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EFFECTIVE VIRTUAL NAVIGATION IN A 3D UNDERWATER ENVIRONMENT BASED ON REAL-WORLD BATHYMETRY

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EFFECTIVE VIRTUAL NAVIGATION IN A

3D UNDERWATER ENVIRONMENT BASED ON

REAL-WORLD BATHYMETRY

BY

JOEL BARRUOS

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OF

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ABSTRACT

Scientific visualization can be viewed as a subset or a type of data visualization in which the data can be mapped to a geometric shape or spatial coordinate system. Geovisualization is a type of scientific visualization in which the data represented are earth data (e.g., bathymetry). As the need for exploring these scientific data sets increases, so will the need to support user interaction with the data. This requires creating user interfaces that allow users to carry out observational (e.g., compare and analyze different data sets) or experimental (e.g., data exploration) tasks on the data sets.

This thesis aims at supporting user interaction with underwater geospatial data sets. More specifically, we are interested in investigating the usefulness and effectiveness of different navigational aids, visual aids, and visualization tools that best support user navigation. This thesis does not implement a sophisticated graphical user interface for analyzing underwater data set. Instead our focus is on supporting user navigation about the underwater data sets.

We have developed, using the Unity3D game engine, our own scientific visualization tool that allowed us to create various aids and investigate their usefulness and effectiveness during user navigation. The visualization tool has the ability to spatially plot underwater geospatial data, supports user interaction/navigation, and has the ability to collect quantitative data on the users of the application.

In order to evaluate the usefulness and effectiveness of the varying aids, we conducted a usability evaluation of the visualization tool. The usability evaluation consisted of running five different scenarios—each with its own unique configuration

of navigation aids and visual aids—and having test participants evaluate each scenario configuration. Participants were asked to complete usability questionnaires for each scenario. Once the quantitative and qualitative data was collected we analyzed the data and observed expected and unexpected user preferences for the both the navigation aids and the visual aids.

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I would like to acknowledge Trek Enterprises Co. of San Diego, CA who funded part of my studies at URI.

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CHAPTER 1

Introduction

1.1 Context and Problem Definition

About 70% of the Earth's surface is covered with water, and the ocean holds about 96% of all Earth's water [1]. The ocean acts as the lifeline for a vast ecosystem and it is the food supply for many civilizations. However, due to pollution, climate change, overfishing, etc., the ocean's characteristics have changed. For instance, the melting of the polar caps is causing sea levels to rise, resulting in floods around the world. Moreover, global ocean heat has continually risen for the last fifty-five years and there are no signs this will slow down in the near future [1]. For scientists and biologists, monitoring the ocean is of great interest due to the global implications changes in the ocean characteristics can have.

There are a large number of different sensing equipment that can be used to monitor the ocean, but for this research we will only discuss underwater gliders and the data they produce. An underwater glider is an unmanned sensing vehicle that can be programmed to navigate the ocean's depths and record measurements of the water's temperature, conductivity, pressure (depth), etc. Underwater gliders can make measurements in the ocean from hours to weeks or months at a time and can travel for up to thousands of kilometers.

The information recorded by this type of vehicle can be used to gain insight on the physical characteristics of the ocean. For instance, temperature and conductivity data collected by the sensing vehicle can be used to calculate salinity values in the

water, which is of great importance, since higher salinity values make it harder for water to store oxygen.

Typically, the data collected by underwater gliders are visualized using 2D visualization techniques (e.g., 2D attribute – attribute plots). However, over the last ten-to-fifteen years the demand for visualizing this data in more interactive forms has increased. Commercial products such as Fledermaus and Makai Voyager (both described in Chapter 2) allow users to create highly interactive visualizations of these underwater geospatial data sets. This includes the ability to create 3D and 4D (position + time), volume renderings, isosurfaces, etc.

The objective of this research is not to create a highly sophisticated visualization tool that supports observational users interactions such as the ability to compare multiple data sets, create cross-sectional views (2D views), etc. Instead this thesis aims at investigating the usefulness and effectiveness of different navigational aids, visual aids, and visualization tools that best support user navigation about underwater geospatial data sets.

1.2 Initial Involvement with Research

In the summer of 2012, Applied Sciences Associates (ASA) of Wakefield, Rhode Island, hired me as an intern to develop an oil spill 3D visualization tool. The tool required the ability to simulate oil spills and support user navigation in an underwater virtual environment. That is, users needed to have the ability to navigate about an oil spill plume to—ideally—gain insight on the oil spill behavior over time.

While the oil spill visualization tool did a satisfactory job at visualizing the oil spill, it did a poor job at supporting user navigation. Upon completion the

visualization tool supported a small amount of navigation support. This included a simple overhead view of the user in the world and a graphical user interface similar to Google Earth. Experts (biologists, scientist, engineers, GIS developers, etc.) stated that navigating in the virtual environment was a very difficult task due to the lack of underwater visual landmarks. All of the experts had experience with 2D visualization tools (e.g., geo-mapping tools). However, a majority of them had little to no experience with virtual environments. Many of the experts often struggled to maintain orientation during navigation in the environment (e.g., hard time determining which way was up or down). Many of the experts strongly stated that some form of navigation support should be provided to support navigation in the environment. For instance, the experts recommended incorporating 2D maps (to show them where in the world they are), different camera views (e.g. third-person view of orientation), compass (help them keep a sense of direction), etc.

Although my internship ended before I could incorporate and evaluate the navigation and visual aids requested by the experts at ASA. Their constructive feedback was influential in the choice of navigation and visual aids I chose to evaluate in this thesis.

1.3 Objective Outline of Thesis

First, we created our own scientific visualization tool using the Unity3D game engine [17], which gave us the ability to create various navigational aids and visual aids through the use of the software's Application Programming Interface (API). The framework was required to have the ability to spatially plot underwater geospatial data

and support user interaction/navigation. The framework and its individual components are described in Chapter 3.

We conducted a usability evaluation of the framework. The usability evaluation consisted of running five different scenarios, each with its own unique configuration of navigation aids, visual aids and visualization tools. Information related to the test participants and usability evaluation procedure is given in Chapter 4.

After collecting the user data from the usability evaluation we analyzed the data and found expected and unexpected user preferences for the navigation and visual aids. The test results and evaluation questions are presented in Chapter 5.

CHAPTER 2

Background and Related Work

2.1 Scientific Visualization

Data visualization can be used to promote user insight of a particular data representation or concept. Visualization can function as cognitive tools that support discovery, exploration and decision-making. If done correctly, data visualization can exhibit large amounts of information that can be rapidly interpreted [16]. Scientific visualization can be viewed as subset or a type of data visualization in which the data can be mapped to some type geometric shape or spatial coordinate system [16].
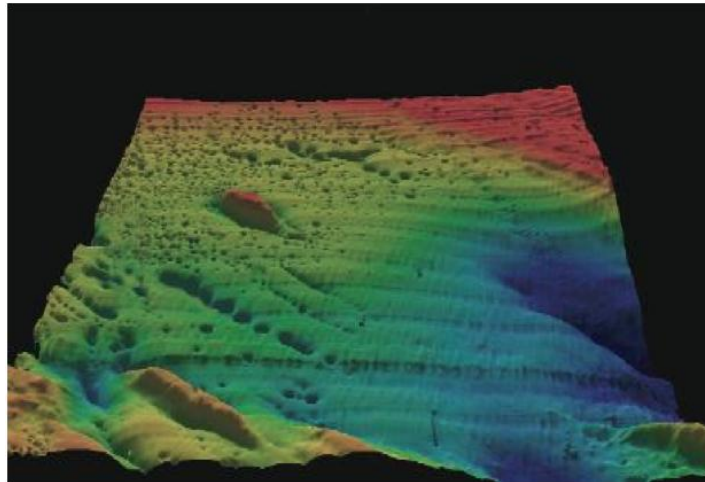
Figure 1: 3D model of the Passamaquoddy Bay seabed (approximately one million data points) [16].

Visualizations can give viewers the ability to quickly detect patterns in the data set. For instance, in Figure 1, patterns in the model are immediately visible. The dark circular spots along the seabed are known as *pockmark*, which are craters in the seabed caused by fluid such as gas and liquids erupting and streaming through the sediment.

A real world pockmark is shown in Figure 2. It must be noted that data visualization can also present information that does not exist (artificially created by the visualization).
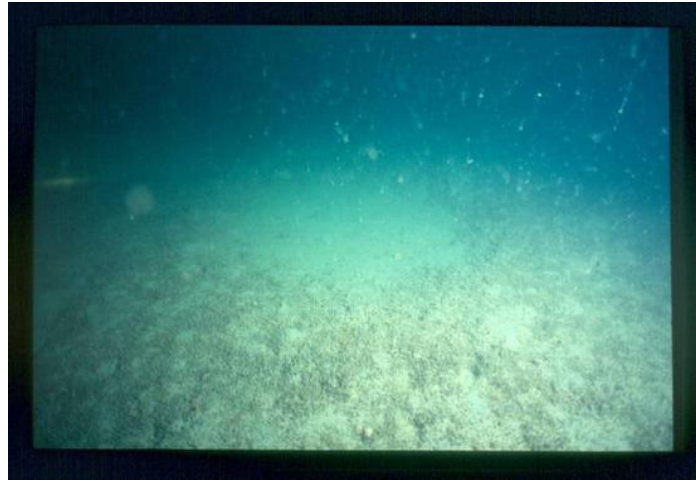
Figure 2: Real world view of pockmarks in the seabed [27].

