations. Each nasal cavity contains a teleportation object that can transport the player directly to the mouth. Each ear consists of two spheres connected by a small tunnel, because a frog's ear consists of two different chambers. The first sphere contains a model of the semicircular canals, an ear organ that helps the frog keep its balance. The second sphere contains the frog's ear bone. The final room in the map is the frog's mouth. This room is located below all other rooms in the map. The mouth is of similar size to the brain, though with a far higher ceiling. The main features of the mouth are the tongue, which acts as the floor the player will stand on, and the teeth, which are located along the ceiling. The mouth also features two teleportation objects, which allow the player to travel directly to each of the nasal canals. Figures 4.2 and 4.3 display the customized Quake III map as viewed externally using the GTKRadiant editor.

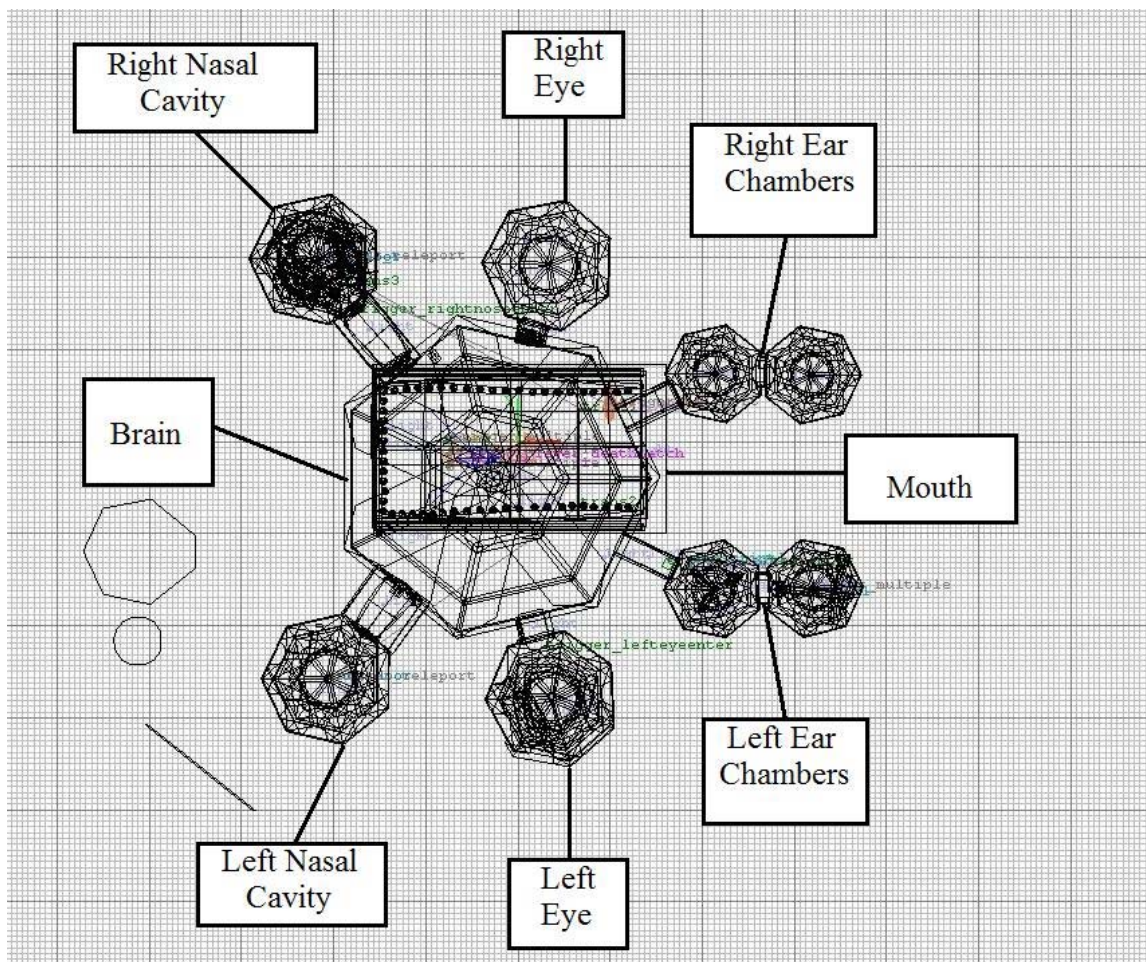


Figure 4.2: Top-down view of the virtual environment in *GTKRadiant* editor.

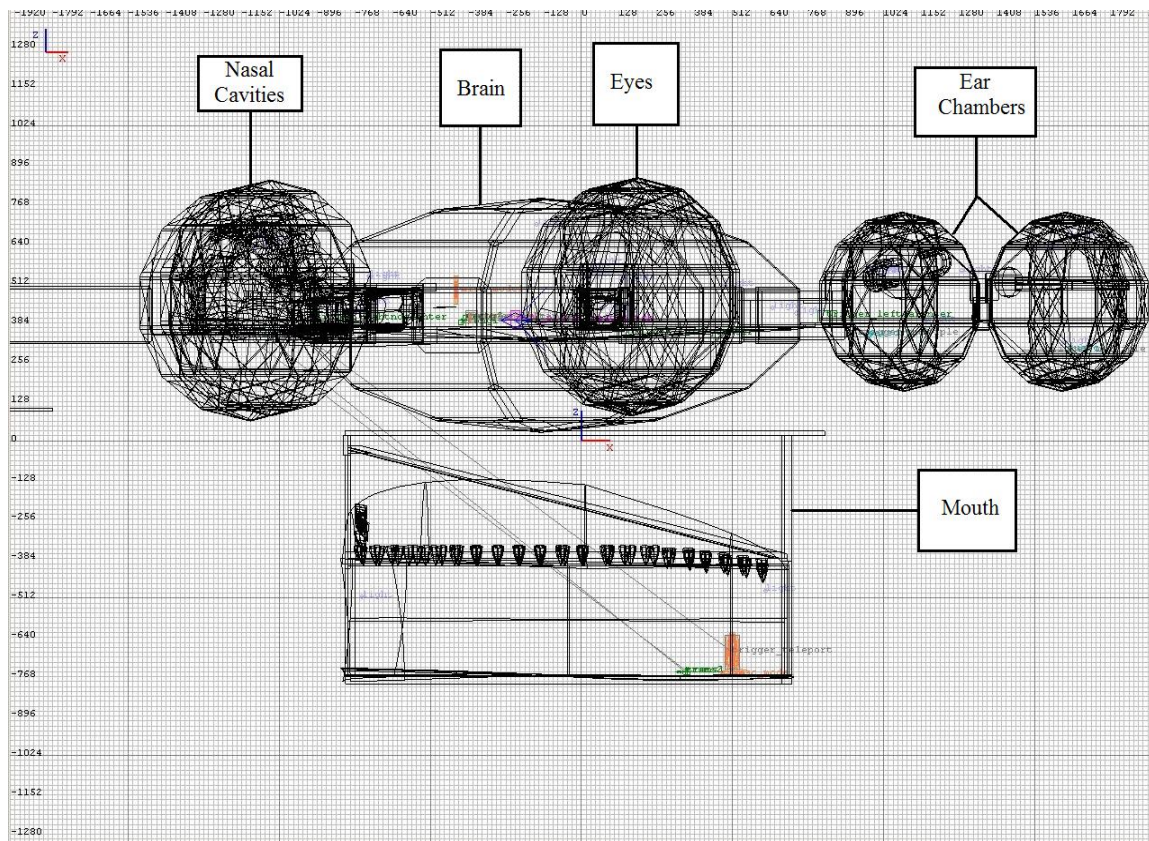


Figure 4.3: Side view of the virtual environment in *GTKRadiant* editor.

Once the rooms had been created, it was time to develop the custom additions that would transform these bland rooms into realistic-looking interiors. The most important of these additions were the custom textures. All surfaces in a Quake III map must be covered in a texture, which gives the surfaces their color and appearance. These textures are stored as .jpeg or .tga image files, with a standard resolution of 32x32 pixels. The GIMP freeware image editor was used to create several textures with the proper organic appearances. Figure 4.4 displays three custom texture examples. The left-most texture is the texture used to cover the majority of surfaces in the brain area. The middle texture is used to cover nerves in the brain, as well as a portion of the semicircular canals in the ear. The rough-looking texture on the right is used to cover the tongue structure that is present in the mouth room.



Figure 4.4: From left to right, the brain, nerve, and tongue custom textures.

The second custom addition was the collection of game objects. These objects were used to populate the rooms with the various biological structures one would expect to find in a frog head, as well as the objects with which the players interact. Many of the objects, such as the ear bone, eye pupil, and teeth, were created within GTKRadiant, using the editor's existing selection of shapes and patch objects. However, certain objects were simply too geometrically complex for the editor, and other objects required custom animations that GTKRadiant cannot create. These objects required full 3-D models. Building 3-D models for Quake III is less straightforward than for other applications, as Quake III uses its own custom modeling format, known as MD3. MD3 requires a specific file structure and has an extensive “tag” system for controlling animations. Most 3-D modeling programs cannot handle MD3 models natively, although custom plugins have been written for 3dsMax, Lightwave, and Maya, which provide a limited degree of functionality. This project, however, used Milkshape 3-D, a shareware modeling program designed with game modification in mind. Milkshape natively supports the MD3 format, and provides automation for the MD3 construction process. For situations where Milkshape would not suffice as a modeler, Lightwave 8 was used to create the model, and exported to a Lightwave 6.5 object, which Milkshape can import and use. Milkshape was then used to convert the model into MD3 format.

Modifications then were made to the source code. As mentioned earlier in this chapter, Id Software released the Quake III source code in 2005, granting free access to

almost every aspect of the Quake III engine. The release of the source code was a primary factor in our decision to use Quake III, as it allowed for greater modifications than most game platforms would normally allow. The source code is written in C, and is separated into three sections: client code, server code, and user interface code. As one might expect, the client modules contain the functionalities of the client (player), the server code contains all the functionality for maintaining a Quake III Arena multi-player server, and the user interface code creates the various icons, menus, and displays that the player sees within the game. The decision was made early on to restrict the scope of the game to a single-player environment, so most of the modifications were within the client and user interface modules. Weapon models, ammunition boxes, hazardous environmental effects, and all other combat-related objects were removed or rendered invisible to the user. In addition, most of the heads-up display (HUD) elements, including the weapon selection icon, ammunition counter, and player health indicator, were removed. The targeting reticle HUD element was left in place, as it always remains in the center of the player view, providing a means of visual orientation. Figure 4.5 displays the default Quake III user interface, before the HUD elements were removed. Figure 4.6 displays the new interface, after the HUD element removal.

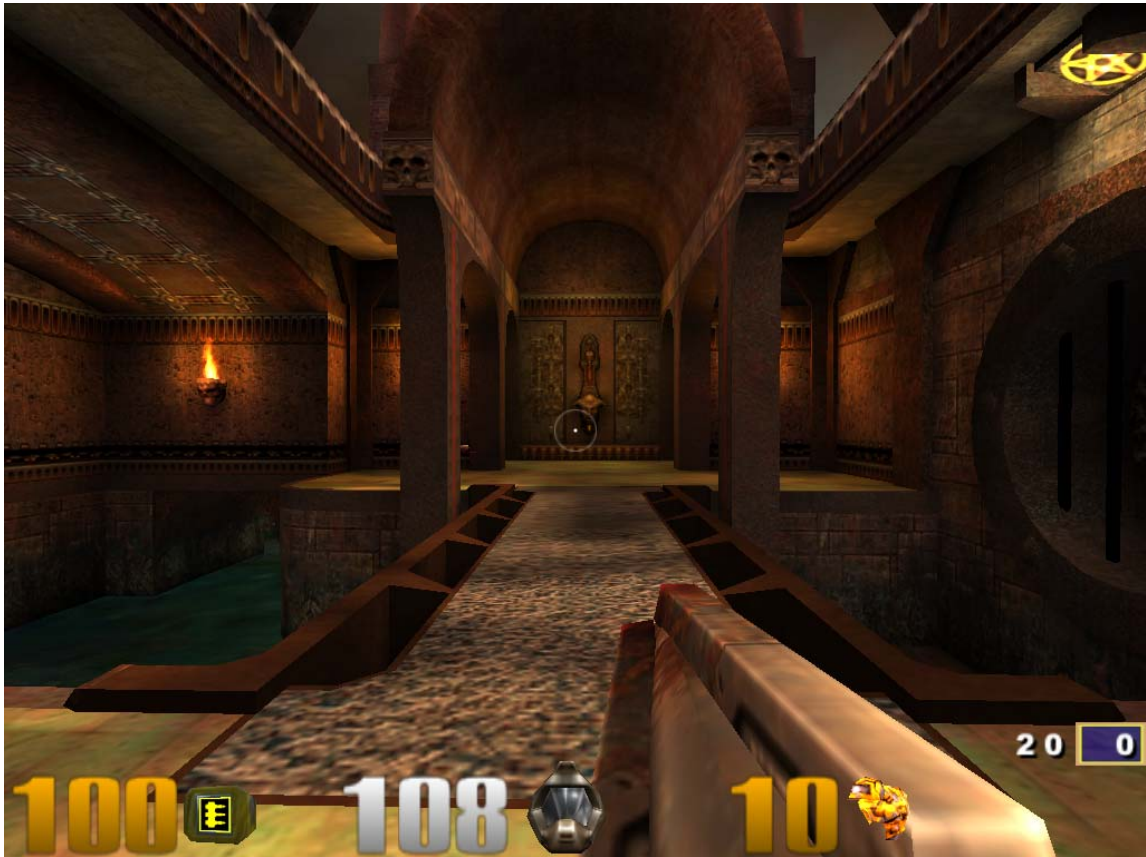


Figure 4.5: Default User Interface.



Figure 4.6: Custom user interface with center reticle.

4.2. SUMMARY OF SYSTEM DESIGN

This chapter covered the development process of *Frog Explorer*. It discussed the criteria by which the Quake III engine was selected for this project. The chapter then discussed the development of the three major project components: the *maps*, the *models*, and the *programming code*. Chapter 5 will discuss the usability evaluation performed on *Frog Explorer*.

5. USABILITY EVALUATION

This chapter will cover the initial usability evaluation performed on *Frog Explorer*. It will begin with a discussion of the experimental procedure, which will include the experimental objectives, the experimental design, and the reasoning behind this design. The chapter will end with a summary of the results of the usability evaluation.

5.1. EXPERIMENT DESIGN

The usability study was a formative, qualitative study designed to identify any usability problems with *Frog Explorer*. Eliminating such problems was of paramount importance, as these problems could have interfered with the learning study intended to evaluate the game's educational value. The primary test instrument for this study was a play-test of the virtual environment. A thorough exploration of the virtual environment by even a few players would reveal any usability problems significant enough to interfere with further user testing [26]. Three child participants, all recruited from the Columbia, Missouri area, participated in the usability evaluation.

5.1.1. Experiment Objectives. The next phase of the project was a small-scale usability study performed on an early prototype of *Frog Explorer*. This study was carried out in preparation for further user testing that would be used to test the effectiveness of *Frog Explorer* as a learning tool, and would be used as the basis for the conclusions of this report.

While the study was designed to uncover unanticipated design issues, it was also conceived to explore specific design details where usability was in question. The specific design issues were as follows:

- The *Frog Explorer* version used in this study utilized Quake III's default keyboard controls, which are standard for PC-based FPS games. These controls use the W, A, S, and D keys to move the player, and use the mouse to turn the player's head. A goal for this study was to determine whether or not the WASD control scheme was usable for the target audience. If not, adjustments to the key bindings would need to be made in order to create a more appropriate control scheme.

- The *Frog Explorer* version used in the study contained no aids to assist the player in navigating the virtual environment. This exclusion was deliberate, as the game was conceived as a game of exploration and discovery. A goal for the study was to determine if users would be able to navigate the environment on their own, or if some form of navigational aid was necessary.
- The route from the nasal cavity to the mouth did not use a tunnel to connect the two areas, but instead used teleportation objects. When the player touched the teleportation object, he or she would be whisked off to the appropriate area within the virtual environment. This approach simplified the transportation medium between the nasal cavity and the mouth, which would have required a considerable amount of development time to create a large and complicated tunnel. However, this method of transportation was radically different from the normal method of simply walking to each room. The usability of the teleportation method was therefore an area of concern.
- A particular problem during the development of this project was the creation of cylindrical tunnels to connect the rooms. Creating biologically accurate, visually appealing, usable tunnels proved to be a particularly challenging task over the course of development. Therefore, a usability test of the tunnels was of particularly strong interest.

5.1.2. Experimental Procedure. The usability study was carried out with individuals in the Columbia, Missouri area. The study was planned out in the following manner:

- *Participants:* Three individuals participated in the study. While the size of the participant pool was small, even for a usability study, it was believed that any usability issue severe enough to impair further user testing would be detectable with this number of users [27]. These three participants were children 11-13 years of age.
- *Materials:* All usability tests were carried out using a Gateway MX6446 laptop. This laptop utilized an AMD 1.60 GHz processor, 896 megabytes of RAM, a 90-gigabyte hard drive, and a Windows XP operating system installation. An incomplete build of *Frog Explorer* was installed on this laptop. The build was

incomplete in that the virtual frog had only one complete version of the ear, eye, and nasal cavity rooms instead of two of each. It was neither necessary nor desirable to complete the full two sets of rooms, as each pair of rooms would be identical in the final version of the game.

- *Procedure:* During the usability study, each participant engaged in a one-on-one, approximately 15-minute session with the tester. The experiment was split into two phases. During the first phase, each participant was placed in front of the laptop, and the keyboard/mouse controls were verbally explained. The participants were then asked to explore the virtual frog head. They were allowed to explore wherever they wished, and to spend as much time exploring as they wanted. The only restriction placed upon the participants was that they were to attempt to explore the entirety of the virtual environment before quitting. Each participant was encouraged to “think out loud” as he or she explored. The tester recorded the participants’ actions and comments on a log sheet (see Appendix A). Each comment was recorded as belonging to one of four categories: Controls, Navigation, Look and Feel, and Miscellaneous. The Controls category contained all comments pertaining to the keyboard and mouse controls the player used to control the virtual avatar. The Navigation category contained all comments pertaining to a player’s ability to traverse the virtual environment. The Look and Feel category contained all comments pertaining to the aesthetic details designed to make the virtual environment appear to be a frog head. During the second phase, the tester directly asked the participants for feedback regarding the specific usability issues described in the previous section. The interview sheet that the tester used to solicit this feedback can be found in Appendix A.

5.2. EXPERIMENT RESULTS

The usability study was successful, as it detected several usability issues that were severe enough to derail further user testing, as well as providing useful feedback on a wide variety of minor issues. The severe usability issues, and their corresponding solutions, are detailed below:

- *Unintuitive Control Schemes:* The default WASD keyboard control scheme had mixed results among the three participants. Two of the participants used the WASD control scheme without any difficulties, but these users explained that they had played other FPS computer games, and were already familiar with the controls. The other participant was not familiar with PC-based FPS controls. This participant visibly struggled to move her avatar through the virtual environment, often having to look at the keyboard to reposition her hands over the correct movement buttons. This user suggested using the arrow keys as the movement control keys, as these keys more intuitively suggest forward/backward/left/right movement. The proposed solution for the issue was to ensure that both control schemes were present in *Frog Explorer*. Instructions for both control schemes were placed at the player starting position within the game. Participants in the learning study held later were allowed to pick between these two control schemes. Figure 5.1 displays the two control instruction postings.
- *Room-to-Room Navigation:* All three users had difficulty navigating the virtual frog head. Two of the participants were completely unable to navigate the frog head systematically, and repeatedly entered rooms they had already visited, even though they meant to discover new areas. The third user displayed the same initial confusion as the first two users, but solved the navigation issue by moving around the diameter of the brain room, visiting each room in turn. These behaviors indicated that the navigation problems were centered on the inability to differentiate between areas when traveling to them from the central brain hub. Players must use the brain as a hub area to travel to almost all other areas of the frog head, yet the passages to the other areas look virtually identical. A player must travel down the tunnel in order to tell where the room actually goes. The solution, as suggested by one user, was to place a sign next to each passageway into the brain, indicating where the passageway goes. Figure 5.2 displays an example of the navigational signs that were later added. To further reduce any navigational confusion, navigation signs also were later placed next to the teleportation objects indicating their destination points



Figure 5.1: Control instruction signs



Figure 5.2: Right ear navigation sign.

- *Teleportation Disorientation Problem:* The teleportation objects used to facilitate travel between the nasal cavity and the mouth proved to be a source of disorientation for all users. The immediate and abrupt nature of the transportation left the participants confused, unable to realize that the teleportation objects modeled the physical connection between the nasal cavity and the mouth. One participant suggested that the teleportation mechanism could be used, but that the appearance of the objects needed to be changed. This participant suggested having the teleportation objects appear as stairs, because that appearance would provide a more intuitive understanding of their use. Later a stair mock-up was built into the floor of the nasal cavity, suggesting the presence of a passage “down” to the mouth. A corresponding stair mock-up was placed in the mouth,

suggesting the presence of a passage “up” to the nasal cavity. Figures 5.3 and 5.4 show the stairs in the nasal cavity and the mouth, respectively.

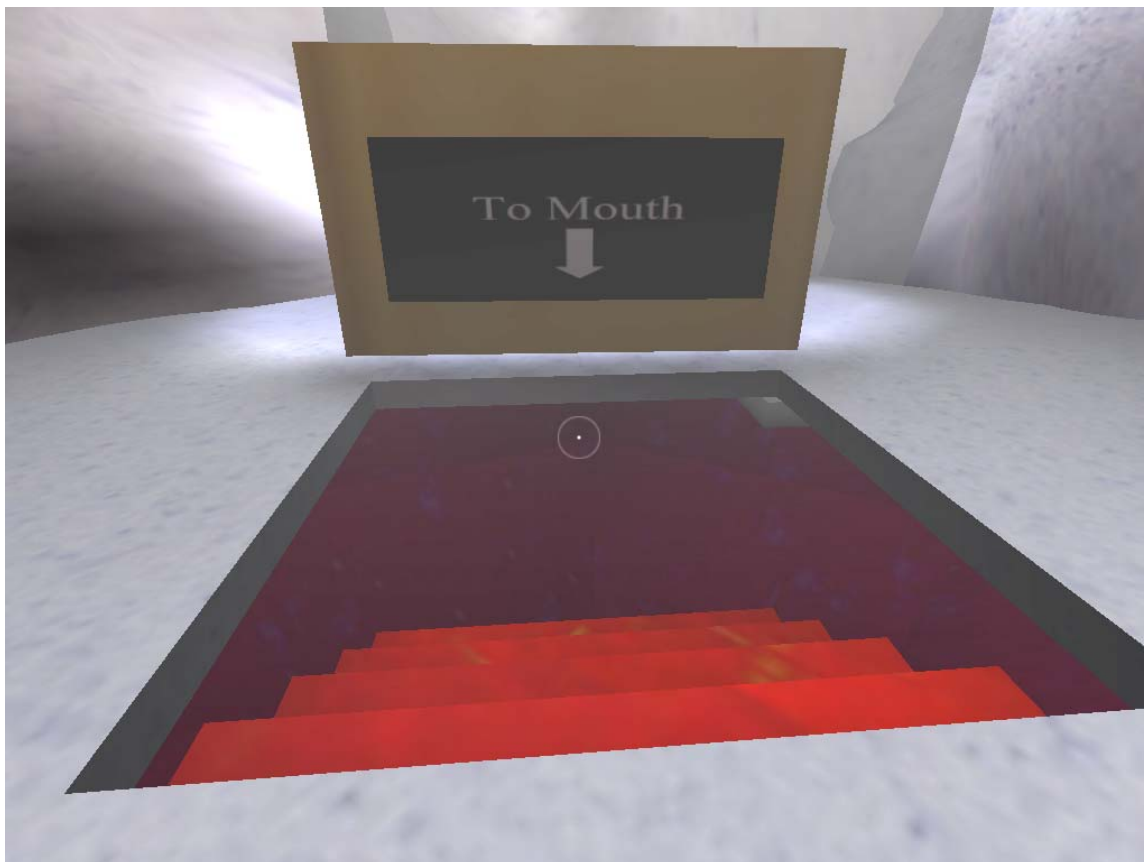


Figure 5.3: Stair mock-up in the nasal cavity.

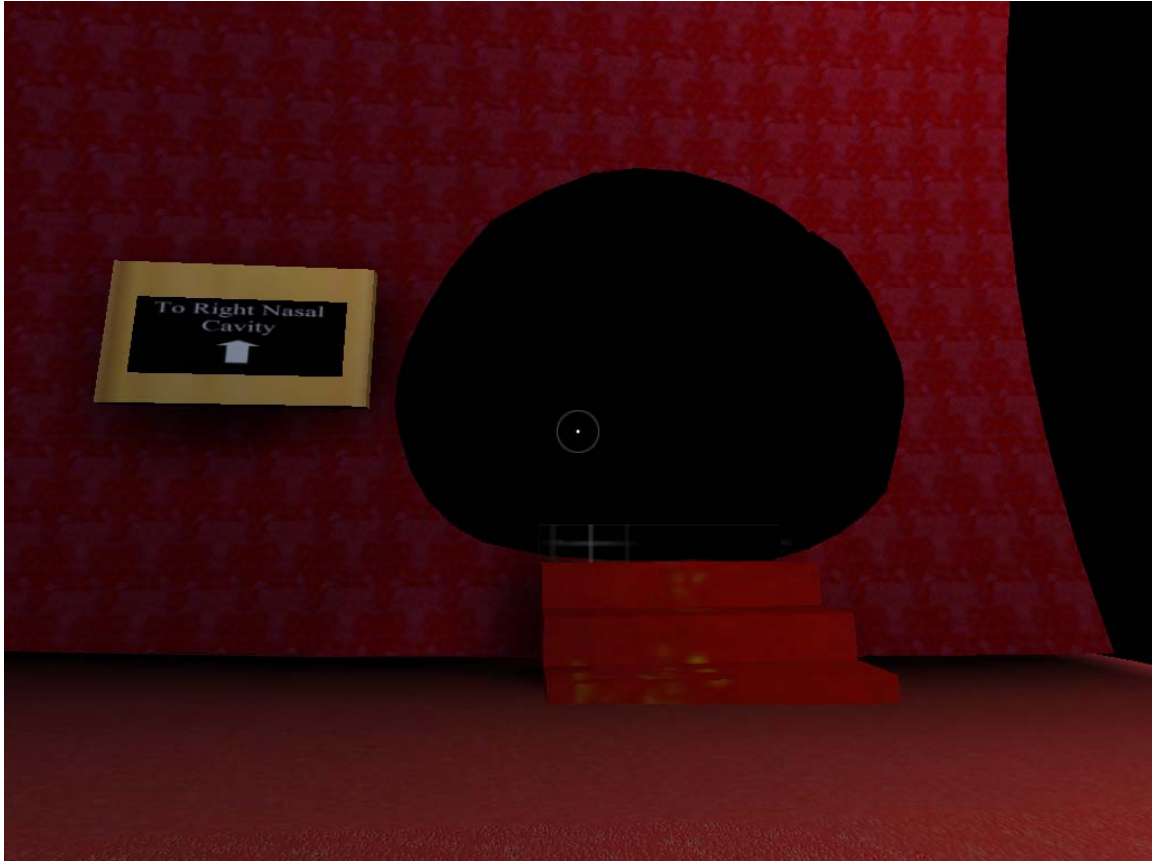


Figure 5.4: Stair mock-up in the mouth.

- *Mouth Door Problem:* All three users had difficulties with the teleportation object that was built in the floor of the nasal cavity. Every participant accidentally triggered the teleportation object multiple times while trying to explore the nasal cavity, even with the sliding door built over it to specifically prevent this problem. As a result, the participants were completely unable to explore the nasal cavity itself, as they would continually travel to the mouth instead. Feedback from the users revealed that the teleportation object and its door took up too much floor space, and was nearly impossible to avoid. While the problem was severe, the proposed solution was simple. The size of the door later was reduced to only slightly larger than the size of the player's avatar,

requiring the players to deliberately enter the door opening if they wished to move to the mouth. Figure 5.5 displays the revised door opening.



Figure 5.5: Avatar-sized mouth door.

In addition to the usability issues just described, the study generated useful feedback on a host of more minor issues. A complete listing of all usability feedback, for both major and minor issues, can be found in Appendix B. Tables 5.1, 5.2, and 5.3 provide a summary of the trends found among the minor issues. Table 5.1 lists trends pertaining to the Control category, Table 5.2 lists trends pertaining to the Navigation

category, and Table 5.3 lists trends pertaining to the Look-and-Feel category. Each of these three tables consists of four columns. The *Trend* column identifies the trend in question. The *True* column identifies the number of participants known to be part of the trend in question. The *False* column identifies the number of participants known to not be part of the trend in question. The *UNKNOWN* column identifies the number of participants whose participation in the trend could not be determined.

Table 5.1. Summary of Usability Experiment Control Trends

Trend	TRUE	FALSE	UNKNOWN
User found WASD control intuitive	2	1	0
User found arrow key control intuitive	1	2	0
User desired on-screen control instructions	2	0	1
User desired game controller controls	1	2	0

Table 5.2. Summary of Usability Experiment Navigation Trends

Trend	TRUE	FALSE	UNKNOWN
User could not discern position relative to other rooms	3	0	0
User was able to tell that they had visited all areas	1	2	0
User found the door in the nasal cavity too small	3	0	0
User desired text-based navigational aids	1	0	2
User did not notice second ear chamber	1	2	0
User identified connection between mouth and nasal cavity	0	1	2

Table 5.3. Summary of Usability Experiment Look-and-Feel Trends

Trend	TRUE	FALSE	UNKNOWN
User found tunnel slopes difficult to walk on	2	0	1
User became stuck inside of a tunnel	1	2	0
User felt curved surfaces to be insufficiently smooth	1	0	2
User recognized brain on sight	3	0	0
User recognized eye on sight	2	0	1
User recognized mouth on sight	2	0	1
User recognized nasal cavity on sight	0	2	1
User recognized ear on sight	0	0	3
User cited textures as immersive factor	1	0	2
Nasal cavity teleporter appearance unintuitive	1	0	2
Mouth teleporter appearance unintuitive	1	0	2
Lighting in the brain uneven	1	0	2
Mouth walls lacked curvature	1	0	2
Tongue lacked curvature	1	0	1
Desire to see outside world from mouth	1	0	2
Need for throat "opening" at the back of the mouth	1	0	2

Several of the minor trends displayed above influenced the redesign of the game and the design of the final user study, and as such, merit a brief discussion. The inter-room tunnels had been difficult to develop, requiring multiple redesigns in order to create tunnels that the user could travel down without getting stuck. The usability study showed that the tunnels were usable, revealing that the numerous tunnel redesigns had been worth the time and effort. In accordance with user suggestions, the sides of the mouth and the

tongue were adjusted to have a greater amount of curved surfaces, resulting in a more organic appearance. The most interesting feedback received amongst these minor issues was the preference for undirected exploration. All three participants expressed a preference for freedom of exploration. The participants did *not* want the game to tell them where to go or what to do. As a result of this discovery, the decision was made to include an exploration activity in the final round of user testing.

The comments in the following list were not mentioned by more than one participant, and thus did not constitute a trend. Although these comments were not significant enough to influence the development of *Frog Explorer*, all feedback is worthwhile, and worthy of mention:

Control Comments:

- Since one user was an experienced FPS gamer, the user expected the mouse button to shoot or otherwise provide a level of interaction with the environment.

Look-and-Feel Comments:

- One user liked the immersive feeling of being inside a frog head. The user did not like seeing out-of-place objects like the teleporter object, as it detracted from the immersive feel. The user stated that this immersive feel was the best part of the experience.
- One user really liked the use of sound, such as the narration and the croaking noise.
- One user found the environment to be, in general, very large. He also felt that this was a good feeling to have.
- One user liked the default gravity, and the fact that he could jump, but that there was a limit to how high he could jump.
- One user commented that he liked the way the map was sectioned into distinct rooms, and thought these rooms would be good places for educational stations in which to have activities.
- One user felt that there would be educational value of having textbook drawings of the various biological areas available in the corresponding rooms. This way,

there could be a comparison between what the player “thinks” the area looks like, and what it actually looks like.

Miscellaneous:

- One user did find it somewhat strange that he could not see any part of his character model.
- One user thought that it would be “cool” if he could see another human running around in the frog head, if for no other reason than to establish an additional sense of scale.
- One user suggested that an “info” button be placed in an out-of-the-way place on the screen (she suggested the bottom-left corner). This info button, when pressed, would display basic information about the particular area of the frog head that the player was currently in, as well as a “fun fact” to get a player interested in what the area had to offer.
- One user liked that the game presented an alternative to actual dissection.
- One user commented that they thought the game would be “good for learning.”
- One user suggested that there could be different “modes” for the environment. As an example, the user suggested that there could be a “diseased” mode, which would result in a different appearance for the various areas. This could dovetail with the idea that frogs can be used as environmental indicators.

5.3. SUMMARY OF USABILITY EVALUATION

This chapter covered the initial usability study that was conducted on *Frog Explorer*. The purpose of the study and the experimental procedure that was used were described. The chapter ended with a discussion of the study results, and their implications for *Frog Explorer*. Chapter 6 will discuss the final step of the project: an evaluation of *Frog Explorer's* ability to educate.

6. LEARNING EVALUATION

This chapter will cover the learning evaluation study that was performed as the final phase of this thesis project. The chapter will begin with a discussion of the purpose and goals of the study. It will then move into an in-depth explanation of the experimental procedure used in the study, and will conclude with a discussion of the study results.

6.1. EXPERIMENT DESIGN

The primary goal of the learning evaluation was to evaluate the effectiveness of *Frog Explorer* as a learning tool. The evaluation was carried out as a formative study, with both qualitative and quantitative assessments. The primary test instruments of the study were a play-test of the virtual environment, followed by a drawing activity. The play-test, an exploration of the virtual frog head, exposed the participants to the educational content present within the game. The drawing activity, which required participants to fill-in areas of a frog head diagram, reproduced the educational content the participants actually learned. By comparing the drawings with the educational content present within the game, it became possible to evaluate the game's effectiveness as a learning tool. Eleven child participants were recruited from the Columbia, Missouri area to participate in the study.

6.1.1. Study Goals. The primary goal of this study was to evaluate *Frog Explorer's* effectiveness as an educational tool. In order to perform this evaluation, the study focused on the game's ability to promote understanding of the spatial relationships between different segments of frog anatomy. The reasoning for this focus was that the creation of a biologically accurate virtual frog head always had been the primary objective of the game's development. The realistic construction of the virtual environment is the game's strongest educational asset, so it made sense to evaluate the game based on this criterion.

6.1.2. Experimental Procedure. The learning evaluation was carried out over the course of two weeks, utilizing eleven middle-school students who were recruited from Hallsville Middle School, located 10 miles from Columbia, Missouri. All middle-school participants belonged to the target audience of 11-13 years of age.

Four participants were female, and seven were male. All study sessions were carried out using the same Gateway laptop that the previous experiment employed, but with an updated version of the game. This version incorporated the changes intended to alleviate the severe usability issues discovered in the previous study. This version also included the complete set of ear, eye, and nasal cavity rooms.

Each participant engaged in a single, one-on-one, 30-minute session with the experimental observer. Each session consisted of three phases. The first phase was an exploration activity similar to that of the exploration activity conducted in the first round of user testing. The participant was asked to explore the virtual environment, thinking aloud as he or she explored the frog head. In this experiment, the purpose of the exploration activity was two-fold. The first purpose of the activity was to give the user the opportunity to gain spatial knowledge of the frog head environment. The second purpose was to again test the usability of the environment, including the changes to the environment as a result of the first usability study. To ensure that all participants had similar times on task, two restrictions were placed on the explorations. Firstly, each participant was only allowed to explore the game for 15 minutes. Secondly, each participant was asked to fully explore all areas of the frog head before the end of the time limit. These two restrictions ensured that all participants would receive an equivalent amount of spatial knowledge. As before, the experiment observer recorded participant comments and observations in each of four categories: Controls, Navigation, Look and Feel, and Miscellaneous.

The second phase of the study was the learning evaluation. This evaluation took the form of a drawing activity. After the first phase, each participant was given a scientific drawing depicting a frog head, viewed from the side. A copy of this drawing can be found in Appendix A. Each of the eye, ear, nasal cavity, mouth, and brain areas depicted in the drawing were enclosed in an unlabeled colored circle. Each participant was given a pencil, and was asked to identify each circled area with a label. In addition to the labeling, the participants were asked to fill in the circles with the details of each area they observed while playing the game. The participants were allowed to fill in these details in writing or by drawing. Each participant was given 10 minutes to complete this

activity. To evaluate the results of the drawing activity, a checklist was created before the learning study was carried out. This checklist consisted of the educational details built into *Frog Explorer*, separated by their location within the frog head. This checklist can be found in Appendix A. The checklist was used on the drawings to determine what spatial details each participant had grasped and remembered.

The third phase of the learning study was identical to the second phase of the usability study. Each participant was interviewed directly about certain usability issues. Again the list of interview questions can be found in Appendix A.

6.2. STUDY RESULTS

6.2.1. Learning Evaluation Results. Once the testing for the learning study was completed, an evaluation of the drawing activity was conducted, using the checklist described in Section 6.1.2. The checklist was compared to each drawing. Checklist items that were correctly described and placed within the correct area of the frog head were marked as “correct.” Checklist items that were described but placed incorrectly were marked “incorrect.” Checklist items that were not present on the drawing at all were marked “blank.” Table 6.1 is a compilation of the drawing activity evaluation results, sorted by area within the frog head. Tables 6.2 through 6.4 contain data derived from Table 6.1, and were used to analyze the results of the learning evaluation. A complete listing of all drawing activity results can be found in Appendix C.