It is important to note that scientific visualizations are not always interactive. Examples of non-interactive visualizations include still rendering, illustrations, and movies. For instance, Figure 3 shows an illustration of how bathymetric data are collected using multibeam sonars. Typically, an interactive visualization will provide users with some form of user interface (UI) that allows the user to interact with the data. Common interactions include adjusting the scale of the data, color mapping of the data, etc.
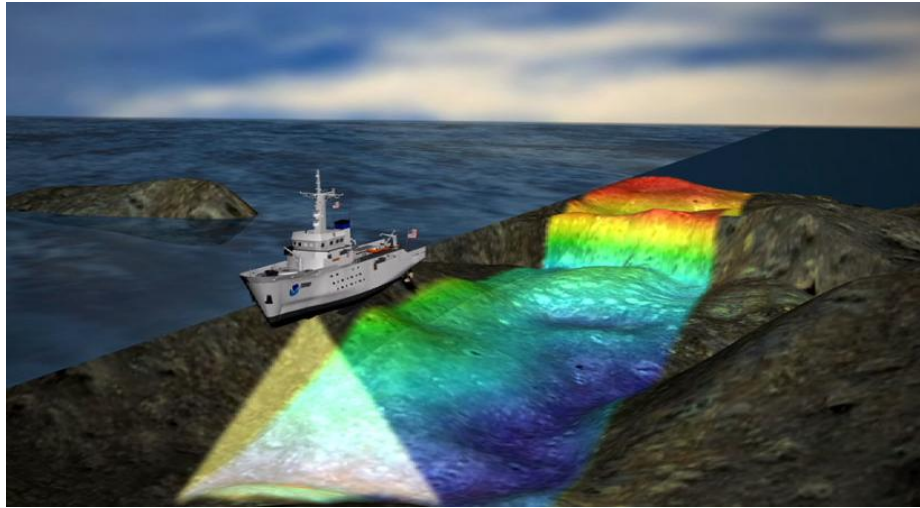
Figure 3: Visualization of multibeam bathymetry [20].

2.2 3D Geovisualization

3D Geovisualization is a subset or type of scientific visualization that is often used for representing real world data (geospatial data). Many of these visualization focus on representing the landscape of the real world and the objects that reside in it, such as trees, roads, and buildings [11]. Examples of geovisualization tools include Fledermaus, Makai Voyager, Google Earth, and COVE (all of which are presented in detail later). A view of Google Earth with a quantitative data overlay is shown in Figure 4.
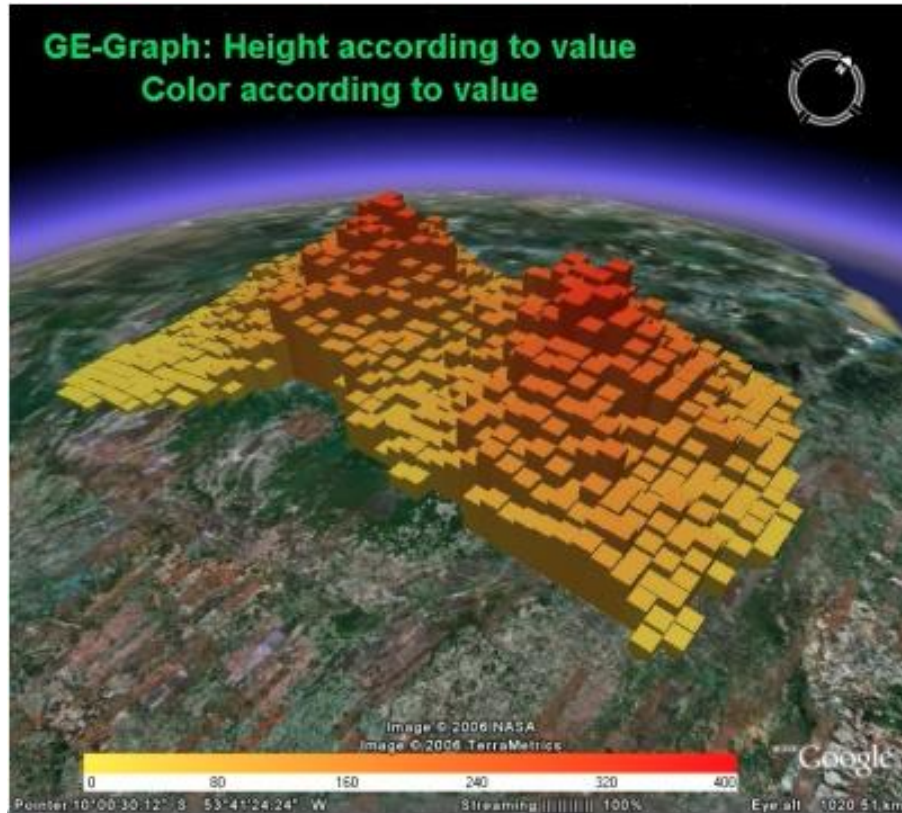
Figure 4: Google Earth with quantitative data overlay [11].

2.3 Data Exploration

Scientific visualization often supports user interactions through the use of UIs. Table 1, as presented by Grochow [9], presents user tasks carried out with interactive scientific visualization.

Table 1: Common user tasks in scientific visualization

Common Task	Task Description
Generation	Create a visual representation of data using system and tools
Examination	Examine attribute-attribute and attribute-time correlations
Orientation	Modify-orientation get a different perspective of data
Comparison	Compare data sets with each other to identify relevant differences
Queries	Find appropriate data sets and select sub-sets of attributes from data
History	Store information on the history, processes, and insights involved

In order to effectively support user interaction with the data sets, a well-designed and well-thought-out interface should be in place to support the anticipated user tasks.

2.4 Graphical User Interface

Interactive visualizations will likely support one the following forms of user interface, be it a command line, gesture-based, or graphical interface. For this research will concentrate on the Graphical User Interface (GUI) as the means for UI. The GUI is often described as the layer between the user and computer that allows users to interact with the computer through graphical elements such as windows, icons, menus, and pointers (WIMP) [21]. GUIs are important to human computer interaction (HCI)

since, they can help minimize the learning curve for a particular system. For instance, GUIs remove the need for users to memorize system commands to carry out tasks.

The most common style GUIs are 2D, which means that GUI components are coplanar to the computer screen. 2D GUIs were first introduced in the mid 1970s, and since then much research has been done to improve the effectiveness of 2D user interfaces [21].

A variant of traditional 2D GUI is the 3D GUI; this type of GUI is often used in virtual environments in which the level of immersion—the feeling of belonging—to a virtual environment is of great importance [2]. Unlike 2D GUIs which lay coplanar to the computer screen, 3D GUIs can be translated along the z-axis and can be rotated along the x, y, and z axes. Thus giving designers the flexibility of positioning the GUI elements inside the virtual environment. This can help improve the feeling of immersion in a virtual environment since it can minimize the obstruction of the user view [2, 12, 13].

It is important to understand that having an effective and useful interface is vital to the success of an interactive visualization system. If the users have a hard time understanding how to use the visualization interface, it can negatively impact their ability to understand the data being represented. Therefore, it is important that designers promote usability by following expert design guidelines and perform usability evaluations of the interfaces. The following section will continue the discussion on usability.

2.5 Usability

As visualization systems provide more and more features to the users it is often the case that the interfaces used by the systems become quite complex to use and understand. Therefore, it is important that designers of these interfaces try their best to support usability. A system that strives for usability, as described by Shneiderman [21], should accommodate for diverse cognitive and perceptual abilities. It is important that any system that relies heavily on user interaction should be designed to minimize the frustration experienced by users. In order to ensure usability, a system designer should understand what are the tasks and subtasks to be carried out by users. In doing so, a designer can maximize or minimize the user's effort for carrying out these tasks, for instance, by reducing the number of steps for completing a task. A common approach for understanding the user task is to create a task testbed as described by Bowman [2]. The task testbed can be used to create scenarios for the testing of different interface elements.

2.6 User Experience

Another important reason for promoting the usability of the interface is related to the user experience. If the interfaces causes the user to get frustrated or overwhelmed, it will likely result in poor user performance and satisfaction. To improve the user experience with an interface, designers should look to minimizing the time it takes to learn the system, improve the user's ability to carry out their task, minimize the rate of errors made by users, and so forth [21]. The motivation behind promoting usability and enhancing the user experience is simple. Disgruntled users will likely avoid using

the system again. The following section describes one approach for designing an effective and usable interface.

2.7 User Centered Design

The user-centered design (UCD) methodology for designing interfaces involves the understanding of users, the user tasks, and the environment. Interface designers are expected to follow expert guidelines for the design interface and develop a task testbed generated from known user tasks. The expected users of the system are then asked to evaluate the interface by completing a series of user tasks (both informal and formal). The data collected at this phase consist of both quantitative (such as task completion times, rate of errors, etc.) and qualitative (such as user preference, overall satisfaction, etc.). This development and testing cycle is continued until all parties agree on an interface prototype. Previous research has shown this design methodology to be successful [5, 8, 9, 12, 13].

2.8 Usability Testing

Let it be clear that there is no de-facto usability testing procedure. As mentioned earlier, one procedure for designing interfaces is to follow the UCD methodology. The UCD methodology uses a formative evaluation (both formal and informal) approach, which involves placing expected users in task-based scenarios in order to identify usability scenarios. Formative evaluations can be used to ask users to assess the interface's design ability to support user exploration, learning, and task performance [26]. The data collected in these evaluations can be both qualitative and quantitative. Qualitative data typically includes user comments, recommendations, etc.