Table 6.1: Compilation of Drawing Activity Results, Sorted by Area.

Brain Details:	Correct	Incorrect	Blank
Large ovoid room shape	0	0	11
Correct label	5	4	2
Wall texture	0	0	11
Connection to ear	3	0	8

Table 6.1 (continued)			
Connection to eye	3	0	8
Connection to nasal cavity	2	0	9
Eye Details:			
Correct label	5	3	3
Main eye texture	1	0	10
Iris and pupil on front wall	5	0	6
Connection to brain	2	0	9
Spherical shape of room	0	0	11
Ear Details:			
Correct label	7	4	0
Semi-circular canals	2	0	9
Earbone & side circle	4	0	7
Main wall texture	0	0	11
Connection to brain	1	0	10
Bullfrog noise	1	0	10
Spherical room shape	0	0	11
Two chambers	2	0	9
Nasal Cavity Details:			
Correct label	7	2	2
Connection to brain	2	0	9
Connection to mouth	5	0	6
Soft tissue on walls	3	0	8
Fog	0	0	11
Nasal hole	2	0	9
Spherical room shape	0	0	11

Table 6.1 (continued)			
Mouth Details:			
Correct label	7	0	4
Connection to nasal cavity	2.5	0.5	8
Tongue shape and texture	2	0	9
Mouth shape and texture	0	0	11
Teeth shape	5	0	6

Table: 6.2: Correct, Incorrect, and Blank Checklist Items percentages, sorted by Area.

Area Name	% Correct	% Incorrect	% Blank
Brain	19.7	6.1	74.2
Eye	23.6	5.45	70.9
Ear	19.3	4.55	76.1
Nasal Cavity	24.7	2.6	72.7
Mouth	30	0.9	69.1

Table 6.3: Top Three Correctly Answered Checklist Items

Detail Name	# Correct
(Ear) Correct Label	7
(Nasal Cavity) Correct Label	7
(Mouth) Correct Label	7

Table 6.4: Top Three Incorrectly Answered Checklist Items

Detail Name	# Incorrect
(Brain) Correct Label	4
(Ear) Correct Label	4
(Eye) Correct Label	3

Tables 6.2 through 6.4 reveal several different trends worthy of discussion. Table 6.2 displays the percentage of correct, incorrect, and blank answers for each area of the frog head. A conclusion can be drawn from the *% Correct* column of Table 6.2. Ordered from the area with the most correct answers to the area with the least, the areas are ordered: Mouth, Nasal Cavity, Eye, Brain, and Ear. The question is, what is the cause behind this order? Why are some areas more correctly described than others? The primary difference between the areas is the educational content that each room presents. Knowing this, the difference in correct answers becomes clear. Those rooms with more memorable, recognizable details had more correct answers than the other rooms. The Mouth is the obvious winner in the detail contest, as it has the teeth, the mouth opening, and the tongue, all readily identifiable details. The Nasal Cavity also has memorable details, such as the volumetric fog, the tissue on the wall, and the door in the floor. The Eye has the iris-pupil structure, another easily recognizable detail. The Brain and Ear rooms, by comparison, have fewer memorable details, and the details they do have are not as immediately recognizable. This trend has design implications for further development of *Frog Explorer*. To help ensure the remembrance of education content, each room should contain at least one “hook”, an easily recognizable and memorable detail. These hooks will give each room a distinct identity that players can use to remember the educational content that they encountered in the room.

Table 6.3 lists the top three correctly placed educational details from the drawing activity. Table 6.4 lists the top four incorrectly placed details. Together, these two tables provide an overview of the educational details that the participants most commonly attempted to place on the drawing. These details share a common characteristic: they are all labels. This trend is easily explained. Out of all of the details the participants were asked to place, the area labels are the simplest to do so. The labels are nothing more than simple one or two-word phrases, with no additional drawing or descriptive writing required. The participants would therefore be more willing to attempt to place those labels more than any other details, resulting in the labels taking up a larger percentage of the correct and incorrect answers.

In addition to the quantitative results, the results of the learning evaluation can be evaluated qualitatively. No participant responded negatively to the game. In fact, almost every participant responded positively to the game, expressing enthusiasm at the prospect of using the game to learn about a frog. Here are some examples of the positive feedback received over the course of the learning evaluation:

- One user stated that she enjoyed the perspective of moving around inside the body like a “little person.”
- One user liked “learning a lot of stuff, but having fun.”
- One user stated that the game was set-up “the way a kid would like it.”
- User quote: “It was really cool and really good.”
- User quote: “The eye's upon you!”--pupil and iris observation.
- User quote: “Boing Boing!”--statement made while trying to climb the wall repeatedly near the earbone.

This positive feedback shows that the participants enjoyed the *Frog Explorer* experience. Such enjoyment will assist learning, as the enjoyment will motivate and encourage players to fully explore the virtual environment, opening themselves up to all the educational content *Frog Explorer* has to offer.

6.2.2. Usability Results. While the primary goal of the study was to evaluate the game’s ability to educate, usability testing was also conducted with the study participants. The usability test was carried out in the exact same manner as the initial

usability study, through a play-test of the virtual environment augmented by a short interview. Again, each feedback comment was placed into one of four categories: Controls, Navigation, Look-And-Feel, and Miscellaneous. A complete listing of all usability feedback for the learning evaluation can be found in Appendix C. Tables 6.5, 6.6, and 6.7 summarize the usability trends discovered in the Control, Navigation, and Look-and-Feel categories. Table 6.5 lists trends pertaining to the Control category, Table 6.6 lists trends pertaining to the Navigation category, and Table 6.7 lists trends pertaining to the Look-and-Feel category. Each of these three tables consists of four columns. The *Trend* column identifies the trend in question. The *True* column identifies the number of participants known to be part of the trend in question. The *False* column identifies the number of participants known to not be part of the trend in question. The *UNKNOWN* column identifies the number of participants whose participation in the trend could not be determined.

Table 6.5: Summary of Learning Evaluation Control Trends

Trend	TRUE	FALSE	UNKNOWN
User did not observe all control instructions	3	0	8
User strained to turn the head of their avatar	3	8	0
User preferred WASD control scheme	2	6	3
User preferred arrow key control scheme	6	2	3
User desired gamepad controls	6	5	0
User was uncomfortable using both hands for controls	4	7	0

Table 6.6: Summary of Learning Evaluation Navigation Trends

Trend	TRUE	FALSE	UNKNOWN
User navigated all areas using the signs	6	0	5
User observed right-eye sign.	7	0	4
User observed left-eye sign	7	0	4
User observed left-ear sign	6	0	5
User observed right-ear sign	6	0	5
User observed right nasal cavity sign	6	0	5
User observed left nasal cavity sign	5	0	6
User observed stairs in nasal cavity	11	0	0
User observed stairs in mouth	11	0	0
User found nasal cavity door to be too small	5	6	0
User missed second ear chamber	1	10	0
User initially did not observe navigation signs	3	8	0
User slipped off stairs in the mouth	1	10	0

Table 6.7: Summary of Learning Evaluation Look-and-Feel Trends

Trend	TRUE	FALSE	UNKNOWN
User visually identified mouth	4	0	7
User visually identified brain	5	0	6
User visually identified eye	2	1	8
User visually identified nose hole	4	1	6
User cited bullfrog croak as immersive factor	4	7	0
User cited textures as immersive factor	5	6	0
User identified bullfrog croak	2	3	6

Several of the usability issues discovered by the learning study are worthy of extended discussion. The first of these issues is the *User did not observe all control instructions* issue listed in Table 6.5. This issue refers to the control instruction signs placed at the player's starting point. These signs are first discussed in Section 5.2 as a solution to the *Unintuitive Control Schemes* problem. The signs are positioned to fill the player's view as he or she first enters the game. The purpose of the signs was to instruct the player in the use of the game's two keyboard control schemes. The signs were partially successful in their purpose, as those participants who fully observed the control signs were able to utilize the control scheme that was more intuitive to them. These participants were able to move around the environment effectively. However, several participants did not observe all of the instructions on the signs, with some not observing any of the instructions at all. This was a very surprising trend, as the control signs are placed in front of the player's starting point, and almost completely fill the player's initial view of the environment. The common explanation given by participants suffering from this trend was the appearance of the signs. The signs have a subdued, dark-toned appearance that gave participants the impressions that the signs were merely obstacles, as opposed to objects of importance. Study participants suggested two solutions, both of which are feasible from a technical standpoint. The first solution suggested was to enhance the appearance of the signs with bright colors and glow effects. Such enhancements would naturally draw a player's attention, increasing the chance that the controls instructions would be observed. The second solution was to remove the signs, and instead have the instructions appear in large text across the screen. The rationale behind this solution was that the approach would force players to read the instructions by flooding the player's view with text. Quake III Arena contains functionality to print text across the screen. This functionality would need to be modified in the source code to ensure that the text was the correct size and stayed on the screen for the correct length of time.

A second issue discovered by the learning study is the *User strained to turn the head of their avatar* issue, listed in Table 6.5. Several participants had difficulty using the mouse to change their view of the environment, visibly straining to make even a 90-

degree turn. The cause of this issue is the default mouse sensitivity. Like many FPS games, Quake III allows the player to adjust how closely the mouse and the in-game view are linked. The more sensitive the mouse is set, the less mouse movement is required to change the view. To solve this issue, the mouse sensitivity would need to be set to a higher level. This would require further user testing, as it is important to avoid setting the sensitivity too high. If the mouse sensitivity was set too high, the in-game view would change rapidly at the mere twitch of the mouse, leading to disorientation and frustration.

As discussed in Section 5, room-to-room navigation proved to be very difficult for the participants of the first usability study. The primary source of the difficulty was the uniformity in the appearance of the passages from the brain to the other areas. As a result of this uniformity, participants were unable to tell which passage lead to which area, and often re-entered areas they had visited before. To alleviate this difficulty, navigation signs were placed at all passage openings in the brain, the trapdoors in the nasal cavities, and the stair mock-ups in the mouth. Each sign denoted the area to which the passage, door, or stair mock-up led. Subsequently, the study participants were clearly able to use the signs to determine which areas they had already visited, and thus were able to navigate the frog head effectively. Several of the participants were even able to use the signs to make the determination that they had visited all of the areas available in the game. The navigation signs were not without flaws, however. A few of the participants did not initially observe the navigation signs, similar to the *User did not observe all control instructions* issue. Future versions of *Frog Explorer* should add bright colors and/or glow effects to the navigation signs. Such modifications should make the signs more apparent to the player.

A fourth usability issue explored by the learning study was the use of the stair mock-ups. The stair mock-ups were previously discussed in Section 5.2 as a solution to the *Teleportation Disorientation* problem. The intent of the stair mock-ups was to provide the player with a more intuitive understanding of how the teleportation functionality actually was intended to function. Combined with the navigation signs, the stair mock-ups successfully served their purpose. The participants of the second study were obviously more comfortable with the teleportation functionality than the first study

group. Thanks to the signs and the stairs, the participants were able to understand that the teleportation was intended to move them up and down inside the frog head.

As with the *Teleportation Disorientation* problem, the proposed solution to the *Mouth Door* was also tested during the learning study. To prevent the player from accidentally falling into the trapdoors in the nasal cavities, the size of the trapdoors was reduced to only slightly larger than the player's avatar. The new trapdoors were successful at preventing the original problem, as no participants accidentally entered the trapdoor during the learning study. However, the new trapdoor introduced a new usability problem; the trapdoors were now so small that several of the participants had difficulty stepping into them. To correct this new problem, the size of the door should be expanded *slightly*. Further user testing will be necessary to ensure that the new doorway is neither too large nor too small.

The final usability issue to be discussed is the issue of immersion. The virtual frog head was designed to give the player the impression of actually being inside a frog's head. During the question-and-answer section of the learning study, each participant was asked to name the factors of the virtual environment that contributed to his/her feelings of immersion. The factor most commonly reported was the custom texturing on the environment's surfaces. The second most common factor was the bullfrog sound in the ear chambers. These responses have design implications for future *Frog Explorer* development. In order to maintain and increase the level of immersion that *Frog Explorer* provides, organic surfacing and biologically inspired sound files should be priorities of any future development.

Similar to the first experiment, the usability portion of the learning study generated feedback that, while interesting, was not influential enough to affect the further development of the game. The following list contains this feedback, presented for the purpose of completeness:

Look-and-Feel Comments:

- One user enjoyed having a variety of rooms to explore.

- One user disliked the fact that it was possible to simply walk on a flat surface in order to travel to the different areas. She wanted traveling to be more involved, with areas to climb up and down, and obstacles around which to maneuver.
- Two users thought that they should have been able to see the uvula at the back of the mouth, even if it was only a picture mock-up.
- One user stated that what he liked the most about the game was that he could see the inside of a frog from a miniature perspective that a human couldn't.
- One user wanted me to avoid overlooking the avatar stepping noise as a means of immersion. He stated that the noise made him feel like he was actually there.
- One user was not satisfied with just exploring the head, and really wanted to see the rest of the body.
- One user had an interesting view comment. He thought that the rooms should be easily visible from the far end of the tunnels in the brain. He felt that the player would have a better experience if they could get a clear view of the various areas even before they journeyed to them.
- One user thought that a fun educational demonstration would be a view in the eye room where the player could view the outside world with the visual appearance that a frog would see.
- One user enjoyed the details of the mouth a great deal.

Miscellaneous Comments:

- One user wanted to have a “basic information” session upon entering each room, to establish a context for each area.
- One user stated a preference for the first-person perspective over the third-person, stating that the first-person point of view was also an important element in the immersion.
- One user suggested the use of doors as a means of recognizing activity locations. Anytime a player sees a door, they would know that beyond the door is a specific activity for them to do.

- One user found it interesting to compare the depiction of frog head anatomy to what she knew of human anatomy.
- User quote: “I didn't know the frog's ears were at the back of it's head.”
- User quote: “Very peaceful except for mouth and ear” --user comment on the distribution of details between the rooms.
- One user stated that he liked learning about the balancing aspect of the ear.
- One user looked at how the ear-bone stretched and wondered if it actually tunneled through to the first chamber, due to its proximity to the inner wall between the chambers.
- One user liked that the game could provide an alternative to dissection.
- One user found all of the areas within the frog head that he expected to see.
- One user liked learning details about the frog head that he didn't know before. As an example, he referred to the connection between the mouth and the nasal cavity as something he didn't know before.
- Several users wanted to explore more of the body than just the head. One user wanted to move down the throat “like a slide” to the stomach.
- One user really liked learning about the balancing aspect of the semi-circular canals and the shape of the teeth.
- One user suggested an event where just before entering an area, the game would show a 360-degree cut-scene which gives a brief visual tour of the area in question.
- One user wished that he had a flash USB drive so that he could take the game home with him.
- One user thought it might be fun to have a tour guide character within the game, possibly in the place of the button tutorials he had encountered earlier.
- One user thought that multiplayer support would be a worthwhile endeavor. He would have liked the opportunity to chat with another player, and exchange knowledge with them. He did not give any specifics beyond this description.
- One user suggested that when the player enters a room, a pop-up could appear, providing basic information about the room.

- One user wanted to go into the throat, and was disappointed when he found out that the game did not cover that area.
- One user, in odds with his earlier desire for freedom, wanted a game separated into specific levels, each with an associated task. Winning then would be contingent on clearing all of the levels. This is the traditional structure for a video game, so the user was basically stating a desire for *Frog Explorer* to provide a traditional video game experience.
- One user like the fact that she could explore freely, but found this aspect intimidating as well. She suggested that the game take a balanced approach, and provide at least a suggestion as to where she should go next.
- One user commented on the absence of informative material, and would have liked the game to actively teach her more about the areas she was viewing.
- One user cited the ability to turn her avatar's head freely as an important factor in her ability to be immersed in the game.

6.3. SUMMARY OF LEARNING EVALUATION

This chapter covered the learning evaluation that was conducted on *Frog Explorer*. The chapter described the purpose of the study, and described the experimental procedure used to carry out the evaluation. The chapter ended with a discussion of the study results, and the implications for *Frog Explorer* to be used as a user-friendly learning tool. Chapter 7 will discuss the final conclusions of the project, as well as the future development of *Frog Explorer*.

7. CONCLUSIONS AND FUTURE WORK

7.1. QUAKE III DEVELOPMENT PLATFORM CONCLUSIONS

The development of *Frog Explorer* has provided great insight into the use of Quake III Arena as a development platform for educational games. Quake III proved to have both significant strengths and weaknesses as a development platform. These strengths and weaknesses will be analyzed within the context of the design considerations for game engine selection that was previously outlined in Section 4.1:

- **System Requirements:** The low-end system requirements of Quake III were a significant benefit to the *Frog Explorer* project. The minimal technical requirements allowed for excellent performance on even low-performance systems. An example low-end test system was a Dell desktop with a 2.6 GHz Celeron processor, 256 MB RAM, and an integrated Intel 82845 video card. This system lacked a dedicated graphics card, but was still able to run the game at 1024 x 768 resolution on high settings. The low-end system requirements, combined with the platform interoperability of the .QVM files, result in a high degree of portability between computer systems. This portability allowed for the use of *Frog Explorer* on whatever system was most suitable for the current phase of the project, whether that was the design, the debugging, or user testing phase. In addition, the portability of the game ensures that the game will be playable on any reasonably modern computer, easing the financial burden of educational institutions, or any other entity interested in the game.
- **Proven Viability:** The *Proven Viability* design consideration proved to be less useful of a consideration than originally anticipated. Research of the commercial use of the Quake III Arena engine revealed that it had been used as a platform for several other commercial FPS games. These games contained features relevant to *Frog Explorer*, such as a variety of different virtual environments, elaborate heads-up displays, impressive visual and audio special effects, and in-game scripted events. The conclusion taken from the research was that using the Quake III engine would allow for a product with the same level of features as the commercial products. What the research did not reveal was that the

implementation of some of these features required a level of modification and additions that were not feasible for *Frog Explorer's* small development group. The creation of a visually realistic virtual environment was feasible even without modifications to the engine. Visual and audio special effects also were implemented, though the scale of these effects was limited to the functionalities already present in the engine. Similarly, modifications to the game's heads-up display were carried out, again limited to the functionalities already present in the engine. Adding scripted events, however, proved to be an impossible task. The Quake III engine has little-to-no scripting capability itself, which indicates that the scripting present in the commercial Quake III-based titles was created specifically for those titles. The creation of a scripting engine was completely beyond the capabilities of the development team. This was truly unfortunate, as it prevented the development team from creating interactive activities.

- **Organic Look-and-Feel:** The Quake III engine was successfully used to create a virtual frog head with a genuinely organic visual appearance. The game engine functionalities primarily responsible for this organic look-and-feel are the custom textures and the use of patches. The custom textures, JPEG image files, were used to give the surfaces of the virtual environments a realistic, organic appearance. The patches, paper-thin virtual objects that can be contorted into a variety of shapes, were used to create many of the organic objects that populate the environment. While the Quake III engine was generally useful in creating an organic look-and-feel, it had a limitation that prevented the environment from appearing completely organic. This limitation is related to the construction of curved surfaces. All parts of a Quake III object, whether it is a door, a wall, or a ball, are built out of polygons layered on top of each other. The more curved the surface, the more polygons are required to create the surface. The game engine is not capable of using enough polygons to create large smoothly curved surfaces, such as large spheres. Instead, the curved surfaces have a blocky, segmented appearance to them. This situation was a significant design limitation, as most of the rooms in the frog head were required by biological reality to have a spherical shape. While the engine was able to provide rooms with an *approximately*

spherical shape, the lack of completely smooth curved surfaces detracted from the organic appearance of the rest of the environment.

- **Modification Tools and Knowledge:** A factor in the selection of Quake III Arena was its history as a development platform for non-commercial modifications. Quake III Arena has been used as a modification platform for 10 years, and has generated an unofficial community with a knowledge base and specialized tools. Since this project was to be a non-commercial endeavor, it was important to have access to such a community, as there would not be official support from the developer. Quake III proved to be an excellent choice in this regard. GTKRadiant[4], a free-ware Quake III level editor, was used to efficiently create the virtual environment, and easily incorporated custom textures and 3-D models into the virtual environment. Milkshape3D, a shareware 3-D modeler, was used to create custom game models, and was used to convert the models into Quake III's specific model format. The development of *Frog Explorer* was also facilitated by the numerous Quake III knowledge resources available on-line. These resources provided tutorials in using the GTKRadiant editor to create virtual environments [19] [14], as well as insight into the structure and specifications of Quake III's source code [13]. Access to this knowledge greatly decreased the amount of time needed to develop *Frog Explorer*.
- **Modification Limits:** One of the reasons why Quake III was selected as a development platform was the fact that much of the source code for the game engine had been released under an open-source license. The rationale for this platform choice was that access to the source code would give the team greater latitude in modification than other FPS games. Access to the source code was useful in terms of modifying and removing pre-existing Quake III capabilities. The source code was modified to remove those elements that make Quake III a first-person combat game, such as weapons and ammunition boxes, and to do so in such a manner that there was no possibility that players would ever accidentally access such content. The source code was also modified to remove most of the elements from the default heads-up display, creating a display more appropriate to an educational game. Attempts to add new functionalities, however, were less

successful. As development on *Frog Explorer* continued, it became apparent that an in-game event-scripting system was desirable. Such a system would allow for the creation of in-game activities that would respond to user input. The Quake III source code has little to no scripting capability itself, so attempts were made to add this capability. However, the creation of a scripting system for a 3-D environment is a non-trivial development challenge, and proved to be infeasible, in terms of both time and development resources.

- **Platform Interoperability:** Over the course of development, *Frog Explorer* was installed on several different computers utilizing the Windows XP, Windows Vista, and Macintosh OS X operating systems. While the game requires a pre-installation of the appropriate version of Quake III, the actual *Frog Explorer* installations files are not platform-dependent, and were used on all three operating systems without any particular difficulty.

7.2. USABILITY AND LEARNING STUDY CONCLUSIONS

7.2.1. Usability Conclusions. Two usability studies were conducted over the course of the development project. Each usability study was carried out by having participants explore the virtual environment, while an observer recorded their behavior and reactions. The play-test was followed up with a short question-and-answer session designed to solicit feedback on specific usability issues. The objective of the first usability study was to identify and correct usability issues severe enough to prevent the player from successfully exploring the game. The study was successful in this regard, as it identified four usability problems severe enough to inhibit any further user testing. In addition, the study generated feedback on 18 usability issues of moderate significance, and 13 comments on minor issues. Several of these less severe comments prompted adjustments to the game's design.

A second usability study was carried out as a part of the learning evaluation study. As the study required the participants to play the game in order to evaluate its learning effectiveness, it made sense to conduct further usability testing during the play-test. The second usability study generated positive and negative feedback on 26 issues of moderate statistical significance, and 43 comments of minor statistical significance. The most

striking result of the second usability study was the revelation that all participants were able to explore the virtual environment completely, without any major usability impairment. This result indicates that the first usability study was successful in eliminating major usability flaws, and that the usability of the game was at an acceptable level.

7.2.2. Learning Tool Conclusions. The primary purpose of the second user study was to evaluate the effectiveness of *Frog Explorer* as an educational tool. The learning evaluation was carried out by having participants explore the virtual environment for 15 minutes, exposing themselves to the educational content within the game. The players then participated in a 10-minute drawing activity in which they placed the content about which they had learned onto a diagram of a frog head. Out of the five areas that make up the virtual frog head, the Mouth had the most correct details, followed by the Nasal Cavity, then the Eye, the Brain, and finally the Ear. The explanation for this order is the type of educational content that each area contained; the areas with the higher number of correct answers contain a higher number of recognizable, memorable educational details. This trend has implications for future development of *Frog Explorer*. In order to improve the process of recollection, each area should contain at least one “hook”, a memorable, easily identifiable detail. A more consistent distribution of such details between the areas of the frog head should result in more consistent learning between the areas. In addition to the quantitative results, the game generated generally positive feedback from the study participants. The participants were excited by their experience with the game, and were very interested in learning about frog anatomy using *Frog Explorer*.

7.3. DEVELOPMENT TIME/EFFORT CONCLUSIONS

Table 7.1 details the estimated cost of developing the *Frog Explorer* game. As the current version of the game is not a complete application in many respects, we cannot conclude that we were able to develop high-fidelity virtual reality educational software with a limited budget and limited personnel. The desired interactive features that were found to be very difficult to implement with Quake III would add considerably to the cost of finishing the game.

Table 7.1: Estimated *Frog Explorer* Development Costs

# Hours of Development Time	439
# Hours of User Testing Time	14.67
# Hours of Advisor Meeting Time	12
Total Time Costs	465.67
Developer Salary	\$7.50/hour
Cost of Software Tools	\$75
Total Financial Cost	\$3285

7.4. RECOMMENDATIONS AND FUTURE WORK

There are several different aspects of the *Frog Explorer* project that could be further developed. The first of these aspects is the extent of the anatomy covered by the game. *Frog Explorer* currently covers only the anatomy found in the head of the frog. Future development teams could take on the task of adding other portions of frog anatomy to the game. A natural means of progression would be to add a virtual throat, since this area would connect directly to the pre-existing mouth area. Development could then begin on the stomach, intestines, and the other portions of the digestive system.

A second avenue of development is the creation of interactive, educational activities. The primary educational value of *Frog Explorer* is the spatial learning promoted by the exploration of the virtual environment the game presents. However, the educational value of the game could be further increased through the placement of activities within the virtual environment. These activities could take on any number of forms, such as interactive simulations of biological processes, question-and-answer sessions, or interactive puzzles. However, the implementation of these activities will not be a trivial task, as it will require significant additions to the Quake III engine itself, even before the implementation begins. In particular, the implementation will require the

addition of in-game event scripting, in order to create specific responses to player actions. This capability proved to be beyond the scope of the original *Frog Explorer* development team, and will be the most significant challenge to the implementation of educational activities.

A third area of expansion for the *Frog Explorer* project is that of user testing. Additional user testing could be used to more thoroughly explore the educational value of *Frog Explorer*. One possible approach would be to perform a comparative study using a control group. This approach would better ascertain whether or not learning is occurring during *Frog Explorer* game-play. This exercise could be further enhanced by using a larger sample of participants, and by using an evaluation tool more appropriate to the target age group.

An intriguing approach to future development would be to base the design of the virtual environment directly on primary anatomical data, similar to the MorphologyNet viewer discussed in the literature review [20]. Instead of using diagrams to build the environment using the GTKRadiant editor, this approach would use the histological data that MorphologyNet uses to automatically generate the virtual environment. The potential advantage of this approach is that it would generate a virtual environment far more consistent with real-world frog biology. However, the technical challenge of this approach would be substantial. It would be necessary to decipher the compilation process that the GTKRadiant editor uses to create the virtual environment, in order to determine the data format used during the map construction. The histological data would then need to be converted into the correct format. Finally, the GTKRadiant editor would need to be modified to construct the virtual environment from a data file, as opposed to the normal method of building the environment manually. These challenges are great, but the benefits would be equally substantial.

One final area of future development is experimentation with other development platforms. While Quake III Arena was an admirable development platform, it had certain weaknesses, as discussed in Section 7.1. Future developers have the opportunity to use a new development platform, and can incorporate the lessons learned from this project's development. Potential development platforms should facilitate in-game event scripting, and should be able to create organic surfaces and texture that are at least on par with

Quake III's ability to do so. In addition, the platform should be able to utilize these functionalities while still maintaining good performance on low-end computer systems. Since Quake III did prove to be an acceptable development tool in most aspects, the logical start for other platform options would be a review of Quake III's contemporaries in the FPS game genre. A game that had scripting capability, organic surface capability, and hardware requirements that were similar to Quake III Arena would be an ideal development platform.

The *Frog Explorer* software development project represents significant progress in the utilization of 3-D game engines for educational purposes. Even with this progress, the *Frog Explorer* project remains an exciting area for further development. One such development effort is already underway at Missouri S&T. A new development team is experimenting with a different development platform, the *Alice* visual programming language discussed in Section 2.3, with the additional goal of teaching the users how to program by encouraging them to add objects and educational activities to the base game program. Regardless of the particular development environment, it is clear that 3-D, immersive visualization and simulation environments are likely to be the future direction for educational software.

APPENDIX A.

USER TESTING INSTRUMENTS

Experiment Log Sheets

Experiment Phase Log:

Control comments:

Navigation Comments

Look-and-Feel Comments:

Misc. Comments



Drawing Activity Score Sheet

Brain Checklist:

- ___ large ovoid room shape
- ___ correct label
- ___ wall texture
- ___ connection to ear
- ___ connection to eye
- ___ connection to nasal cavity

Eye Checklist:

- ___ correct label
- ___ main eye texture
- ___ iris and pupil on front wall
- ___ connection to brain
- ___ spherical shape of room

Ear Checklist:

- ___ correct label
- ___ semi-circular canals
- ___ earbone & side circle
- ___ main wall texture
- ___ connection to brain
- ___ bullfrog noise
- ___ spherical room shape
- ___ two chambers

Nasal Cavity Checklist:

- ___ correct label
- ___ connection to brain

___ connection to mouth

___ soft tissue on walls

___ fog

___ nasal hole

___ spherical room shape

Mouth Checklist:

___ correct label

___ connection to nasal cavity

___ tongue shape and texture

___ mouth shape and texture

___ teeth shape

Misc. Comments:

APPENDIX B.

USABILITY STUDY RESULTS

Experiment 1-1 Results

Control Comments:

C1: User found the WASD control scheme easy to use, but admitted to having played computer games extensively before, and was already familiar with the scheme.

C2: User mentioned that some kind of tooltip or information about the control scheme could be displayed, at least at the beginning.

Problem Level: Medium.

Est. Difficulty Level: Medium

Navigation Comments:

N1: The user had obvious difficulty in navigating from the brain to other areas. He could not tell where he had already been, and he could not identify any rooms until he was all the way into them. The user did say that he did like the lack of navigational aids, and that the difficulty in navigation was not necessarily an issue for him.

Problem Level: Severe.

Est. Difficulty Level: Medium-Severe.

N2: User discovered that the “Entering XXX “ messages also replayed themselves up exiting.

Problem Level: Medium.

Est. Difficulty Level: Medium.

Environment Comments:

E1: User had problems entering the non-brain-room-side of tunnels. He found that the tunnels sloped up very sharply, and had a strange bump at the top of the slope.

Problem Level: Severe

Est. Difficulty: Medium-Severe

E2: User occasionally got caught on the inside of the tunnels.

Problem Level: Severe

Est. Difficulty: Medium-Severe

E3: The user felt that the sphere portion of the semi-circular canals had too many rectangular segments, and the look detracted from the object. He wanted it to actually be a sphere.

Problem Level: Minor-Medium

Est. Difficulty: Minor-Medium

E4: The user wondered if he should be able to see the cartilage structure of the nose as he traveled from the brain to the nasal cavity.

E5: The user was able to recognize the mouth on sight.

E6: The user was not able to recognize the nasal cavity on sight. He attributed this to the fact that the nasal hole did not really look like an actual hole to him.

Problem Level: Medium.

Est. Difficulty: Minor-Medium.

E7: The user was able to recognize the brain on sight.

E8: The user was not able to recognize the eye on sight.

E9: The user wondered if the pupil and iris structure in the eye needed to be curved instead of flat.

E10: The user stated that he really liked the texturing for all the different areas, especially the brain, tongue, and tunnels. He felt that they really added to the feel of actually being in the frog head.

E11: The user thought that instead of having the swirling blue object be the teleporter in the nasal cavity, it would be better if he could somehow peer into the mouth as if there really was a hole there.

E12: User said he expected to move “down” from the brain to the nasal cavity, and suggested that the tunnel be sloped down.

E13: User felt that the edges of the mouth were too straight, and expected them to be more curved.

E14: The user found the lighting to be very uneven, particularly in the brain and tunnels.

Problem Level: Minor-Medium.

Est. Difficulty: Minor.

E15: The user felt that the teleporter object was inappropriate for the game, and would like to have seen instead some kind of tunnel opening “leading” back to the nasal cavity.

Problem Level: Medium.

Est. Difficulty: Medium.

E16: The user noticed that in the eye, when standing very close to the pupil, the white area on the pupil seemed to merge with the white area on the upper part of the eye. He found the effect somewhat visually unappealing.

Problem Level: Minor.

Est. Difficulty: Minor-Medium.

E17: The user felt that there was too much light in the eye.

E18: The user felt that the brain looked inorganic, due to the rectangular panels it is made out of.

Problem Level: Medium.

Est. Difficulty: Severe.

E18: User felt that the tongue should be much more rounded, instead of a flatter surface.

E19: The user thought that the tongue should be extended partially outside the mouth, so that he could walk out and see the frog from the outside. He also felt that this outside area would make an admirable starting location for the game.

E20: In general, the user would like to be able to look outside and observe the frog exterior far more than he was able to. He felt he should be able to view exteriors from the eyes, nose, and brain.

E21: User felt that the nasal cavity rooms should have been closer together.

E22: The user felt that the eye rooms should have been closer together, moved to the front of the brain area instead of the sides, and mounted at an upward angle from the central area.

E23: The user felt that the ears should have been moved toward the sides of the brain, instead of the back.

E24: The user emphasized that curved surface should really be paid attention to, and given a high priority in the environment design.

Misc. Comments:

M1: The user liked the immersive feeling of being inside a frog head. The user didn't like seeing out-of-place objects like the teleporter object, as it detracted from the

immersive feel. The user stated that this immersive feel was the best part of the experience.

M2: The user did find it somewhat strange that he could not see any part of his character model.

M3: The user really liked the use of sound, such as the narration and the croaking noise.

M4: User thought that it would be “Cool” if he could see another human running around in the frog head, if for no other reason than to establish an additional sense of scale.

M5: The user found the environment to be, in general, very large. He also felt that this was a good feeling to have.

M6: The user was a very big fan of the freedom of movement he got while performing this activity. He liked being able to pick where he wanted to go, and getting to stay in a particular location as long as he liked.

M7: User like the default gravity, and the fact that he could jump, but that there was a limit to how high he could jump.

Activity Suggestions:

Brain/Nerve activity: Player could deliver messages from brain to other areas, possibly with a time limit.

Heart: Player could deliver blood from the heart to parts of the frog.

Mouth/Lungs: Player could deliver air bubbles from lungs to other parts of the frog.

Nose: User suggested an activity in which the smells what the frog was smells in the form of balloons, which the player could catch in some kind of directed activity.

Experiment 1-2 Results

Control Comments:

C1: The user had a disorientation problem while traversing the nasal cavity. This problem involved the mouse-look used in the FPS control scheme. The user lost track of her orientation relative to the environment, and spent approximately 20 seconds trying to climb a wall that she thought was a floor. I believe that this problem was a result of first-time use with an FPS game, as well as the location itself. The nasal cavity has soft, rumpled objects that might appear to be a floor. I did not observe this problem occurring at any other point during the test, so I believe that this problem is not likely to occur for other users. However, I am making this notation in case my assumption is wrong. I will be on the lookout for this problem in the testing of other users.

C2: The user preferred using the arrow keys instead of the WASD keys to control her avatar. She stated that in her mind, using the arrow keys made more sense.

C3: The user stated a preference for an on-screen display identifying the controls.

C4: The user liked the idea of using a controller similar to a console video game controller to control the game. She was more familiar with a controller than mouse and keyboard controls, and would have like the option to play the game with such a controller.

Navigation Comments:

N1: The user had difficulties in recognizing which rooms she had visited before. On at least three occasions, she entered a room she had already visited, even though she had the intent to find a new room to visit. The user eventually started working her way around the circumference of the brain area in order to visit the rooms systemically. The user

suggested signs be placed near the tunnels openings in the brain area, to advise the user as to which room they were about to enter.

Problem Rating: Severe.

Est. Difficulty Level: Minor-Medium

N2: The user was able to tell that she had visited every room. This was due to her systemic approach to visiting the rooms, moving in a constant direction around the wall of the brain room. We may want to add some kind of indication that a player has in fact visited every room at least once.

N3: The user after using the teleporter object in the nasal cavity to travel to the mouth and back, was able to understand that the nasal cavity and the mouth were connected to each other, and that the nasal cavity was placed “above” relative to the mouth. This is an example of the spatial learning we are trying to go for.

Environment Comments:

E1: The slopes where the tunnels connect to the various rooms continue to be a problem area. The user in particular had significant difficulties when trying to move up the slope in the right eye. While I believe that this was exasperated by her in-experience with the mouse-look controls, this is still a problem that will likely need to be addressed.

Problem Rating: Severe.

Est. Difficulty Level: Medium-Severe.

E2: The user recognized the mouth on sight, due to the rough tongue texture, the teeth objects, and the mouth opening.

E3: The user did not initially recognize the brain, as she was expecting to see the wrinkly tissue one normally associates with the brain. She eventually recognized the brain room by virtue of its use as the hub for the other rooms, feeling that the brain should lie closer to the “center” of the frog head.

E4: User recognized the left eye on sight, due to the pupil and iris structure in the room.

E5: The user quite obviously missed the nose-hole in the nasal cavity, an important environmental feature for recognizing the nasal cavity. It is obvious that the nose-hole needs to be re-designed to be much more apparent.

Problem Rating: Medium.

Est. Difficulty Level: Medium.

Misc. Comments:

M1: The user suggested that an “info” button be placed in an out-of-the-way place on the screen (she suggested the bottom-left corner). This info button, when pressed, would display basic information about the particular area of the frog head the player was currently in, as well as a “fun fact” to get a player interested in what the area had to offer.

M2: The user liked that the game presented an alternative to actual dissection.

M3: The user stated a preference for freedom and non-linearity. She liked that she was allowed to go where she wished, when she wished, during the activity, and stated a preference for this freedom, instead of a directed, “go-here, now go here” experience.