Quantitative data typically includes user data that can be quantified such as number of errors, completions speed of tasks, etc.

On the other hand, one can also test an interface using a summative evaluation (both informal and formal). Summative evaluation is an evaluation and statistical comparison of two or more configurations of interface designs, interface components, and or interface techniques [26]. Similar to formative evaluation, users are typically asked to carry out scenario-based tasks, while evaluators collect both qualitative and quantitative data. Unlike formative evaluations that involve the user during the design phase, summative evaluations are typically done on completed interface designs. By doing so, it allows evaluators to measure and compare the cost and benefits of different interface designs.

The research presented in this thesis uses a summative evaluation to determine the usability of different navigation and visual aids.

2.9 Virtual Navigation

Another important feature of interactive visualization is that they often support user navigation in the virtual environment. As described by Burigat and Chittaro, navigation can be defined as the process whereby people determine where they are, where to everything else is and how to get to particular objects or places [6]. In more practical terms, navigation is a combination of wayfinding and travel [2, 26]. Wayfinding is the cognitive process of determining a path based on visual cues, knowledge of the environment, and aids such as maps or compasses. Travel is defined as the control of the user's viewpoint motion in the three-dimensional environment [2, 26].

As presented in Section 2.3 a common user task of interactive visualizations involves the user changing their orientation to get a different perspective of the data representation. In order to accomplish this task the user must carry out some form of navigation. The ability for users to effectively navigate virtual environments depends on how well users can plan their movements using spatial knowledge. However, as stated by Burigat and Chittaro, spatial knowledge of virtual environments typically develops very slowly after long periods of navigation or study, and it is quite possible that users are not always willing to spend the time to properly learn a virtual environment [6].

If virtual navigation is not effectively supported it is likely that users will become disoriented and get lost in the virtual environment. The problem worsens in large-scale environments where the user does not have the ability to see the entire world from one viewpoint. In large-scale virtual environments, users are often required to navigate the world to build spatial knowledge of the environment. In order to support user navigation, it is often recommended to use some form of navigational aid to help minimize the possibility of getting lost or disorientated. While a significant amount of work has been done on developing navigation aids for supporting virtual navigation, research on determining the effectiveness of different navigation aids is still under way. Burigat and Chittaro [6] conducted a usability evaluation of different location-pointing aids such as 2D arrows, 3D arrows, and a radar metaphor for supporting user navigation in large-scale virtual environments. The following section describes different navigational aids that have been evaluated.

2.10 Navigation Aids

A navigation aid that has been shown to effectively support user navigation is an overview map (bird's eye view). The overview map typically allows users to see more of the world than what they can from a single view. It allows users to build landmark knowledge—developed by using environment features and using them as reference points—and develop survey knowledge—from knowledge of reference points user can devise mental routes for movement. It has been shown that an overview map can help users develop a better understanding of the environment space, but places a higher cognitive demand on the users, which decreases their performance [3, 4].

Research has shown that 3D maps can be helpful in assisting user navigation [3]. These maps are miniature models of the virtual environments that allow the users to see the entire world in one view. They are often known as Worlds in Miniature (WIM) [3]. In addition to a display of the entire virtual environment, visual cues such as a you-are-here (YAH) indicator are used to inform the user of where they are in the world. The 3D maps are often interactive and support user manipulation such as rotation of the WIM, which give users the ability to quickly explore areas of the world without having to explicitly navigate.

Some navigation aids are in place to guide the user around a virtual environment. For instance, some aids work as guiding objects that inform the user where they should move in the environment. Examples of such navigation aids are 3D and 2D arrows [6]. Some aids are passive, in the sense that they provide users with a

tour along the environment, possibly highlighting particular areas of interest related to the data set.

2.11 Geographic Visualization Systems

There currently exist a number of geovisualization tools that allow users to explore geographical data sets. This section describes a few well-known geovisualization systems and highlights their strengths.

Fledermaus is a powerful interactive 3D visualization system that is used for a wide range of geoscience application, both in research and teaching. Fledermaus can be used to visualize ocean data, wind currents, and can be used for other geospatial research as well. Fledermaus gives users the ability to render high-quality terrain and bathymetric surface models, and supports the ability to overlay different types of data sets over these models [15]. A view of Fledermaus is shown in Figure 5.
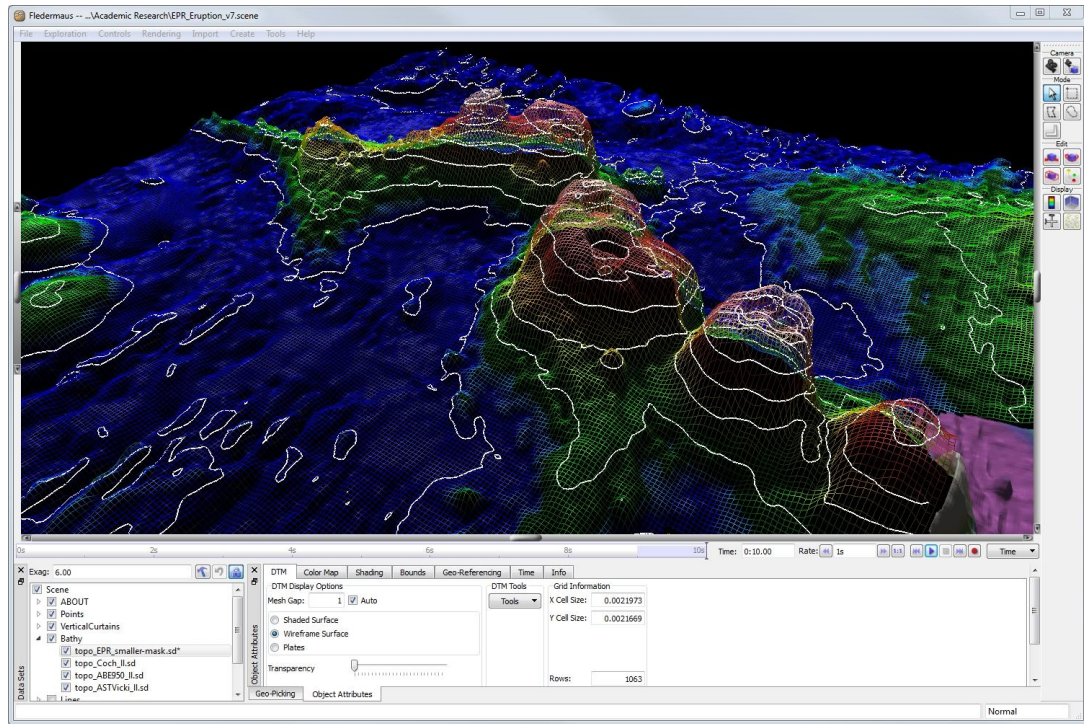
Figure 5: Fledermaus bathymetric model with contours [19].

Makai Voyager is a 3D visualization system that enables users to import, fuse, view, and analyze large earth, ocean, and atmosphere scientific data as it is collected or simulated in a global geo-referenced GIS platform. The difference between the Makai Voyager and other geovisualization tool is the ability to support large level of detail (LOD) and still provide an interactive system. It also supports the ability to streamline data into the system for real-time rendering. Highlights of the system include advanced visualization of volumetric data, support for 4-D models (3D + time), display of dynamic data on the ocean surface, support for customizable graphs of scientific data, etc. [14]. A view of Makai Voyager is shown in Figure 6.
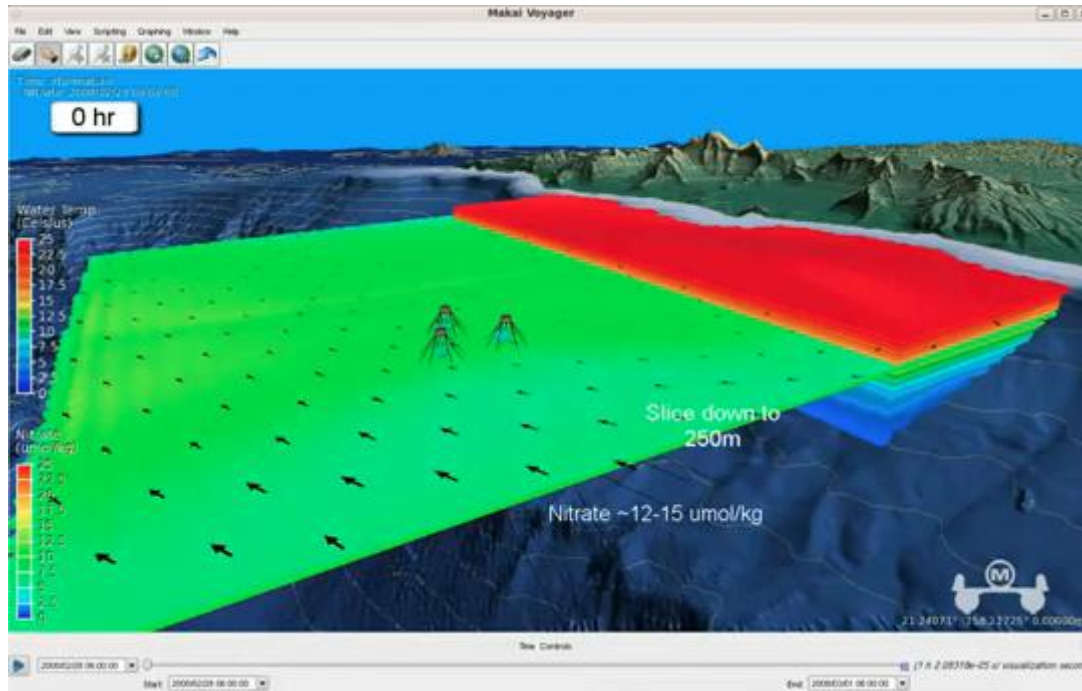
Figure 6: Makai Voyager rendering simulated discharge from offshore plants [18].