Experiment 1-3 (with non-minor subject) Results

Control Comments:

C1: The user thought that the arrow keys would be more intuitive for players than the WASD controls. The user also felt that the turn properties of the left and right arrows would be better for players than the sidestep properties of the A and D keys.

Navigation Comments:

N1: The user slipped into the mouth opening in the nasal cavity by accident. This thus far is a recurring problem among users that needs to be fixed.

Problem Rating: Severe

Est. Difficulty: Medium

N2: The user recognized that they were in the nasal cavity after having taken the mouth teleport up.

N3: In order to navigate, the user went around the diameter of the brain area in a constant direction, visiting each room in turn.

N4: The user was confused after having entered the left nasal cavity, moved to the mouth, and then came out the right nasal cavity. Some extra navigational aid is necessary.

Problem Rating: Medium.

Est. Difficulty: Minor-Medium

N5: The user suggested that a stair mockup be added to the mouth teleporter in the nasal cavity. This way, players would easily recognize that the teleporter lead “down”.

Environment Comments:

E1: The user recognized the brain area by its appearance.

E2: The user commented that he thought they should be able to see out of the inside of the eye.

E3: After having been in the right ear, the user was able to recognize the left ear by the overall room structure, even though there were none of the ear objects populating that room.

E4: The user was not able to recognize the left eye, due to the organic Quake texture being used as filler.

E5: The user thought that they should be able to see out of the mouth.

E6: The user commented that it would be interesting to hear multiple bullfrog croaks in the ear, as if the frog was near enough other frogs to hear them.

E7: The user felt that the brain area was too simplistic of a central hub room. Such a simple room only displayed the rooms as if they were in a showcase, and did not foster an exploration that would lead to the player believing that they were actually inside a frog.

Misc. Comments:

M1: Through the user test, I discovered that the install file does not include the sound files. Add them to the installer!

Problem Rating: Major.

Est. Difficulty: Minor.

M2: There was a visible patch piece left over from the design process. Remove this piece.

Problem Rating: Minor.

Est. Difficulty: Minor.

M3: The user commented that they thought the game would be “good for learning”.

M4: The user commented that they liked the way the map was sectioned into distinct rooms, and thought these rooms would be good places for educational stations to have activities in.

M5: The user felt that there would be educational value of having textbook drawings of the various biological areas available in the corresponding rooms. This way, there could be a comparison between what the player “thinks” the area looks like, and what it actually looks like.

M6: The user suggested that there could be different “modes” for the environment. As an example, the user suggested that there could be a “diseased” mode, which would result in a different appearance for the various areas. This could dovetail with the idea that frogs can be used as environmental indicators.

Experiment 1-4 Results

Control Comments:

C1: The user felt the controls worked well, but it was apparent from my conversation with the user that they had played computer games with the WASD controls extensively before.

Navigation Comments:

N1: The user liked the text-based navigational aids, and thought that every single one of the rooms should have them.

Problem Level: Medium.

Est. Difficulty: Medium.

N2: The user was apparently confused by the appearance of the second ear chamber, looking in from the first chamber. The user got turned around and ending up going out of the ear while trying to get into the second ear chamber. According to the user, this was caused because the opening between the first ear chamber and the second was too small.

Environment Comments:

E1: The user was able to recognize the brain by its appearance and size.

E2: The user recognized the mouth because of the teeth objects.

E3: The user was confused during their exploration of the mouth because they expected a throat structure at the back.

E4: The user didn't recognize the nasal cavity chamber.

E5: The user recognized the eye due to the pupil and iris objects.

E6: The user thought that for some of the areas, including the tunnels between rooms, the steps that the player hears as they move should be modified to have a “squishy” sound, as if the player was really stepping on soft tissue.

Misc. Comments:

M1: The user felt that the best features of the game were the freedom of movement and the first-person perspective.

M2: Since the user was an experienced FPS gamer, the user expected the mouse button to shoot or otherwise provide a level of interaction with the environment.

APPENDIX C.

LEARNING EVALUATION RESULTS

Experiment 2-1 Results

Control Comments:

C1: User saw, but did not observe the control blackboards. I had to explain the mouse-look and left/right controls. The user had some nearsightedness, so that may have contributed to the lack of observation. I need to observe this issue closely in the next test.

C2: The user had a very difficult time manipulating the mouse to turn her avatar's head. From observing the users hand movement, I could tell that she felt she should not have had to move the mouse as far as she did. She was admittedly inexperienced in computer games and FPS games in particular, but I need to watch the next user for this issue as well. I may need to turn the mouse sensitivity up.

C3: The user preferred the arrow key, and in particular, preferred the left and right arrow keys to turn, instead of the arrow keys.

Navigation Comments:

N1: User noticed the area labels and was able to use them to tell where they had already been.

N2: The user had problems remembering which room she was in once she was past the label part. She suggested that there be some kind of indicator letting her know where she was at all times. I am unsure if this would be a good idea, as it might interfere with the exploration enjoyment that other users had, but I will keep the idea in mind.

N3: Add a label for the brain!!! Also, maybe add labels inside the inner entrances of the areas attached to the brain, letting the user know which way leads back to the brain.

Environment Comments:

E1: User liked the look of the mouth a great deal.

Misc. Comments:

M1: User couldn't tell that the goal of the experiment was to test spatial learning.

M2: As far as activities goes, the user wanted to have a “basic information” session upon entering each session, to establish a context for each area.

Drawing Activity Score-sheet

Brain Checklist:

- large ovoid room shape
- correct label
- wall texture
- connection to ear
- connection to eye
- connection to mouth

Misc. Comments:

Brain Labeled as Ear
 Nasal Cavity labeled as Eye
 Eye and Ear unlabeled
 Obvious lack of spatial understanding,
 though I believe that the results of this
 user are atypical.

Eye Checklist:

- correct label
- main eye texture
- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Experiment 2-2 Results

Control Comments:

C1: The user chose to use the arrow keys option to control his avatar. He chose this method because he found the arrow keys to be more intuitive. He could remember what they did easier than the WASD scheme.

C2: The user did not observe the mouse control text line on the control blackboards. The user had to be told that he could use the mouse to turn his avatar. It may be necessary to find a more obvious control explanation method.

Problem Rating: Medium.

Est. Difficulty: Medium.

C3: The user stated a liking for the control blackboards as a means of explaining the control schemes.

C4: The user stated that he would have preferred gamepad controls, as he was more used to playing console video games.

Navigation Comments:

N1: The user observed the right-eye sign.

N2: The user observed the left-eye sign.

N3: The user observed the left-ear sign.

N4: The user observed and was able to use the stairs in the mouth.

N5: The user used the signs to recognize that he had visited every area in the frog head.

N6: The user stated that he had no real problems navigating due to the use of the room signs.

Look and Feel Comments:

E1: The user recognized the mouth by the appearance of the teeth and tongue.

E2: The user recognized the brain area without the need for the label. He attributed this recognition to the use of the brain as a central starting area.

E3: The user stated that he did find the game immersive; he felt like he was actually inside a frog's head.

Misc. Comments:

M1: The user enjoyed having a variety of rooms to explore.

M2: This user stated a definite preference for a directed experience, as opposed to the free-roaming experience given during the user test. He wanted the game to give directions as to where he was supposed to be going, and what he was supposed to be doing.

M3: The user stated that he would like to have questions for an activity. Each room would have a question that the player could answer, with some fancy visual effect, like “stars” flashing across the screen with a correct answer. At the end of the experience, the player would answer a quiz with material from all the rooms.

Drawing Activity Score-sheet

Brain Checklist:

- large ovoid room shape
- correct label
- wall texture
- connection to ear
- connection to eye
- connection to nasal cavity

Eye Checklist:

- correct label
- main eye texture
- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain

- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Misc. Comments:

-The user recognized that the brain was a central hub area, but did not specify the room connections.

-The user recognized that there were two separate nasal cavities during this activity.

-The user mentioned that their mouth did in fact have “sharp teeth”, but did not go into the details of the teeth shape or placement.

-The user mentioned that the ear was “big from inside it because there is a lot of space”. This is not exactly the “spherical room shape” criteria I was looking for, but it resembles the criteria.

Experiment 2-3 Results

Control Comments:

C1: The user had a very difficult time using the mouse/keyboard controls. The difficulty seemed to be centered on the need to use both hands. The user did not feel comfortable using her left hand. It is possible that this level of two-handed coordination isn't a realistic expectation for users of this age group. I must watch and see if any participants exhibit this problem.

C2: Quote: "I'm not good at typing". This may indicate that the control problems the user experienced are atypical.

C3: The user did not observe the control blackboard explaining the arrow key control scheme. She commented that using the arrows would have been easier for her. It is possible that the current explanations are not obvious enough. A move to large text placed directly on the screen or a formal control tutorial may be necessary.

C4: The user commented that a game controller might have been a better option; the limited number of buttons on a controller would have helped her remember how to control her avatar.

Navigation Comments:

N1: The user observed the left ear sign.

N2: The user observed the right nasal cavity sign.

N3: The user observed the left-eye sign.

N4: The user had a small amount of trouble getting into the mouth trapdoor. The user seemed to walk over and around the trapdoor without actually going into it. It appeared as though the door may have been too small. This problem was exasperated by the control difficulties the user was having. However, it is very possible that the size of the door requires too much precision on the part of the user. I will monitor this issue in other participants.

N5: The user was able to tell that she had visited every area.

N6: While the user did visit the ears, she completely missed the second ear chamber in both ears.

N7: Occasionally, the user would miss the navigation signs the first time she came across them. She felt that the signs were not noticeable enough. She stated that it would be “cool” to have the signs glow like the top step of the stairs in the mouth.

Environment Comments:

E1: The user recognized the mouth due to the presence of the teeth.

E2: The user liked the rough tongue texture used in the mouth.

E3: The user was particularly pleased by the use of sound in the ear. She wished that sound had been used in all of the areas as effectively.

E4: The user stated that the texturing of the various surfaces was a primary component of the immersion the game exhibited.

Misc. Comments:

M1: Quote: The user liked “learning a lot of stuff, but having fun.”

M2: Quote: The user stated that the game was set-up “the way a kid would like it”. I was unable to have the participant be more specific on this quote.

M3: The user stated a preference for freedom of exploration, as opposed to a directed experience.

M3: The user disliked that voice was used in only the ears. She wanted informative segments in all areas of the frog head.

M4: When asked, the user stated a preference for the first-person perspective over the third-person, stating that the first-person POV was also an important element in the immersion.

M5: The user suggested the use of doors as a mean of recognizing activity locations. Anytime a player sees a door, they will know that beyond the door is a specific activity for them to do.

M6: Quote: “It was really cool and really good”.

Drawing Activity Score Sheet

Brain Checklist:

- large ovoid room shape
- correct label
- wall texture
- connection to ear
- connection to eye
- connection to mouth

Eye Checklist:

- correct label
- main eye texture
- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Misc. Comments:

-The brain was labeled as the “right cunamle” (misspelling of “nasal cavity”), and the nasal cavity was labeled as “left cunamele”. Is “nasal cavity” too complicated of a phrase for this age group?

-It was apparent that the user did not recognize that the diagram was a view of the skull from the side, and therefore, there would be only one ear, eye, and nasal cavity to label. I don't think I explained this aspect of the diagram well enough (I'm not sure I mentioned that it was from the side). I must make this clear in further tests.

Experiment 2-4 Results

Control Comments:

C1: The user did not like using both hands for the mouse/keyboard controls. She did not feel comfortable using her left hand. Is it possible that two-hand keyboard/mouse coordination is not appropriate for users of this age group, who are still learning how to type? Is it possible to move and look using only the mouse?

C2: The user chose to use the arrow key control method.

C3: The user was not experienced in the use of computer games.

C4: Oddly enough, the user did say she liked the control scheme. The lack of a mouse-look was not an issue for her.

Navigation Comments:

N1: The user stated a liking for the navigation signs, feeling that she would have been totally lost without them, but that using them made navigation a trivial affair.

Environment Comments:

E1: The user appreciated the fact that the central hub area was “quiet”, with no sounds, moving parts, or activities in it. She felt that this environment kept her from being overwhelmed as she entered the game and started exploring.

E2: The user got stuck on the inside exit of the left nasal cavity. The tunnel entrances are still a problem here, as it' still possible to get stuck on them.

Problem Rating: Medium.

Est. Difficulty: Medium-Severe.

E3: The user liked the use of sound in the ear rooms. She stated that the sound was one of the primary factors for the feeling of immersion she had.

E4: The user recognized the pupil, and interestingly, stated that she used the location and orientation of the pupil to help determine where the front of the head was.

E5: The user enjoyed being able to look “outside” from the mouth. This has proven to be a popular aspect of the game.

E6: The user identified the custom textures as a primary factor in the immersion ability of the game.

E7: The user did feel as if she were actually inside the head of some organism. She stated that the environment gave her a foreign impression, as if she was really looking at the inside of an organism, something she would not normally be able to do.

E8: The user wanted to see the outside of the frog head too, in order to establish a context for viewing the interior. She suggested that the player start off viewing the frog from the outside, and then move or be moved inside. This suggestion is very interesting, as it was an initial concept for the game during development.

Misc. Comments:

M1: The sound of the bullfrog conflicts with the sound of the tutorial, and it's impossible to make the tutorial audible. If the audio tutorial is to be used, adjustments will need to be made in order to be audible.

M2: The user stated a preference for free-form exploration, instead of a directed experience.

M3: The user found it interesting to compare the depiction of frog head anatomy to what she knew of human anatomy.

M4: The user disliked the fact that it was possible to simply walk on a flat surface in order to travel to the different areas. She wanted traveling to be more involved, with areas to climb up and down, and obstacles to maneuver around.

Drawing Activity Score Sheet

Brain Checklist:

- large ovoid room shape
- correct label
- wall texture
- connection to ear
- connection to eye
- connection to nasal cavity.

Eye Checklist:

- correct label
- main eye texture
- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain

- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Experiment 2-5 Results

Control Comments:

C1: The user was experienced with playing computer games, specifically Runescape, a free MMO.

C2: The user chose to use the WASD, and due to his experience, was able to use the controls easily and effectively.

C3: The user felt that it took too much effort to turn using the mouse. It is quite possible that the default mouse turn speed is too low. This can be adjusted in the Q3 options menu.

Navigation Comments:

N1: User observed the right-eye sign.

N2: The user had a small amount of difficulty moving up the stairs in the mouth. The user did not move straight up the stairs, and fell off the sides of the stairs. It may be necessary to place a railing along the sides of the stairs to prevent this problem.

Problem Rating: Minor.

Est. Difficulty: Minor.

N3: The user recognized the brain from its centralized location and custom texture. No label was needed.

N4: The user stated that he found navigation trivial, for the most part, due to the use of the navigational signs.

N5: The user suggested that a sign be placed on the inside of the second ear chamber, identifying the route back to the first chamber and the brain room. He felt that this would

be a good idea simply because the ear actually has two rooms, as opposed to the one room each other area has.

Environment Comments:

E1: The user recognized the nasal hole in the nasal cavity.

E2: The user tried to go out of the back of the mouth. He was a little disappointed that he could not travel to the stomach. Is there a better way to delineate where the traversable area ends? Maybe a construction sign?

E3: The user noticed the circles of light projected by the light sources. While it was not a significant issue, it was a small distraction. It might be a good idea to attempt to diffuse the large light sources into more numerous, smaller sources, so as to provide lighting without the light circles.

E4: The user heard the bullfrog croak but was unable to determine what the noise was meant to be. I may want to replace the current croak with a more generic frog noise, as this is not intended to be a mystery.

E5: The user thought he should be able to see the outside through the ear-hole, in the same way he could see out the mouth. I don't actually know if the biology is consistent with this idea, and I believe that it will require an additional room to accommodate the functionality. This is probably not a high priority at this point in the project.

E6: The user particularly enjoyed the footstep noise when landing from a drop, and repeated doing so several times. This indicates that adding a squishy noise to the footstep sound may add enjoyment value to players.

E7: The user stated a particular liking for the mouth wall and tongue textures.

E8: Interestingly, the user commented that while the level of realism in terms of textures and detail was not perfectly realistic, he actually preferred it that way. He felt that he would have felt uncomfortable and possibly nauseous if the game had been perfectly realistic.

E9: The user was able to infer the identity of the eye room from the visual look of the pupil-iris structure.

E10: The user was able to infer the identity of the ear rooms from the ear-bone structure in the second chamber.

Misc. Comments:

M1: Quote: “didn't know the frog's ears were at the back of its head.”

M2: Quote: “the eye's upon you!”--pupil and iris observation.

M3: “boing boing”--statement while trying to climb the wall repeatedly near the earbone.

M4: The sound for the tutorial is currently drowned out by the bullfrog croak on the laptop speakers. I must ensure that the tutorial is significantly louder than the croak, probably by lowering the volume of the croak itself.

Problem Rating: Severe

Est. Difficulty: Medium.

M5: quote: “very peaceful except for mouth and ear”...user comment on the distribution of details between the rooms.

M6: User thought that he should have been able to see the uvula at the back of the mouth, even if it was only a picture mock-up. I am not sure if this organ actually exists in frog biology.

M7: The user stated that what he like the most about the game was that he could see the inside of a frog from a miniature perspective that a human couldn't.

M8: The user suggested an activity where the player took on the role of a red blood cell, delivering blood like a mailman.

M9: The user suggested an activity where the player took on the role of a white blood cell “warrior”, fighting viruses and other infectious agents.

Drawing Activity Score Sheet

Brain Checklist:

large ovoid room shape

correct label

wall texture

connection to ear

connection to eye

connection to mouth

Eye Checklist:

correct label

main eye texture

iris and pupil on front wall

connection to brain

spherical shape of room

Ear Checklist:

correct label

semi-circular canals

- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Experiment 2-6 Results

Control Comments:

C1: User was experienced with computer games, having played Runescape before.

C2: User used both hands for the mouse/keyboard combination. Had no problems using it due to his computer game experience.

C3: The user used the arrow keys because the arrow keys made more intuitive sense for him as movement keys.

C4: The user liked having both control options available.

C5: The user thought having a game controller control option would be a good idea, but that it would really only be helpful for players who are more used to controllers. It should be an additional option, not a replacement for a current control option.

Navigation Comments:

N1: The user observed the left-eye sign.

N2: The user recognized the brain due to the texture used and the centralized hub location.

N3: The user had no problems with the steps to the nasal cavities.

N4: While trying to enter the door from the nasal cavity to the mouth, the user stepped over the door several times. Is the door too small?

Problem Rating: Medium-Severe

Est. Difficulty: Minor-Medium.

N5: The user stated that the navigation signs made navigation trivial for him.

Look and Feel Comments:

E1: The user commented that the teeth appeared sharper than he would have expected them to be.

E2: The user stated that he liked viewing an environment that he would never be able to view normally.

E3: The user recognized the nasal hole in the nasal cavity.

E4: The user was enthusiastic about being to see outside the mouth.

E5: The user heard the bullfrog croak, but did not recognize it. I did not expect the recognition of the noise to be a problem. Do I need to use a more generic “ribbit” noise?