Google Earth is not a pure geovisualization system but it allows users to import geospatial data sets and layer them together to make observations on the data being represented. Users have the ability to view 3D imagery, satellite data, ocean data, etc. Google Earth also provides users with the ability to explore the earth in 3D virtual environments based on real world data. Users have the ability to store geographical information such as locations of interests, data views, etc. A view of Google Maps with a quantitative data overlay in shown in Figure 7.
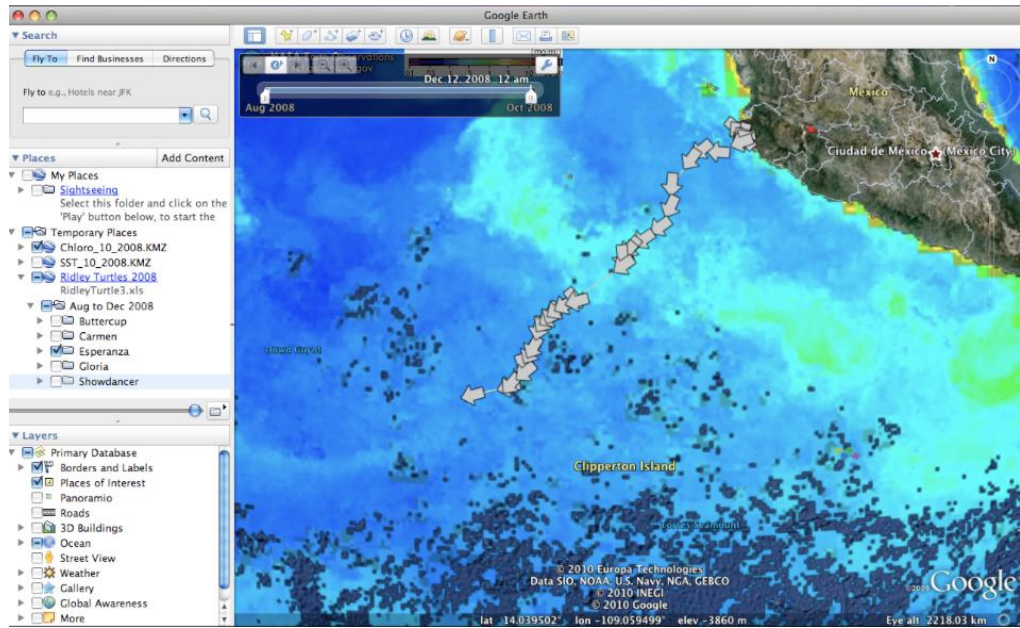
Figure 7: Google Earth rendering of olive ridely turtle trackline layered onto chlorophyll concentration [22].

2.12 Underwater Scientific Visualization System

Collaborative Ocean Visualization Environment (COVE) is a set of collaborative tools used to support deep-water ocean observatories. These observatories allow hundreds of scientists from various fields to conduct experiments together, provide real-time sensor and data access through the Internet, and create vast archives of data. COVE provides users with sophisticated data exploration tools that can run interactively on a local machine over terabyte-scale data set in the cloud [9]. A view of COVE is shown in Figure 8.
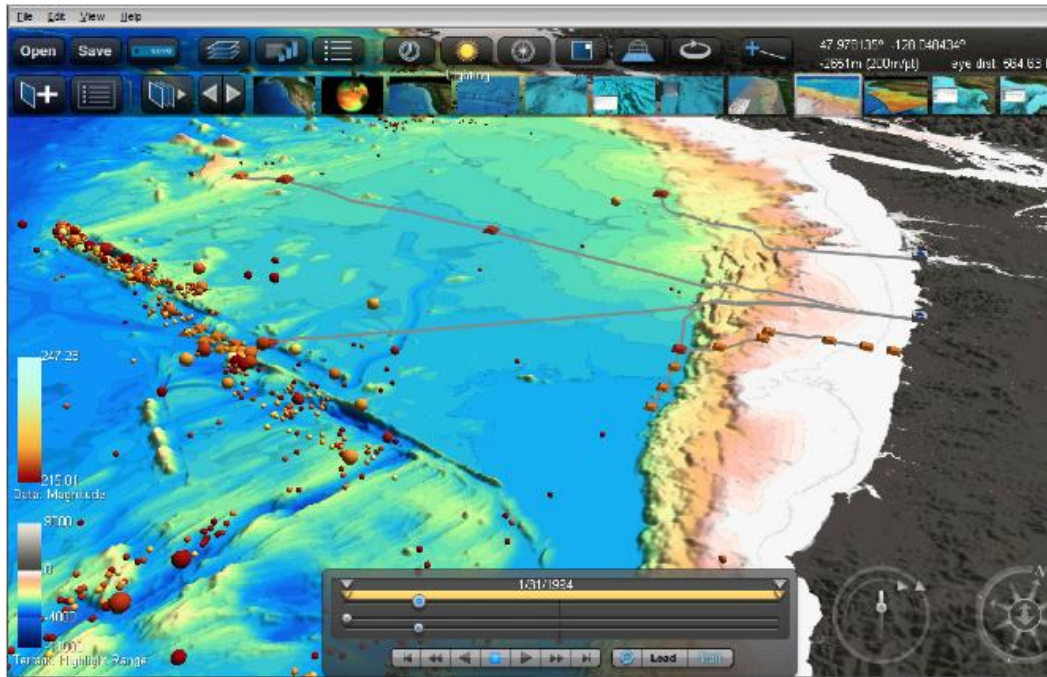
Figure 8: COVE visualization of ocean observatories [9].

2.13 Related Work

Formal evaluations of navigational aids that best support user navigation for exploring underwater geospatial data sets is lacking. However, previous research has been conducted to evaluate navigation aids for geospatial virtual environments.

Darken and Cevik [4] provided some early work on evaluating the effectiveness of navigation aids for supporting user navigation. The goal of their research was to make the execution of the navigation tasks as simple as possible. They explain in their research that it is often a good idea to design navigation aids based on real-world metaphors. For instance, they suggest the use of maps as a way to support spatial knowledge of a virtual environment and, more specifically, large environments where a user cannot view the entire world form one viewpoint. Figures 9 and 10

display two implementations of a 2D bird's eye view map. Darken and Cevik discuss the challenges associated to using maps in virtual environments. For instance, for maps of very large virtual environments, there are scaling issues designers may encounter. How does one properly scale a map so that a user can see enough detail to navigate the world but still maintain a sense of overall space in the world? Another problem tackled in this research involves the orientation of maps; the authors evaluate two forms of map orientation (North-up and forward-up) and report their respective performances.

The participants in the research were asked to wear a head-mounted display and told to complete a simple find-the-target navigation task. A head-mounted display is a device worn by a user that places images (e.g., virtual environment) in front of the user's eye using one or two small screens [26]. The virtual environment was designed as a sparse open ocean environment with very few landmarks or visual cues. The participants were asked to navigate to a target location shown on the 2D map. Occasionally the users were asked to navigate to targets of known locations, but not shown on the 2D map; other times they had to locate a target not shown on the 2D map or not seen before.
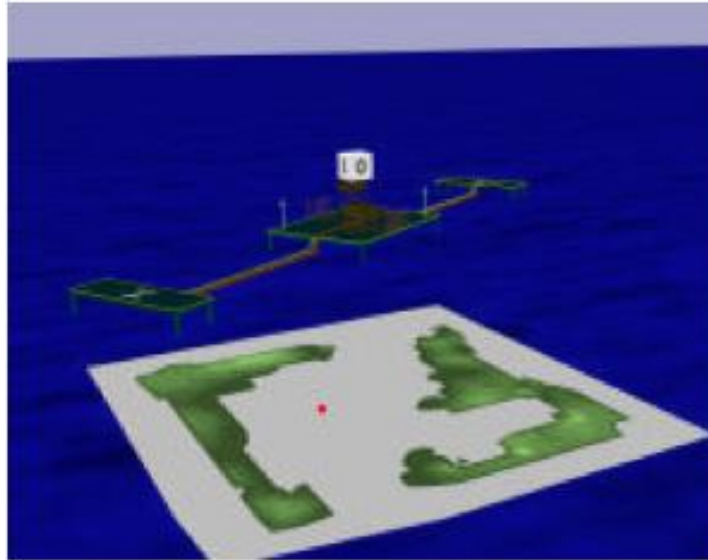
Figure 9: The forward-up configuration with a dot for a you-are-here indicator. The map rotates as the user's viewpoint is rotated in the environment. The map is aligned to the environment and not with the viewer [4].
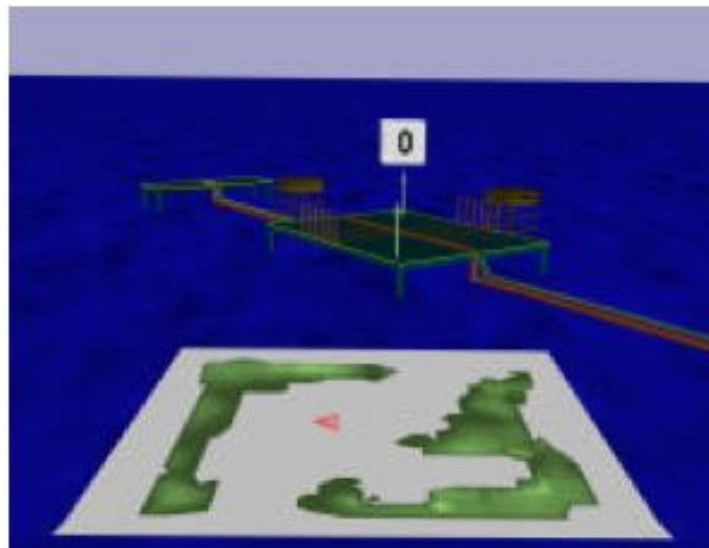
Figure 10: The North-up configuration with a you-are-here indicator. The map is aligned with the viewer and not with the environment [4].