E6: Quote: “It must be daylight outside.”--user response to the brightness level of the eye room.

E7: The user disliked the flat, geometric surfaces of the spherical rooms, as they detracted from the organic look of the game.

Misc. Comments:

M1: The user stated that he liked learning about the balancing aspect of the ear.

M2: The user looked at how the ear-bone stretched and wondered if it actually tunneled through to the first chamber, due to it's proximity to the inner wall between the chambers.

M3: The user wanted me to avoid overlooking the avatar stepping noise as a means of immersion. He stated that the noise made him feel like he was actually there.

M4: Move the patch!!!!

M5: The user liked that the game could provide an alternative to dissection.

M6: The user found all of the areas within the frog head that he expected to see.

M7: The user liked learning details about the frog head he didn't know before. As an example, he referred to the connection between the mouth and the nasal cavity as something he didn't know before.

M8: The user wanted to see more of the body than just the head.

M9: The user liked freedom of exploration, and did not want a directed experience.

Drawing Activity Score Sheet

Brain Checklist:

- large ovoid room shape
- correct label*
- wall texture
- connection to ear
- connection to eye
- connection to nasal cavity

Eye Checklist:

- correct label**
- main eye texture

- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label***
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label****
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Misc. Comments:

*the eye area was labeled and described as the brain. The details were correct for the brain, but it appears that the user got the brain and eye labels confused.

** the brain area was labeled as the eye. All details of the eye were correct, but it appears that the user got the eye and brain locations mixed up. I think that this is due to the lack of elevation in the game between the brain and eye areas. I should monitor this mix-up in the next tests.

/* the user got the ear and nasal cavity locations switched with each other. The only explanation I have for this is that the user misunderstood which side of the diagram was the front and which side was the rear. I thought that this would be self-explanatory. Is this something that I should have explained directly?

Experiment 2-7 Results

Control Comments:

C1: As I watched the viewer play, I noticed that he seemed to be straining to get the avatars viewed turned completely around. This problem looked like it was due to the mousepad we were using at the time, but it may also be that the default mouse turn speed is too low.

C2: The user suggested that inexperienced players might get disoriented by the ease of turning using the mouse look. He suggested that the left and right arrow keys be set to a certain turning distance (i.e each push of the left key turns the character 45 degrees to the left).

Navigation Comments:

N1: The mouth door in the nasal cavity might be too small, as the user stepped over the opening multiple times while trying to go into the opening.

Problem Rating: Medium.

Est. Difficulty: Medium.

N2: The user was able to navigate their way back to the spawning point of the map. I think this is a definite proof that the game is easily navigable, as there are no specific signs or navigational aids that lead back to this point.

N4: The user stated a preference for free-form exploration, as opposed to directed activities.

Environment Comments:

E1: The tunnel corners continue to be a problem. The user had to avoid the corners of the tunnel opening while traversing the tunnels, moving through the direct middle of the opening. At this point, I'm still not sure how to fix the problem. Fortunately, it has yet to get any user permanently stuck, and has been performing much better than previous iterations.

E2: As already covered in a previous test, the tutorial voice is far too soft.

E3: The user thought that the brain room was actually inside of the skull, due to the location of the room, and the white color of the texture. This is actually a reasonable guess, and an argument for the addition of a navigation aid identifying the brain room.

E4: As with many other users, this user enjoyed being able to see “out” the mouth.

E5: The user expected the nasal hole to display the outside world, in the same way as the mouth. I'm not actually sure if the biology supports this, but if it does, I should modify the nasal hole entity to display the skyscape.

E6: The user mentioned the lack of a crease running down the middle of the the tongue. Does a frog tongue have this crease like a human one? If it does, adding the crease should be a fairly simple affair (I just need to modify the shape of the tongue patch a little).

E7: The user thought that the sound for the croak should be more positional. He felt that the sound should be faintly heard even outside of the ear chambers, and then get a lot louder as he enters the ear. The Q3 sound engine is already positional, and while I can play with the location of the sound object within the Q3 map, it may be difficult to create a croak more positional than what I have now.

Misc. Comments:

M1: The user encountered a glitch I haven't encountered before. The user was in the mouth, facing the mouth opening from the back right of the room. While in this spot, the user could not move to the left.

M2: The user was not satisfied with just exploring the head, and really wanted to see the rest of the body.

M3: The user thought he should be able to see the uvula at the throat. As discussed in an earlier test summary, I'm not sure the biology supports this, but if it does, I can add a picture of the uvula to the texture of the back mouth wall.

M5: The user had an interesting view comment. He thought that the rooms should be easily visible from the far end of the tunnels in the brain. He felt that the player would have a better experience if they could get a clear view of the various areas even before they journeyed to them.

M6: The user expected there to be discernible elevation differences; going down to the nose, and up to the eye. While the biology doesn't seem to support those exact elevation changes, it does support elevation changes beyond what the current map structure provides.

M7: The user noticed a tile pattern on the texture of the mouth walls. This led the mouth wall to look more artificial and less organic. This is a problem that could be fairly easily fixed with the surface texture editor in GTKRadiant.

Problem Rating: Minor.

Est. Difficulty: Minor.

M8: The user really liked learning about the balancing aspect of the semi-circular canals and the shape of the teeth.

M9: The user did want interactive activities, but did not end up specifying the actual nature of the activities.

M10: The user suggested an event where, just before entering an area, the game would show a 360 degree cut-scene which gives a brief tour of the area in question.

Drawing Activity Score Sheet

Brain Checklist:

- large ovoid room shape
- correct label
- wall texture
- connection to ear
- connection to eye
- connection to mouth

Eye Checklist:

- correct label
- main eye texture
- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain

- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Misc. Comments:

--The ear was labeled as the center room/skull.

--The brain was labeled as the eye.

--The eye was labeled as the ear.

--Since the user mentioned being confused due to the lack of elevation between rooms, this may account for the confusion in the room position. It did seem that the user remembered some of the details of the rooms.

Experiment 2-8 Results

Control Comments:

Navigation Comments:

N1: The user observed the right-eye sign.

N2: The user observed the right nasal cavity sign.

N3: The user observed the right-ear sign.

N4: The user observed and understood the connection between the nasal cavity and the mouth, and stated that he had not known there was a connection between the two before.

N5: The user recognized the brain from its location and use as a central hub location.

Environment Comments:

E1: The user liked the first-person perspective used in the game, as he related it to the fun experiment he had with first-person shooter games.

E2: Similar to other participants, the user quickly observed and enjoyed viewing the teeth entities in the mouth.

E3: Similar to other tests, the user found the audio tutorial far too soft.

E4: The user thought that he should be able look at the outside world from the inside of the eye. We experimented with this feature in previous iterations and had to drop it due to technical problems. It may be time, however to re-visit this issue.

E5: The user stated that he found the glow effect on the stairs used in the mouth useful. He say the glow effect as a statement of “come here”, which alerted him to the presence of an interactive object, and prevented him from getting lost in the mouth.

E6: The user pointed out that the mouth really should have ambient sound in it. The user suggested re-using the bullfrog croak, as he felt it would be logical to hear the bullfrog croak in the mouth if it was currently being heard in the ears.

E7: The user cited the noise made by the footsteps of the avatar as an important factor in his immersion of the game.

Misc. Comments:

M1: The user suggested a quiz activity be added. He envisioned having a button located in each area. When pressed, the button would activate a tutorial that would present some information to the user. Once all the button tutorial were activated, the user would be presented with a quiz testing the knowledge gained from all the tutorials. The user did not elaborate any further on exactly how this activity would work.

M2: The user wished that he had a flash usb drive so that he could take the game home with him.

M3: The user thought it might be fun to have a tour guide character within the game, possibly in the place of the button tutorials he had come up with earlier.

M4: The user thought that multiplayer support would be a worthwhile endeavor. He would have liked the opportunity to chat with another player, and exchange knowledge with them. He did not give any specifics beyond this description.

Drawing Activity Score Sheet

Brain Checklist:

- ___ large ovoid room shape
- ___ correct label
- ___ wall texture
- ___ connection to ear
- ___ connection to eye
- ___ connection to mouth

Eye Checklist:

- ___ correct label
- ___ main eye texture
- ___ iris and pupil on front wall
- ___ connection to brain
- ___ spherical shape of room

Ear Checklist:

- ___ correct label
- ___ semi-circular canals
- ___ earbone & side circle
- ___ main wall texture
- ___ connection to brain
- ___ bullfrog noise
- ___ spherical room shape
- ___ two chambers

Nasal Cavity Checklist:

- ___ correct label
- ___ connection to brain

___ connection to mouth

___ soft tissue on walls

___ fog

___ nasal hole

___ spherical room shape

Mouth Checklist:

correct label

___ connection to nasal cavity

___ tongue shape and texture

___ mouth shape and texture

teeth shape

Misc. Comments:

--The nasal cavity was labeled as the brain.

--The eye was labeled as the ear.

--The ear was labeled as the nasal cavities.

--The brain was labeled as the eye.

--It does not appear that spatial knowledge was correctly passed in on in the case of this user.

Experiment 2-9 Results

Control Comments:

C1: The user used the arrow keys, due to the fact that he had used the arrow key control scheme in other computer games.

C2: The user thought that using a game controller might have been a better control experience for him, as he thought being able to hold a single controller in both hands would have made it easier for him to use both hands to control his avatar.

Navigation Comments:

N1: The user observed the left-eye sign.

N2: The user observed the left-ear sign.

N3: The user, upon entering the brain, thought that the nasal hole was a hole back up to the brain room. This was one of the first rooms the user entered, so he was obviously still trying to ascertain the overall structure of the environment.

N4: The user stated that the navigation signs made navigation trivial. He felt that navigation would have been problematic without the signs.

Environment Comments:

E1: The user recognized the frog croak as what it was intended to be.

E2: The user recognized the brain due to its use as the central hub location. No label was necessary.

E3: The user stated that he would have preferred to not be able to see the rooms from the brain-side of the tunnels. He wanted the rooms' appearances to be more of a surprise than that. He suggested that a bright light or a door be used to block the view of each room until the player actually arrived in each room.

E4: The user identified the iris/pupil structure as a strong element in the immersion of the game.

E5: The user thought that the tunnels looked like blood veins, and felt that they were also an important element in the immersion.

E6: The user identified an immersion element he felt was missing. He thought that the mouth should have a moist appearance, as though water or spit was coating the mouth surfaces, and pooling up wherever appropriate.

E7: The user felt that the instruction signs, due to their size, non-organic appearance, and central location, detracted from the immersive quality of the game. He suggested using a pop-up window at the beginning of the game to introduce the game controls, instead of the persistent signs.

E8: The user suggested making the navigation signs look like stone instead of blackboards. He felt that this appearance would appear more natural to the environment than the blackboard approach.

Misc. Comments:

M1: The user recognized that he had been to all the rooms. He stated that he was able to do this using the navigation signs. He used them to identify all the different areas, and determine which ones he had visited and which ones he had not.

M2: The user preferred free-form exploration. He did not want directed exploration.

M3: The user wanted to keep exploring the rest of the body...moving down the throat “like a slide” to the stomach.

M4: The user suggested that a fun activity type for the game might be a scavenger hunt. He wanted to be able to click on objects in the environment, learn about the objects, and pick up some kind of item for clicking on it. “Winning” the game would involve exploring all the various rooms, and collecting all the items in each room.

M5: The user thought that a fun educational demonstration would be a view in the eye room where the player could view the outside world with the visual look that a frog would see.

M6: The user suggested that when the player enters a room, a pop-up could appear, giving out basic information of the room.

Drawing Activity Score Sheet

Brain Checklist:

large ovoid room shape

correct label

wall texture

connection to ear

connection to eye

connection to mouth

Eye Checklist:

correct label

main eye texture

iris and pupil on front wall

- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Experiment 2-10 Results

Control Comments:

C1: The user did not seem to understand that he could use the mouse to change the direction his avatar was facing. I asked him to explain to me the deficiencies of the sign in explaining the mouse look. He stated that the mouse line was not as noticeable compared to the arrow key explanations, which had arrows that jumped out at him.

C2: The user was able to control his avatar once mouse-look was introduced. He did not have a problem using both hands to use the mouse/keyboard controls.

C3: The user chose to use the arrow key control scheme. He stated that he chose to use this scheme because the arrow keys were “liked a PS3 controller a little bit.” He chose to use the arrow key scheme because it was more similar to the game controllers he was used to than the WASD scheme.

C4: The user experimented a little with the WASD keys in the last few minutes of the play-test, but returned to the arrow keys before the end. He was able to use the WASD keys proficiently, but obviously preferred the arrow keys.

C5: Due to the lack of a need for it, I did not add the jump key to the control explanations. I wonder if I should disable all controls that I do not intend to be used for the game itself. Using the load game option, for example, might prove to disrupt the experience, and get them into an actual Q3 game, which is something I don't want to happen.

C6: The user suggested that the control blackboards should use colored letters to catch the eye. He believed that this would have alleviated the issue described in C1.

Navigation Comments:

N1: The user did not initially observe the navigation signs posted by each area. He visited a nasal cavity without observing the sign for it. Once he visited the next area, the right eye, he observed the nav sign, and from then on, looked for, and found the navigational sign.

N2: The user initially guessed that the nasal cavity was in fact the eye, due to the white tissue on the walls and the hole in the front wall.

N3: The use recognized the “holes” at the tops of the stairs in the mouth as the holes leading to navigable areas that they were intended to be.

Environment Comments:

E1: The user recognized the mouth due to the presence of the teeth in it.

E2: The user stated that he recognized the brain “easy peasey” due to its use as the central hub area.

E3: The user recognized the black back wall of the mouth as where the entrance to the throat should be.

E4: The user observed the fog in the left nasal cavities.

E5: The user wanted to see a slightly different portrayal of the nasal hole. He wanted to climb a ladder to the nasal hole, and view the outside world just as in the mouth.

E6: The user recognized the tongue due to its shape and texture.

E7: The user stated that he enjoyed the mouth's look the most, since it had the most recognizable details out of all the rooms.

E8: The user stated that he enjoyed the eyes because of the predominately white color of those rooms.

E9: The user identified the custom textures and sounds as the primary sources of his immersion into the game experience.

E10: The user thought that animating the tongue so that it moves in and out of the mouth, would add a significant immersive experience to the game.

Misc. Comments:

M1: The user had problems entering the mouth door in the nasal cavity. He stepped over the hole multiple times while trying to go into in. He stated “no fair”, and explained that the hole was too small for him to easily step in.

M2: The user like having the freedom to explore, and did not want a directed experience.

M3: The user wanted to go into the throat, and was disappointed when he found out that the game experience did not cover that area.

M4: The user suggested have a activity where the player would find and destroy viruses, employing traditional FPS game mechanics.

M5: The user, in odds with his earlier desire for freedom, wanted a game separated into specific levels, each with an associated task. Winning would then be contingent on clearing all of the levels. This is the traditional structure for a video game, so the user was basically stating a desire for Frog Explorer to provide a traditional video game experience.

Drawing Activity Score Sheet

Brain Checklist:

- large ovoid room shape
- correct label * misspelled but recognizable
- wall texture
- connection to ear
- connection to eye
- connection to nasal cavity

Eye Checklist:

- correct label
- main eye texture
- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label *”nous” but close enough

- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label *"moth"
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

Misc. Comments:

The user put teeth on the bottom jaw of the mouth, even though there were no teeth present there in the actual game.

Experiment 2-11 Results

Control Comments:

C1: The user tried to click on the control blackboard for the WASD keys. She thought that she was supposed to select which controls scheme she wanted to use by clicking on its blackboard.

C2: While the user was capable of using both hands, she was not comfortable doing so. She only used the mouse-look when it was absolutely necessary for her to do so. She stated a desire for the mouse-look controls to be bound to keys, so that she did not have to use the mouse.

C3: The user had to visible strain to turn her avatar around using the mouse controls. This indicates that the default mouse-turn speed may be too low.

C4: The user chose to use the WASD control scheme. She stated that she chose to use this scheme because it put her hands closer to the screen, which made it more comfortable for her to move her face closer to the screen.

C5: The user stated that she would have appreciated the opportunity to control her avatar with a game controller. She would have preferred this format because the limited buttons would have prevented her from hitting keys accidentally, as she was occasionally doing with the keyboard controls.

Navigation Comments:

N1: The user observed the left-eye sign.

N2: The use was able to recognize that she had visited every room, using the navigation signs to determine which rooms she had been in.

N3: The user stated that navigation was easy due to the navigation signs. She liked that she could use the sign to identify what was in a particular room, and compare what she saw to her own mental image of what should be in the room.

N4: The user stated that the boards were not as noticeable as they should be, as she missed the navigation sign for the first room she entered.

N5: The user recommended changed the “nasal cavity” label to “X side of the nose”. “Nasal Cavity” was a phrase she did not know or understand.

Environment Comments:

E1: The user did not recognize the pupil of the left eye on her first visit there. She only recognized what the pupil was intended to be after she observed the left-eye sign. This indicates to me that the navigation signs play an important role beyond simply navigation. They help establish a context for the user, helping them to understand what it is that they are viewing.

E2: The user recognized the tongue due to the appearance of the tongue texture.

E3: The user recognized the bullfrog croak as such.

E4: Initially, the user thought that the eye was the stomach. She did not elaborate on why she came to this impression.

E5: The user initially thought that the nose was the mouth. She stated that she came to this impression due to the presence of the soft tissue patches, with their white color.

E6: The user could not figure out what the left nasal hole was intended to be.

E7: The user felt that the control and navigation boards detracted from the immersion experience, due to their use of words. She felt that using pictures instead of words would feel more natural.

Misc. Comments:

Drawing Activity Score Sheet

Brain Checklist:

- large ovoid room shape
- correct label
- wall texture
- connection to ear
- connection to eye
- connection to nasal cavity

Eye Checklist:

- correct label
- main eye texture
- iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise

- ___ spherical room shape
- ___ two chambers

Nasal Cavity Checklist:

- ___ correct label
- ___ connection to brain
- ___ connection to mouth
- ___ soft tissue on walls
- ___ fog
- ___ nasal hole
- ___ spherical room shape

Mouth Checklist:

- ___ correct label
- ___ connection to nasal cavity
- ___ tongue shape and texture
- ___ mouth shape and texture
- ___ teeth shape

Misc. Comments:

- The brain was labeled as the left ear.

- The ear was labeled as the right eye.

- The eye was labeled as the "right cavity".

- The mouth was labeled as the right ear.

- The nasal cavity was labeled as the mouth.

- No details were even attempted.

Experiment 2-12 Results

Control Comments:

C1: The user chose the arrow keys, stated that she had an easier time remembering what each key did than the WASD scheme.

C2: It was obvious as I observed the user that they were very uncomfortable using their left hand to manipulate the keyboard controls.

C3: The user stated that she would have preferred the use of a game controller, as she would have been more comfortable using both hands with this type of control device.

Navigation Comments:

N1: The user observed the “up to” right nasal cavity sign in the mouth.