Darken and Cevik's research highlighted that users preferred to use the North-up map as opposed to the forward up even though the forward-up consistently provide the best user performance (task completion time). The qualitative data demonstrated that users preferred the North-up 2D map because it felt more comfortable to them. From the demographics collected it was concluded that this was due in large part to the participants' experience with video games, in which the 2D North-up maps are frequently used. In addition, it was found that users enjoyed having the ability to annotate their position (positional cues) and orientation (directional cues) in the environment. This ability allowed users to create trails of their movement in the virtual environment, thus informing them of areas already explored, as shown in Figure 11. However, the authors noted that if users are allowed to annotate the virtual environment, designers must be weary of allowing the user to clutter the view space with excessive information, which can hinder navigation performance.
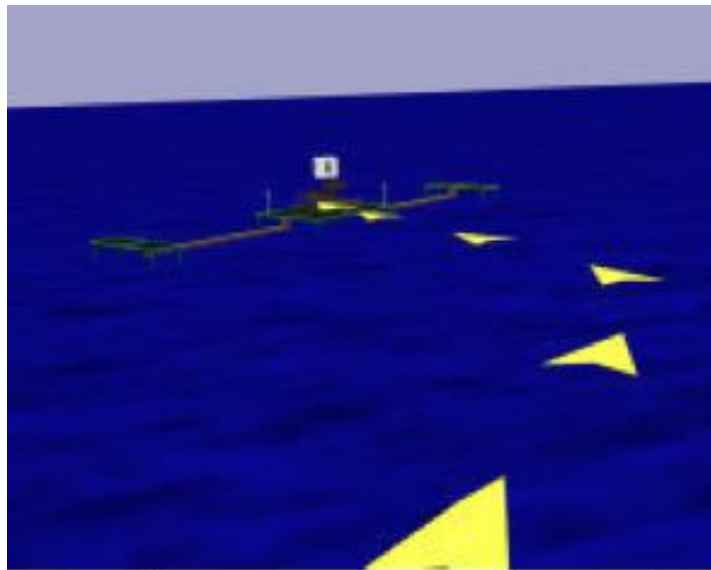
Figure 11: The user annotating their path along the ocean surface [4].

Burigat and Chittaro [6] conducted an experimental study on the effects of user experience and location-pointing navigation aids. The goal of this research was to compare three navigation aids that help user perform wayfinding tasks in desktop virtual environments by pointing out the location of objects of interest (e.g., a target). They collected quantitative data such as navigation performance time (total time to complete a primed search task) for over forty-eight users. The three navigation aids included a 2D arrow, a 3D arrow (see Figure 12), and a radar metaphor. One of the virtual environments used in this experiment was a geographic VE that resembled an airport. The dimensions of the environment were 13 km by 13 km and it was fitted with runways, roads, hangars, and a control tower.

Figure 12: The 3D arrow navigation aid used to point toward targets or places of interest [6].

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The testing procedure followed by Burigat and Chittaro [6] consisted of running four different scenarios. A control scenario (no navigation aids) and a scenario for each of the following navigation aids: a 2D arrow, a 3D arrow, and a radar metaphor. User performance was measured using the total time it took a user to find five targets in the geographical virtual environment in each of the above-mentioned scenarios. Before subjects executed any test they were asked to complete a pre-test questionnaire containing demographic information (such as sex, age, computer experience, virtual navigation experience, etc.). The testers were also informed of the navigation task to be performed in the virtual environment. Once users were ready to test the different scenarios, they were allowed to spend an unlimited amount of time in the training scenario during which they could learn the controls of the system (mouse controls). The positions of the targets in each scenario were varied to prevent users from memorizing the target locations. To help minimize user misunderstanding and ambiguities in target recognition, the users were given supporting documentation on the geospatial environment.

Some of the highlights from the test evaluations [6] revealed that inexperienced users (unfamiliar with virtual navigation) spent significantly more time searching for targets in the scenario with no navigation aids as opposed to using the 2D arrow, 2D radar, and the 3D arrow. It was also determined that experienced users also spent more time searching for targets in the scenario with no navigation aids as opposed to the other three scenarios. However, interestingly, it was found that inexperienced users spent significantly less time searching for targets using 3D arrows as opposed to using the 2D arrows and 2D radar metaphor. Conversely, it was determined that experienced

users showed statistically no difference in performance when using any of the three visual aids to find the targets.

The research presented by Medina [7] involved creating a dynamic visualization tool for analyzing ocean data collected by an underwater glider. The visualization tool developed in this research gives users the ability to create volumetric rendering and isosurfaces of the data, create cross-sections of the data for examining attribute-attribute (depth vs. salinity, depth vs. temperature), adjusting color mapping and data value thresholds, and more through the use of a GUI. A salinity gradient plane with overlaid data points is shown in Figure 13. In addition to the GUI, the system has two navigation aids, a 3D glider (that travels along data path), and a 2D compass. A temperature gradient plane with an overlaid glider trackline is shown in Figure 14. However, the author states that due to time constraints he was not able to conduct an in-depth user evaluation of the tool. Therefore it is unclear how effective the navigation aids and GUI are for supporting user navigation in the virtual environment.
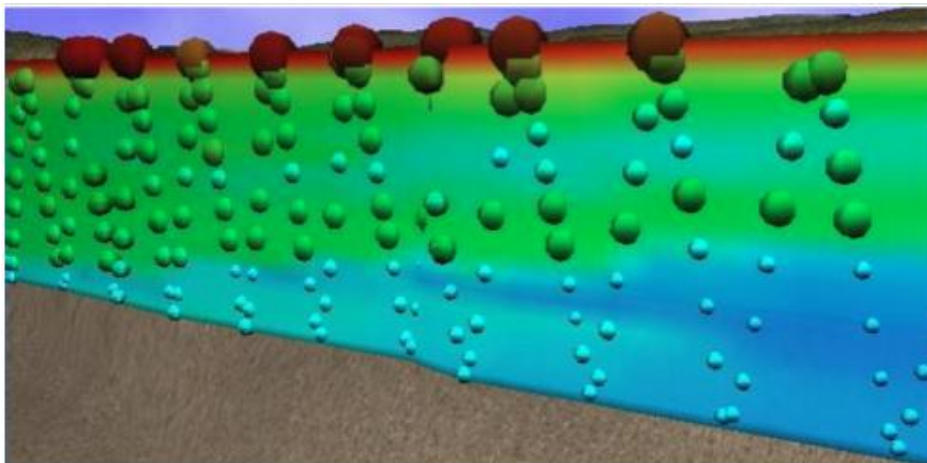
Figure 13: Temperature data points collected by the glider combined with gradient plane [7].
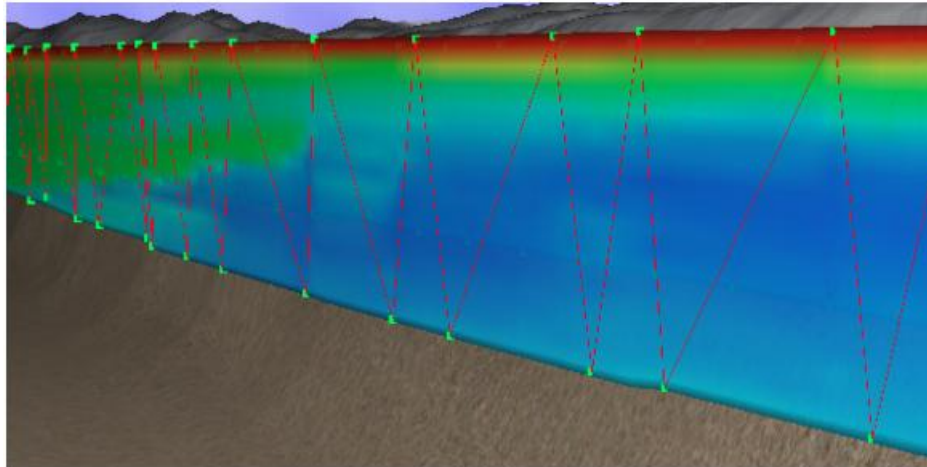
Figure 14: Temperature gradient plane with glider trackline [7].

The first two works presented provide evaluations of navigational aids for above sea surface geospatial virtual environments. By contrast, the research presented in this thesis is interested in investigating the effectiveness and usefulness of various navigation aids and visual aids for supporting user navigation in an underwater environment.

CHAPTER 3

Methodology

3.1 Underwater Glider Data

An underwater glider is an unmanned vehicle that can be programmed to navigate the ocean's depths and make measurements of the waters temperature, conductivity, pressure, and more. A rendering of an underwater glider is shown in Figure 15. Some of these gliders have the ability to make measurements in the ocean for long stretches of time. These survey missions can last from weeks to months at a time. They have the ability to travel up to several kilometers and have the ability to transmit the data collected to workstations. The motion of a glider in the water can be visualized as a sawtooth-like path through the water, as shown in Figure 16.

Figure 15: Underwater glider
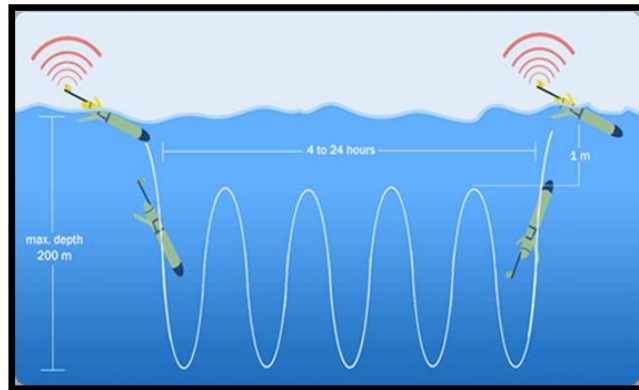
Figure 16: Visualization of glider movement in the water [23].

3.2 Underwater Glider Data Visualization

It is common to use computational software such as MATLAB to visualize the data collected by gliders. The visualizations often consist of 2D renderings of attribute vs. attribute collected by the gliders. A 2D plot of geographic coordinates with corresponding salinity concentrations is shown in Figure 17. A 2D plot of salinity concentrations vs. depths (in meters) is shown in Figure 18.
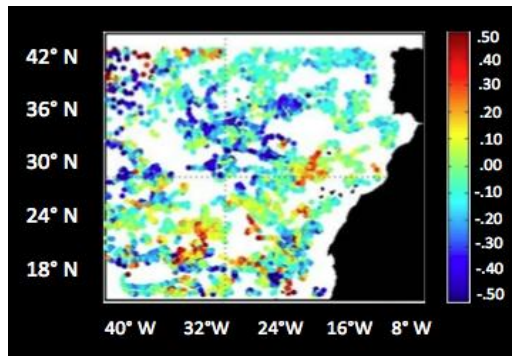
Figure 17: Sea surface salinity plot
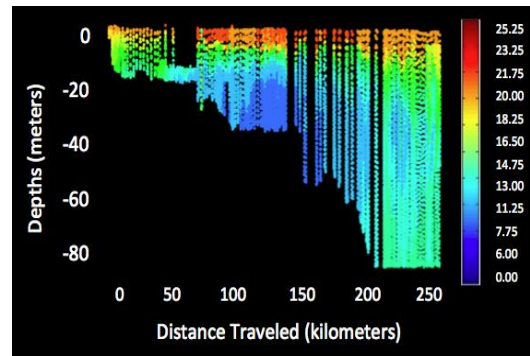
Figure 18: Deep water salinity plot

In addition to 2D renderings, using computational software, glider data can be visualized in 3D. This can be achieved by plotting 3D points (latitude, longitude, and depth) or by using a projection model for the data such as Mercator projection. Figure 19 and 20 demonstrate two examples of 3D geospatial points plotted using the Mercator projection.
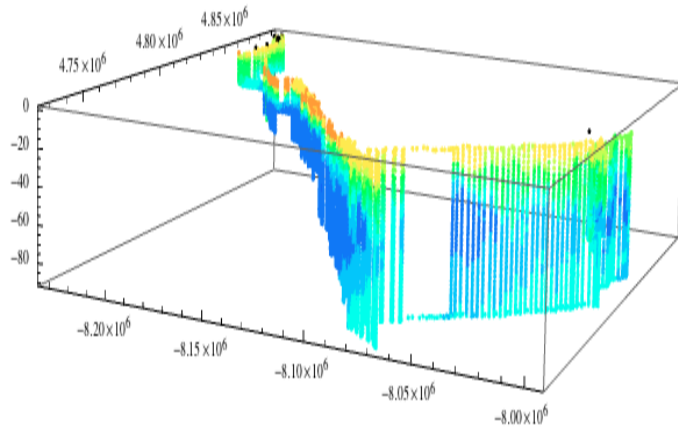
Figure 20: Glider data visualized in 3D using Mercator projection with scaling applied to the coordinates
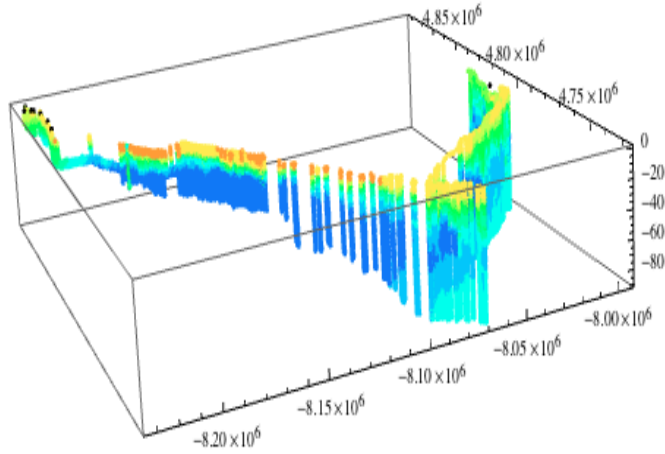
Figure 19: Glider data visualized in 3D using Mercator projection with scaling applied to the coordinates from a different view

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While computational softwares are powerful tools and can be used to create content-rich visualization of the glider data, they typically do not support 3D user navigation for interacting with the data sets. That is, if users want to examine a particular region of the data set they must recode their program to re-render the data with some form of visualization constraint (i.e., updating the visualization rendering bounds).

If users wish to explore the geospatial data in a pure 3D environment it is likely they will have to use a scientific / geovisualization tool similar to ones described in Chapter 2.

3.3 Context of Use and User Requirements

The focus of this research was not in making a high-end visualization toolkit with a fully implemented GUI for supporting exploration of geospatial datasets. Instead the focus was on investigating the type of visual aids, navigational aids, and visualization tools that best support user navigation.

In order to support user navigation a collection of navigation aids were designed and implemented. This research will evaluate the effectiveness of this tool for supporting navigation. While there exist geovisualization tools that support visualization of 3D geospatial data, they were not used in this application. Due to time constraints and unfamiliarity with the geovisualization tools described in Chapter 2, we decided to create our own visualization tool for usability testing of the navigation aids.

The requirement for the framework was that it have the ability to spatially map geospatial data and support user navigation, two common features of geovisualization tools. To build the testing framework we made use of the Unity3D game engine. This software provides developers—through the use of application programming interface (API)—the ability to create a wide-range of applications including video games, serious games, data visualization, and scientific visualization [17].

3.4. Framework

The following section describes the various components of the visualization framework created with the Unity3D game engine.

3.4.1 Terrain

The terrain in the virtual environment is generated using NOAA's Etopo2 (2 minute grid) bathymetric data. The terrain was made large enough to cover the full extent of the glider's mission and has dimensions 100 km by 100 km. The terrain has a resolution of approximately 4 km and contains approximately 65,000 data points. A rendering of the terrain in Mathematica is shown in Figure 21. A rendering of the terrain in Unity3D is shown in Figure 22.
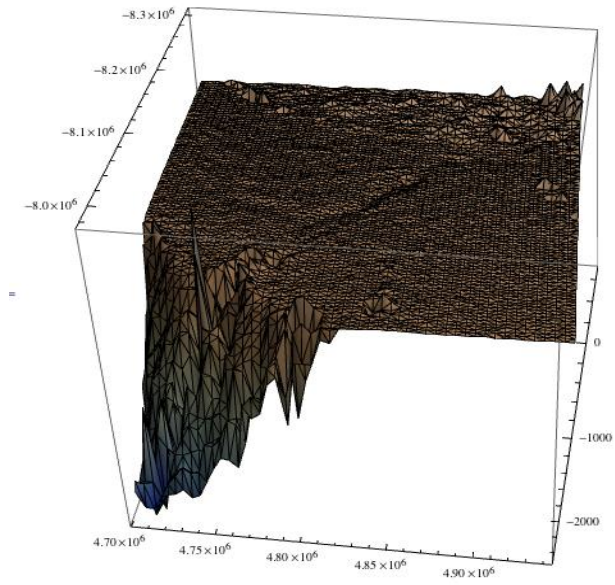
Figure 21: Etopo2 bathymetric data rendering
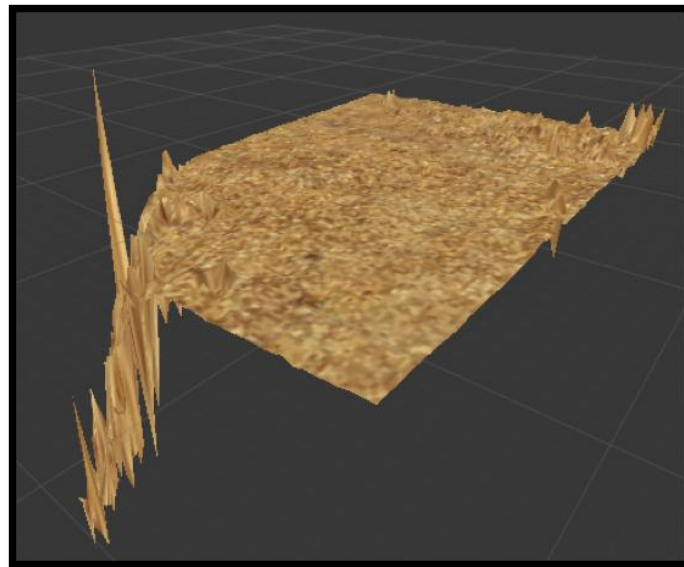
Figure 22: Etopo2 bathymetric rendering in Unity3D

The bathymetric data was not interpolated or sampled, therefore large peaks (noise) exist in the bathymertic data. These large peaks are exggarated with the scaling of the virtual environment, which can be seen in Figure 22.