N2: The user didn't realize that she was actually supposed to walk up to the “hole” in the mouth to move up to the nasal cavity. He suggested that the sign next to the hole be modified to make it clearer that it was a passage to the nasal cavity, such as “Go up here to the nasal cavity.”

N3: The user observed the left-eye sign.

N4: The user observed the left-ear sign.

N5: The user stated that she now realized that there were in two connections to the mouth, one in each nasal cavity,

N6: The user was able to use the navigation signs to tell that she had visited every area.

M7: The user stated that the navigation signs made navigation easy for her.

Environment Comments:

E1: The user thought that the nasal cavity was the inside of the skull on her first visit there. She came to this conclusion after observing the white tissue samples covering the walls. She thought that they were supposed to represent the inside surface of the skull.

E2: The user recognized the brain due to the “squiggly lines” on the texture used in that area.

E3: The user felt that the rooms were too empty to feel “real” to her. She suggested adding more organs and other biological details to the game, and fill up the space within it.

Misc. Comments:

M1: The user like the fact that she could explore freely, but found this aspect intimidating as well. She suggested that the game take a balanced approach, and provide at least a suggestion as to where she should go next.

M2: The user thought that the coloring using in the game was particularly well done.

M3: The user enjoyed the details of the mouth a great deal.

M4: The user stated that she enjoyed the perspective of moving around inside the body like a “little person”.

M5: This user felt the absence of informative material, and would have really liked the game to actively teach her more about the areas she was viewing.

M6: The user cited the ability to turn her avatar's head freely as an important factor in her ability to be immersed in the game.

M7: Like many other users, this user wanted to explore other parts of the frog.

M8: The user suggested a mini-game. Within the game, show a drawing or diagram of a particular part of the frog head, and have the player guess which part is depicted from a small list.

M9: A second activity the user suggested was to have a puzzle to put together. The pieces of this puzzle would be small 3-D renditions of the different areas the player visits, and the players job would be to correctly assemble the frog's head using these pieces.

Drawing Activity Score Sheet

Brain Checklist:

- large ovoid room shape
- correct label
- wall texture
- connection to ear
- connection to eye
- connection to nasal cavity

Eye Checklist:

- correct label
- main eye texture
- x_ iris and pupil on front wall
- connection to brain
- spherical shape of room

Ear Checklist:

- correct label
- semi-circular canals
- earbone & side circle
- main wall texture
- connection to brain
- bullfrog noise
- spherical room shape
- two chambers

Nasal Cavity Checklist:

- correct label
- connection to brain
- connection to mouth
- soft tissue on walls
- fog
- nasal hole
- spherical room shape

Mouth Checklist:

- correct label
- connection to nasal cavity
- tongue shape and texture
- mouth shape and texture
- teeth shape

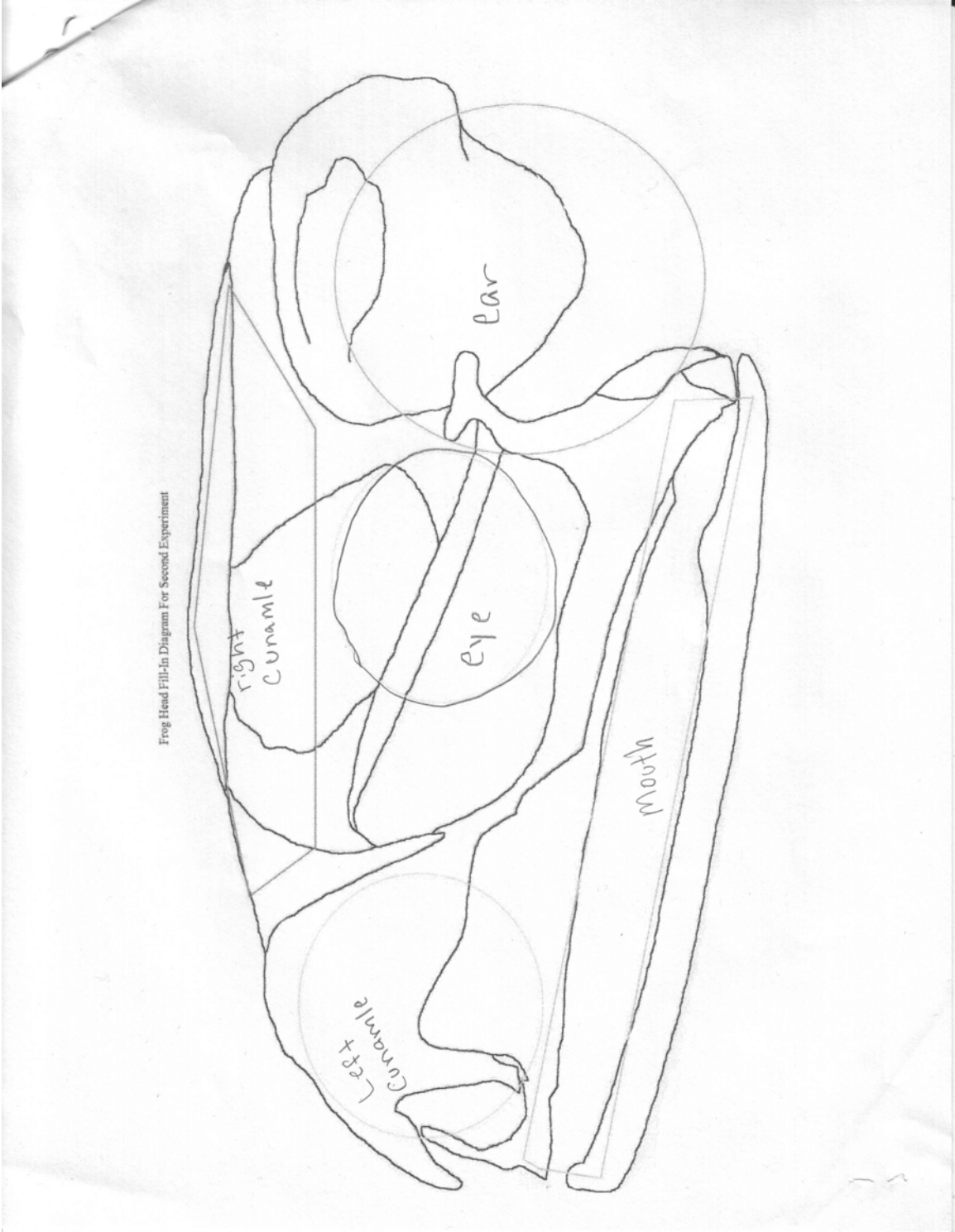
Misc. Comments:

--The user had an arrow labeled "nasal to mouth" pointed at the back of the brain area. I believe she meant to indicate that she thought one of the nasal-to-mouth holes in the mouth was located here.

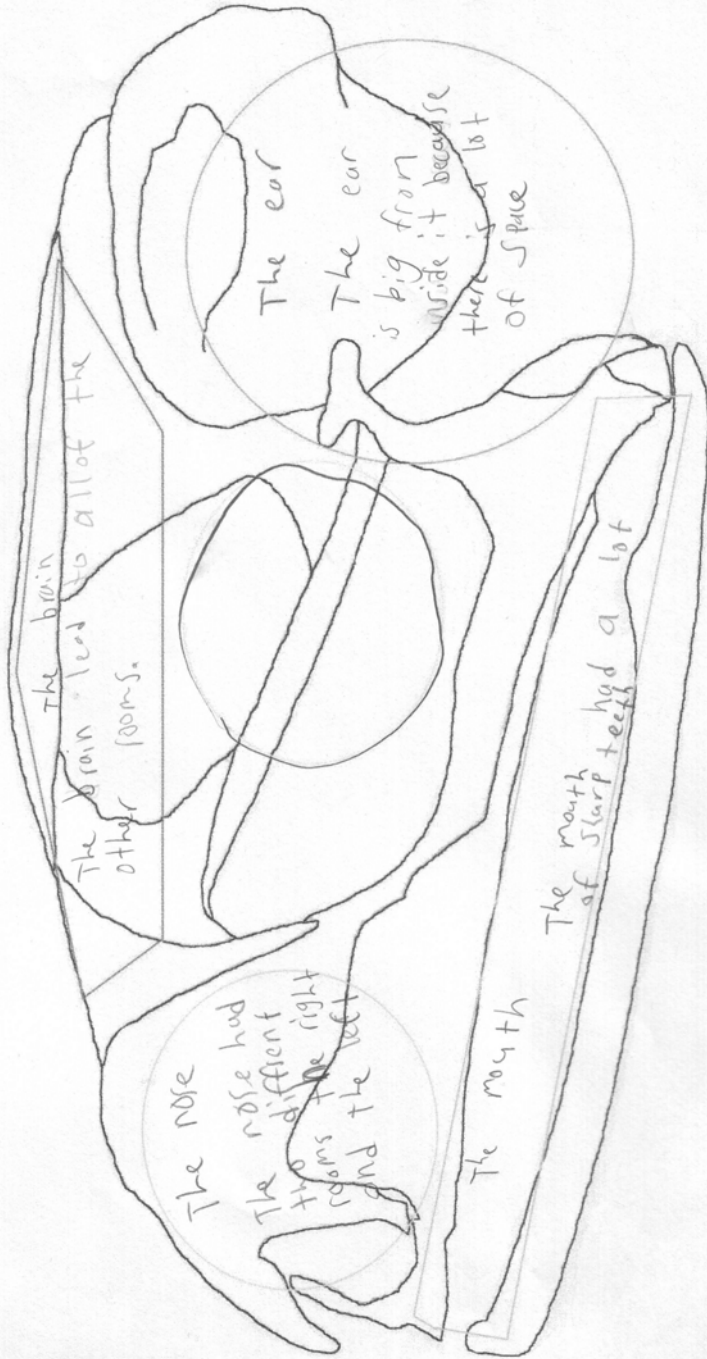
--The ear was labeled as the eye.

--There was a similar “nasal to mouth” arrow pointing to the back area of the actual mouth section.

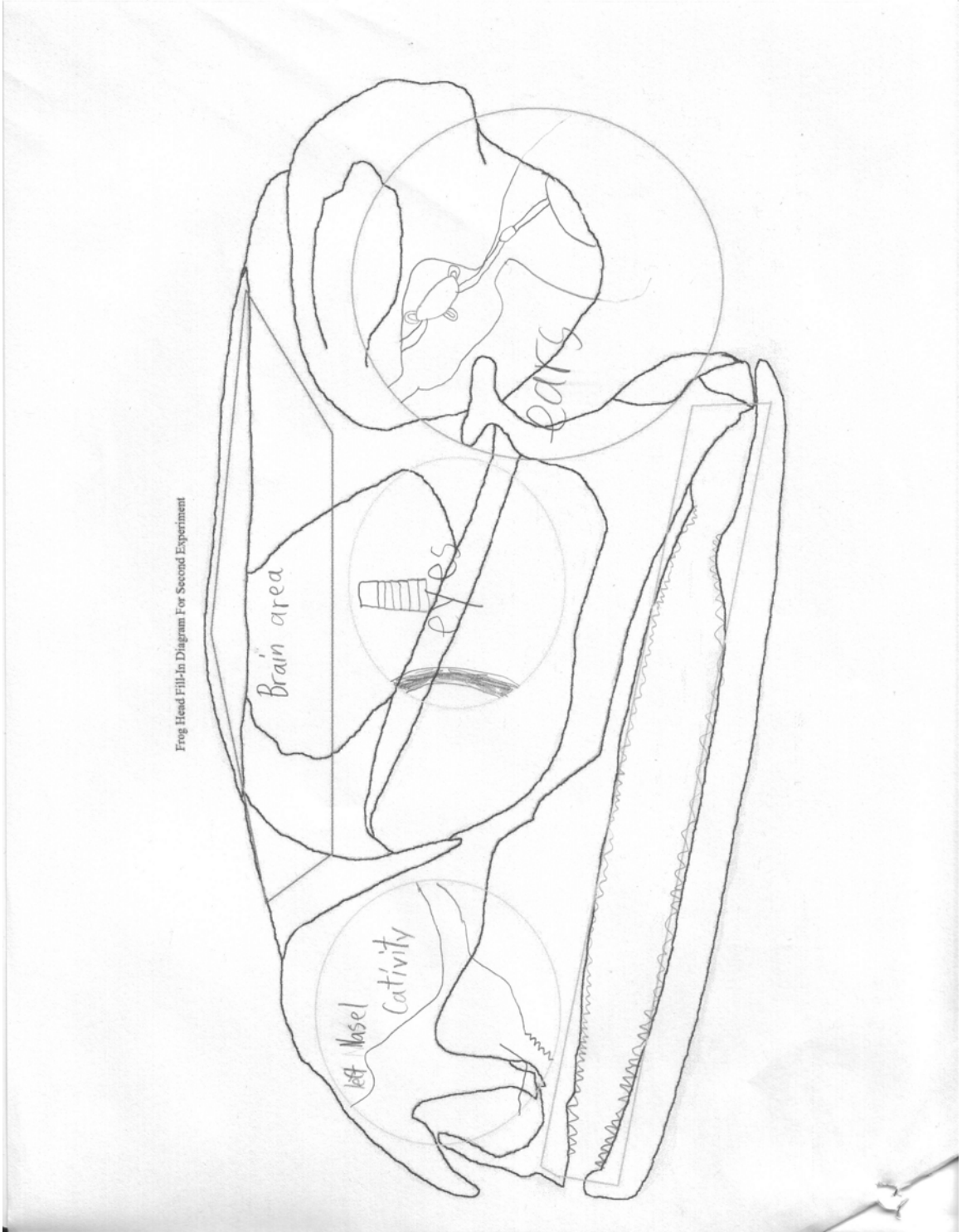
Frog Head Fill-in Diagram For Second Experiment