3.4.2 Glider Data Points

The glider data represented in the virtual environment consist of approximately 20,000 geospatial data points. The points are projected in the virtual environment using a Mercator projection and have been scaled to produce a representation that is similar to Figure 20. The glider data points are represented as low-resolution spheres. The sphere's color is mapped to a salinity concentration value and its size is determined by the salinity concentration value. Higher concentrations are rendered as larger spheres and lower concentration are rendered as smaller spheres. A view of the 3D data set is shown in Figure 23.
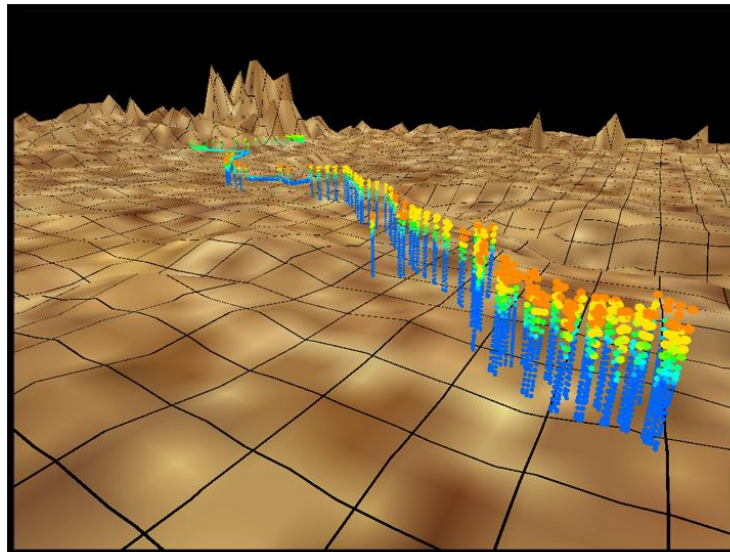
Figure 23: Glider data points rendered with a color mapping and variable size

3.4.3 Water Surface

The water surface is created using water-creation features of the game engine. The water's surface supports both reflection (disabled for this research) and refraction. The surface waves are animated over time and users have the ability to enable or disable the water surface. A rendering of the water 's surface and 3D data set is shown in Figure 24.
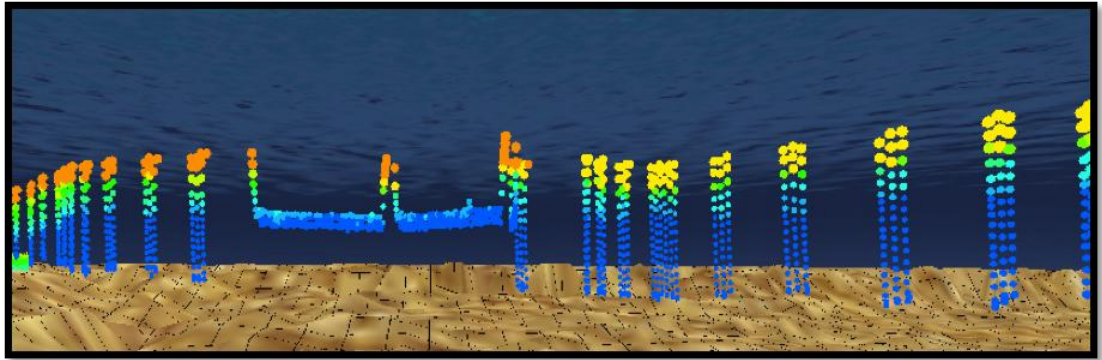
Figure 24: Glider data points and water surface

3.4.4 User-Controls

The visualization framework supports both keyboard and mouse controls. The keyboard controls follow a standard configuration of the WASD keys: users have the ability to move forward, backward, left, or right using the WASD keys. The framework also supports the combination of keyboard keys Shift and Alt with the WASD. Combination keys allow users to rotate left and right, tilt up and down, roll clockwise and counter-clockwise, and move vertically up and down. The mouse controls are straightforward and allow the user to move up, down, left, and right by dragging the mouse and holding down the left button. The user can rotate using the

mouse by dragging the mouse and holding the right mouse button. The user can move forward or backward by scrolling the mouse forward and backward.

3.4.5 Graphical User Interface

The following section introduces the various GUI elements available in the framework.

3.4.5.1 Help Menu

Users have access to a help menu that informs them of the current objective in the visualization and has information on the available user controls (see Figure 25).

Figure 25: Help Menu

3.4.5.2 User-Control Settings

The visualization tool provides users with menus for adjusting the sensitivity of user-controls and other aspects of the visualization (see Figure 26).
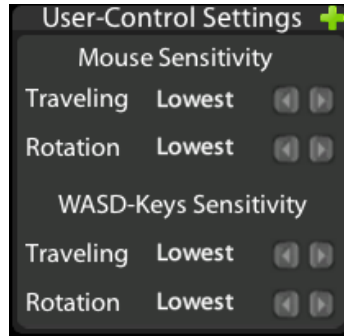
Figure 26: User-controls window

3.4.5.3 Reset Orientation and Home Buttons

The visualization also provides users with GUI elements for resetting the user view and position in the case the user gets lost or disorientated in the world (see Figure 27).

Figure 27: Reset orientation and Home buttons

3.4.6 Visual Aids

The following section describes the various visuals aids available in the framework. We differentiate between visual aids and navigation aid by the following: Visual aids are in place to help the user gain insight on the data represented in the virtual environment. Navigation aids are in place to support user navigation about the data represented in the virtual environment.

3.4.6.1 Camera Position Window

This visual aid displays the user's geographical (latitude and longitude) and elevation (in meters).

3.4.6.2 Color Lookup Table

This visual aid displays a color lookup table, as shown in Figure 28. This table demonstrates the mapping of salinity concentration values to colors from the rainbow color scheme. The rainbow color scheme was used since most visualization of oceanic data sets use this color scheme.
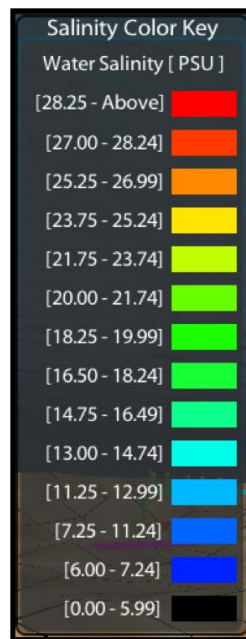
Figure 28: Salinity color lookup table

3.4.6.3 Data View

This visual aid displays an orthographic 2D data view of the data set being represented in the world. This 2D data view displays the current data in the users viewport, indicated by the red arrow. The 2D data view is shown in Figure 29.
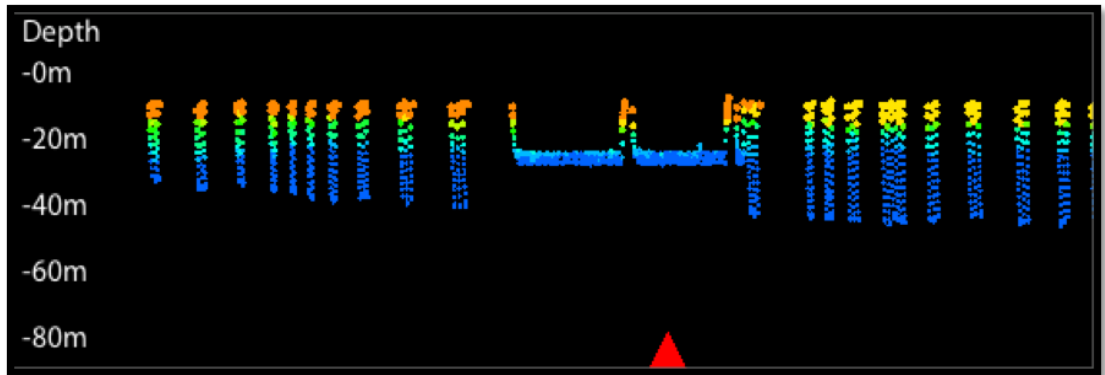
Figure 29: Orthographic view of the data set with an arrow indicating the current data section in view.