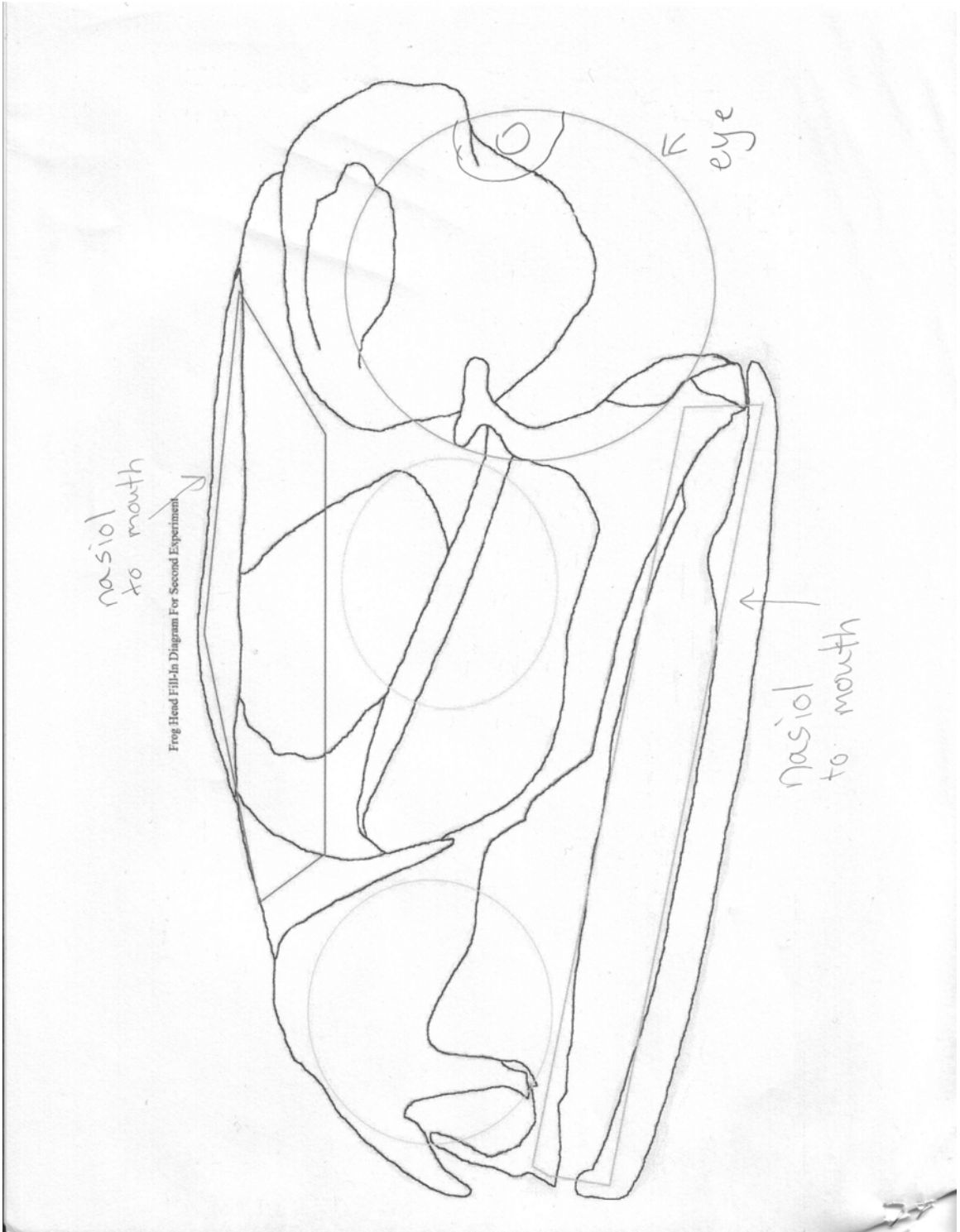


Frog Head Fill-In Diagram For Second Experiment



Frog Head Fill-In Diagram For Second Experiment



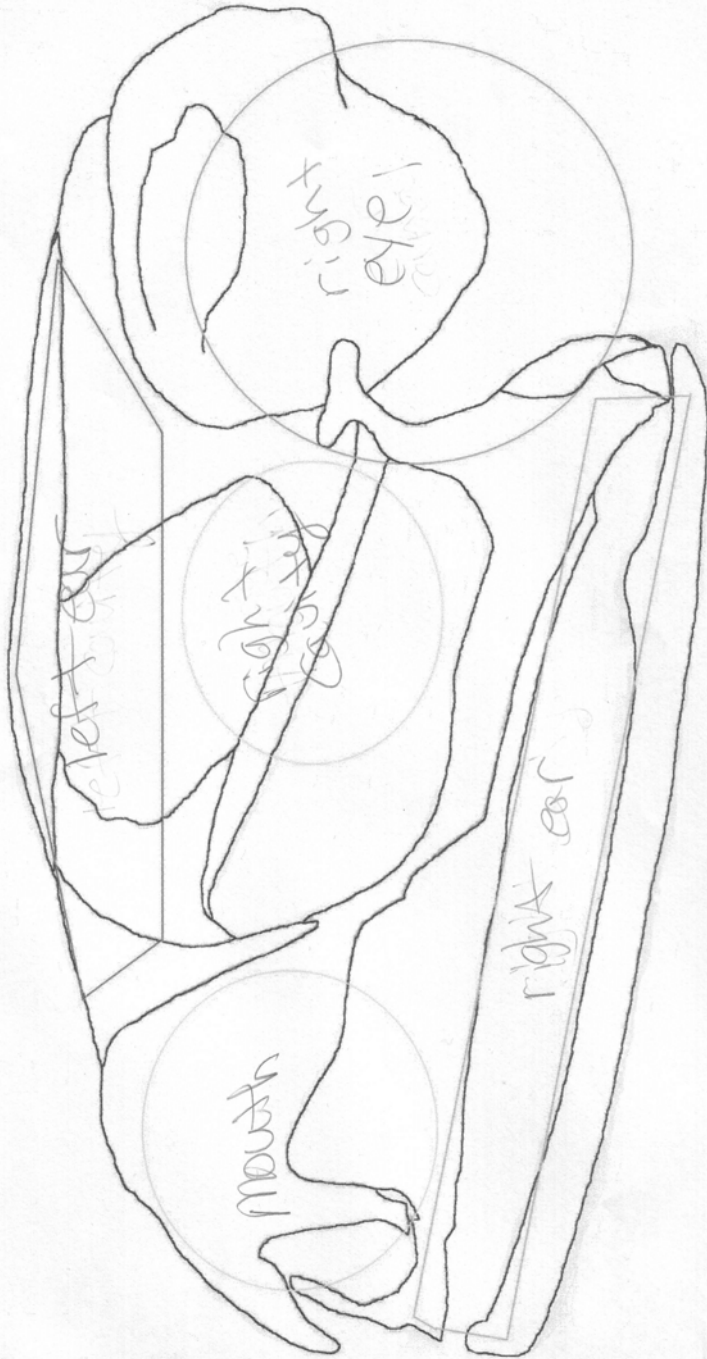


nasial to mouth
Frog Head Fill-In Diagram For Second Experiment

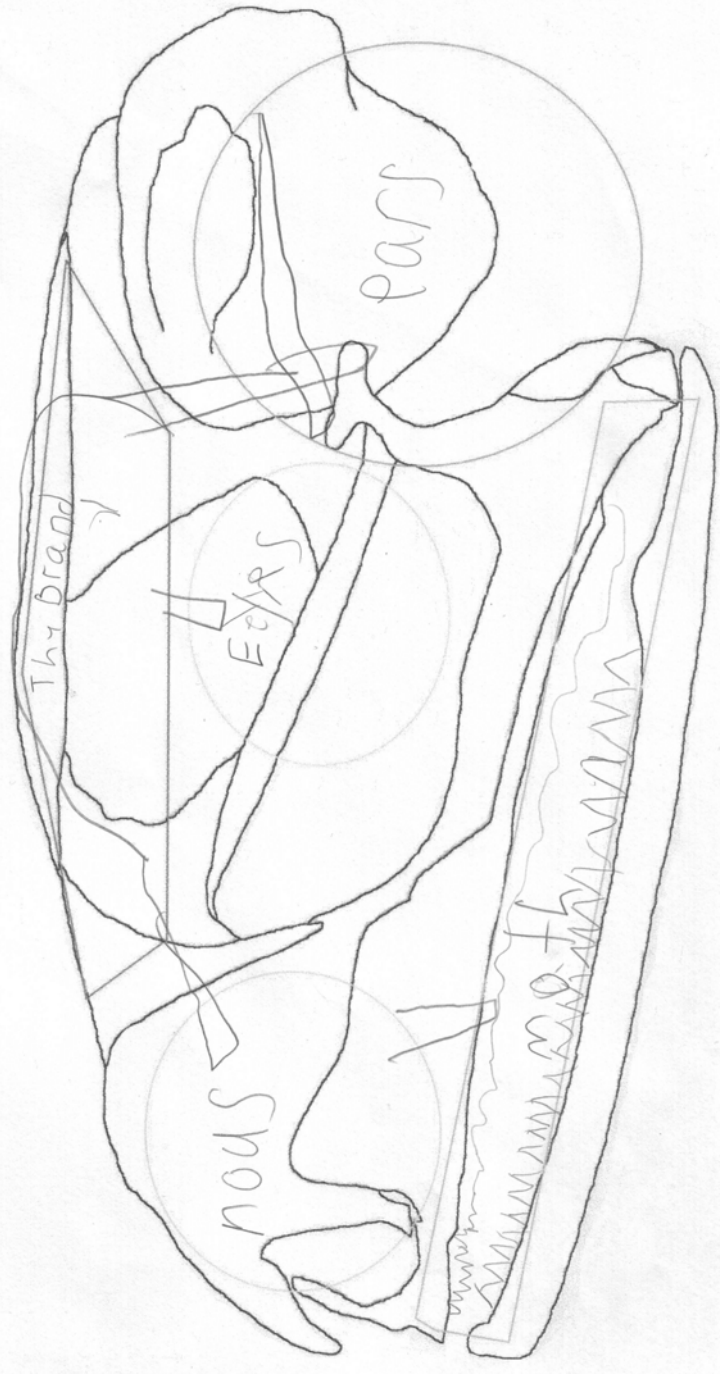
eye

nasial to mouth

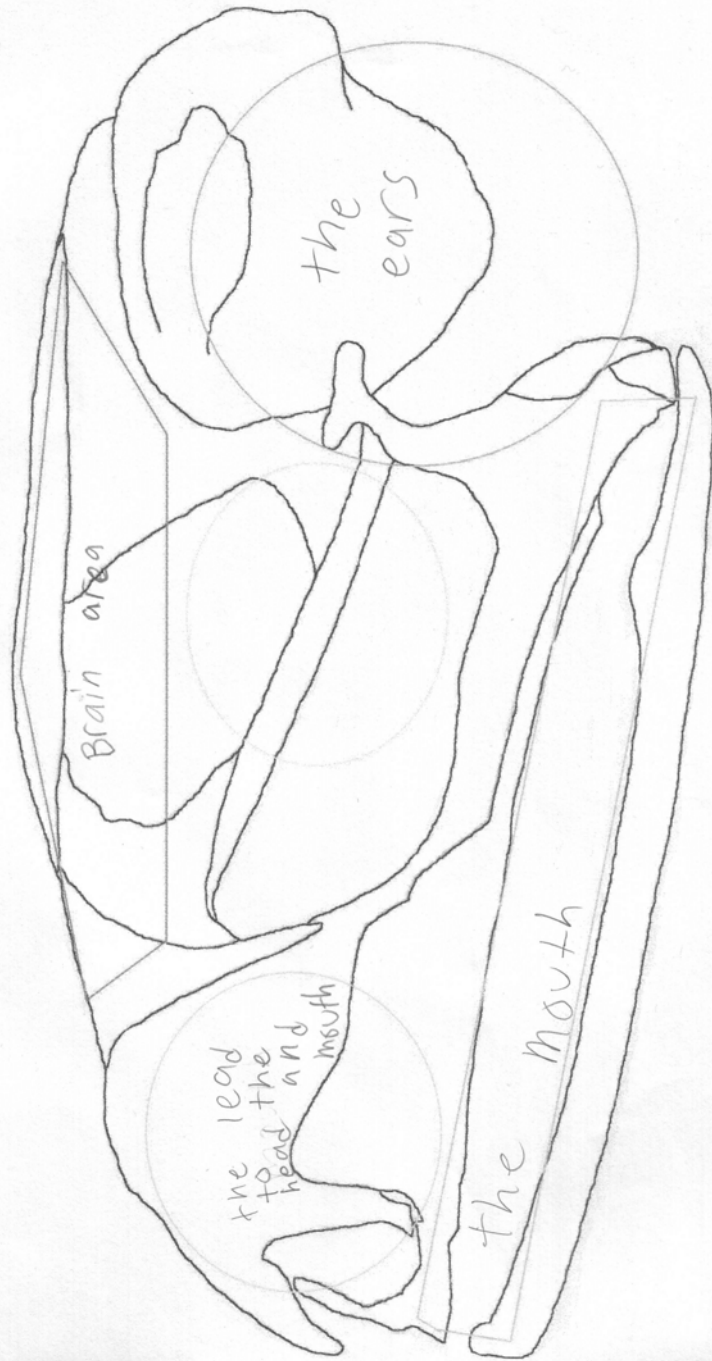
Frog Head Fill-In Diagram For Second Experiment



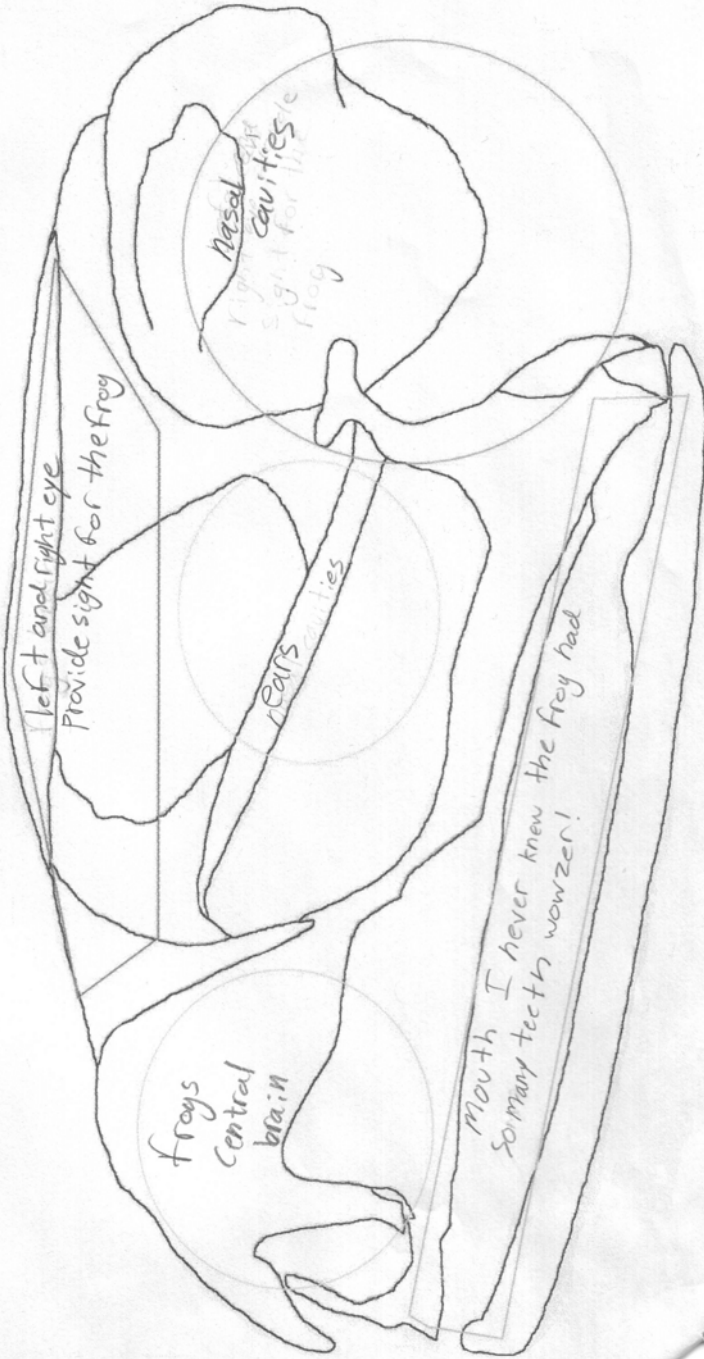
Frog Head Fill-In Diagram For Second Experiment



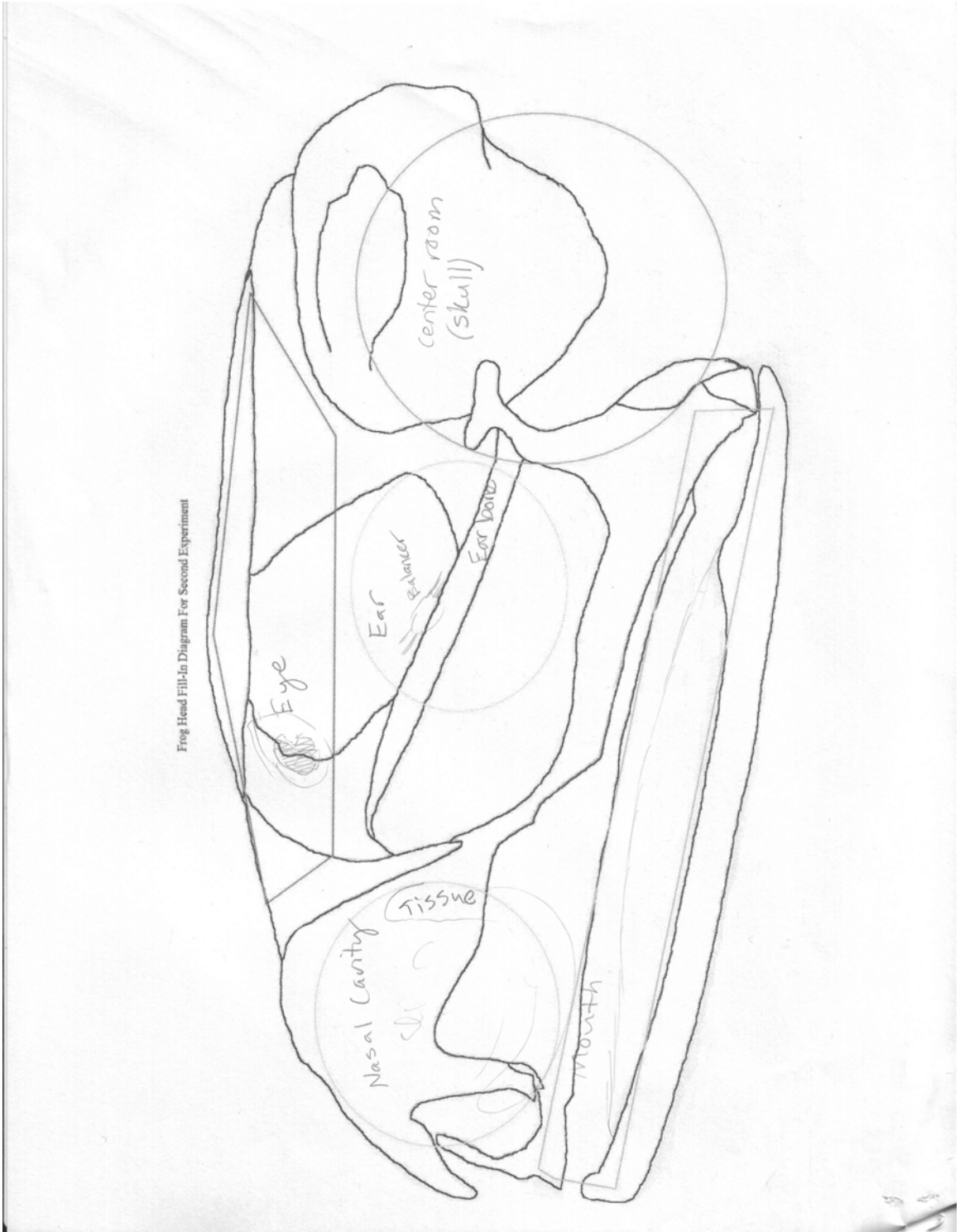
Frog Head Fill-In Diagram For Second Experiment



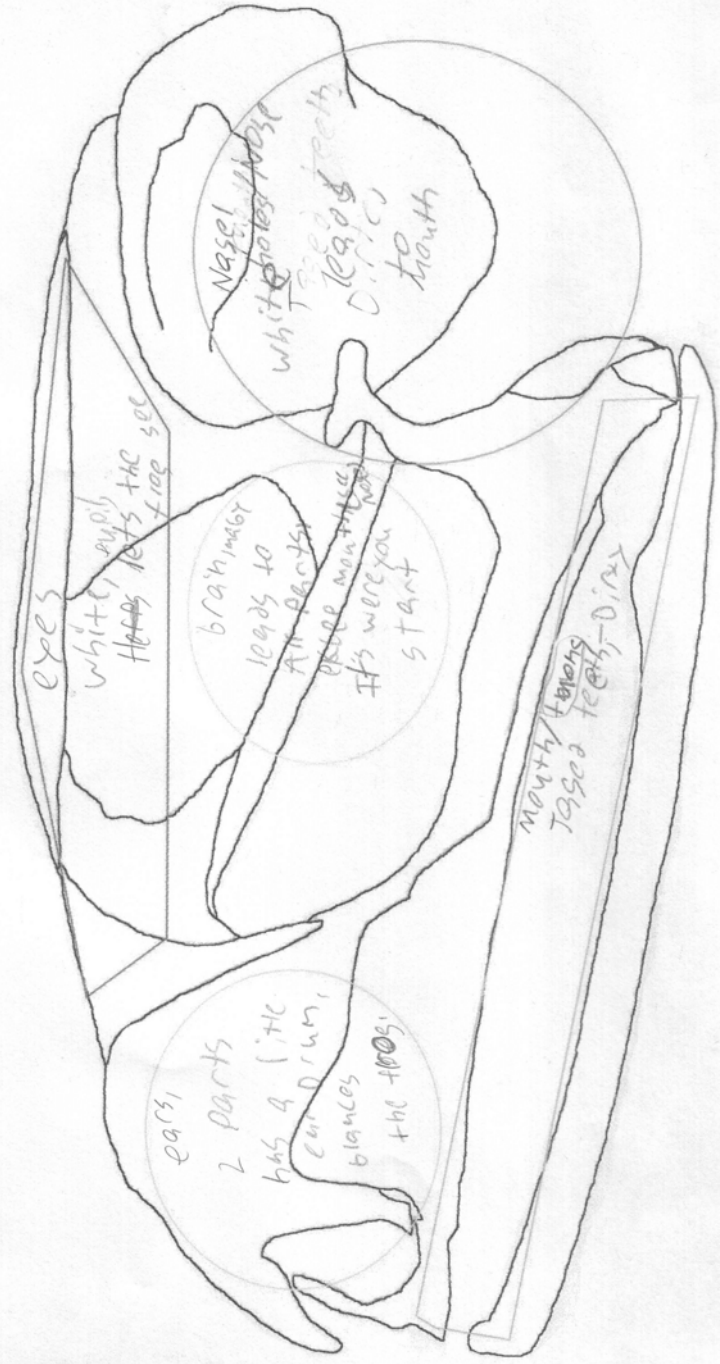
Frog Head Fill-In Diagram For Second Experiment



Frog Head Fill-In Diagram For Second Experiment



Frog Head Fill-In Diagram For Second Experiment



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VITA

Hussain Makki Alafaireet is the son of Mr. Makki Ali Al-ofaireet and Patricia Elaine Alafaireet. Hussain was born in Columbia, Missouri on August 4, 1982. Even during his youth, Hussain was interested in computers and computer programs, and by the end of his high school career, Hussain had achieved college-level proficiency in the C++ programming language. Hussain graduated with a Bachelors degree in Computer Science from the University of Missouri-Rolla in 2005. Prior to beginning his Masters, Hussain worked on custom medical record software for the University of Missouri-Columbia's Health Management and Informatics department. Hussain began his graduate studies in Computer Science at Missouri University of Science and Technology (formerly, the University of Missouri-Rolla) in the fall of 2006. He will receive his Masters degree in the summer of 2009.