3.4.6.4 Bounding Box

This visual aid creates a bounding box around the data set. This visual is not helpful while the user is underwater, but if the user chooses to a bird's eye view of the data set they can turn on the bounding box to get a better understanding of the extent of the data set. A rendering of the bounding box is shown in Figure 30.
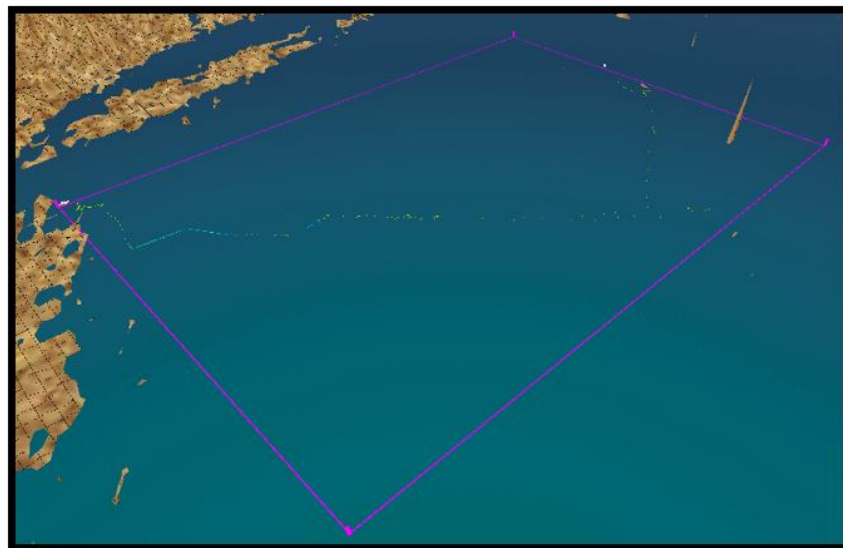
Figure 30: Bounding box encapsulating the user data

3.4.6.4 Terrain Gridlines

This visual aid is overlaid on the virtual terrain. The spacing of the gridlines matches the resolution of the terrain. Previous research [13] has shown that draping gridlines along a surface helps illustrate the shape of the surface. A rendering of gridlines is shown in Figure 31.
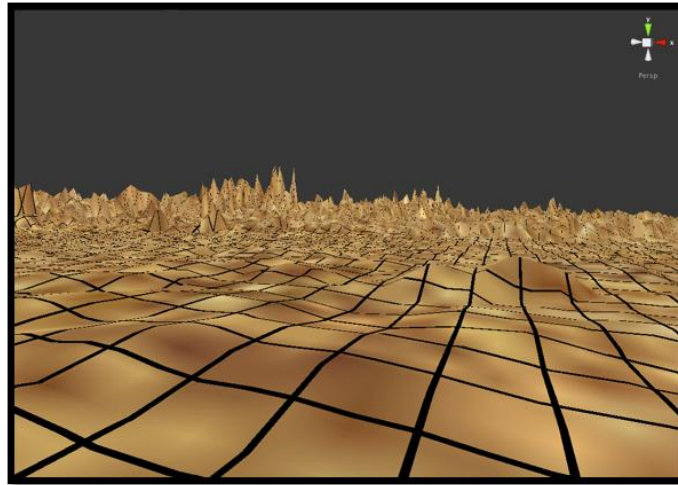
Figure 31: The gridline spacing of approximately 4km

3.4.7 Navigation Aids

The following section describes the various navigation aids in place to support user navigation.

3.4.7.1 2D Map

This navigation aid is a 2D map with a you-are-here visual indicator. The you-are-here indicator can either be a dot or an arrow with direction. The map uses the OpenStreeMap [24] tiling system for the texture of the map. A rendering of the 2D map is shown in Figure 32.

Figure 32: 2D map with you-are-here dot

3.4.7.2 Bird's Eye View

This navigation aid gives users a bird's eye view of their current location. The camera is set to some predetermined height above the user and orientated to look down at the user. This view gives users another perspective of the environment, hopefully supporting the user's ability to build survey knowledge. A rendering of the bird's eye view is shown in Figure 33.
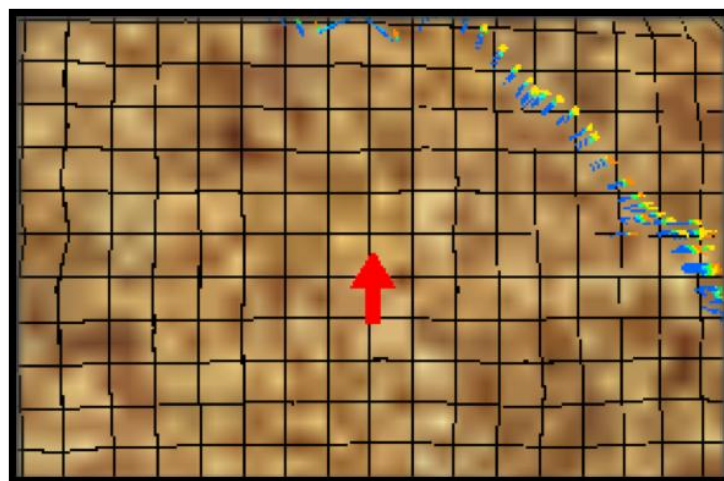
Figure 33: Bird's eye view with you-are-here arrow and gridlines
with resolution of approximately 4km

3.4.7.3 2D Compass

The compass points in the direction of the North Pole as the user navigates the virtual environment. A rendering of the compass is shown in Figure 34.

Figure 34: 2D compass

3.4.7.4 2D Radar

The radar displays objects of interest (i.e., targets, landmarks, etc.) within a radius of four kilometers. A rendering of the 2D radar is shown in Figure 35.
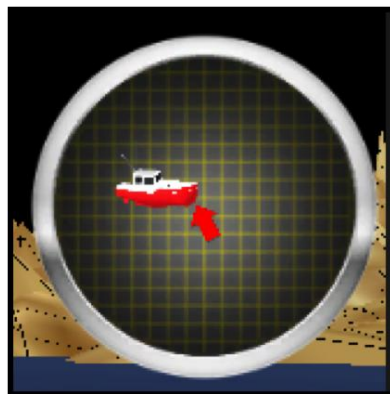
Figure 35: 2D radar

3.4.7.5 3D Camera Orientation Window

This navigation aid displays the current orientation of the user in the world. A 3D boat is used to represent the user's orientation. In addition to the 3D model, a 3D axis is also rendered to further assist the orientation awareness of the user. A rendering of the 3D orientation window is shown in Figure 36.
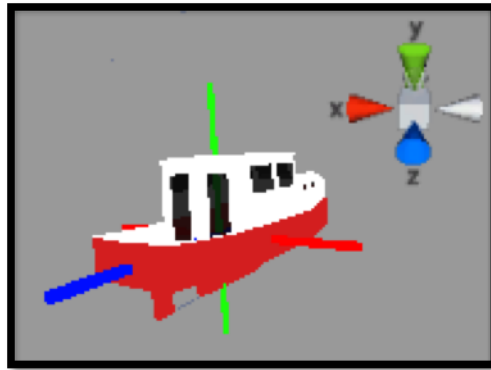
Figure 36: User orientation in the virtual environment

3.4.7.6 3D Snapshot Tool

The navigation aid allows users to take snapshots of their current locations in the virtual environment. This tool gives users the ability to transition between the different snapshots by clicking on the snapshots taken. The transition interpolates the between the users current position and rotation and the annotated position and rotation. In addition to the images, icons of the snapshots are placed on the 2D map to help maintain spatial awareness of the snapshot locations. A rendering of the snapshot tool is shown in Figure 37.
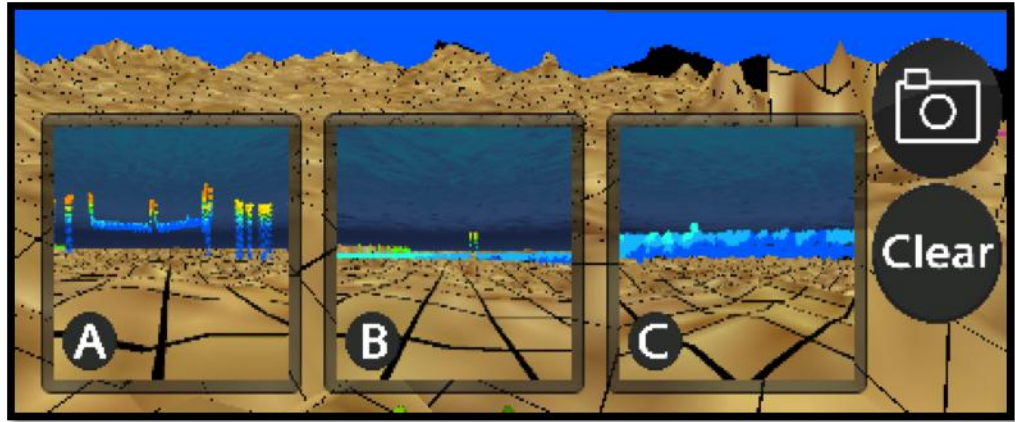
Figure 37: Snapshoot tool with three pictures (annotations)

CHAPTER 4

Usability Evaluation

4.1 Hypotheses

Since navigation is a complex activity when no support is provided to users, and since the underwater virtual environment inherently lacks visual landmarks, any navigation aid should improve the user's ability to maintain spatial awareness and orientation while exploring the virtual underwater world.

Inexperienced users in virtual environment navigation should be expected to use as many different navigation aids as possible. Experienced users should prefer to use the smallest amount of visual aids possible.

4.2 Testing Procedure

The testing procedure consisted of participants running five different "find-the-target" scenarios. Each scenario had a unique configuration of navigation aids and visual aids. The participants were asked to navigate to four different locations in the virtual environment as shown in Figure 38. The locations of the targets were varied for each scenario to minimize the possibility of users memorizing the target locations.

At each target location the participants were asked to orientate themselves to look at a secondary target as shown in Figure 39. Therefore, each navigation task required participants to navigate to a particular location and to orientate themselves in the environment. The navigation task was not timed and participants were encouraged to take their time to evaluate the available navigation aids. It was stated to the users

that this research was not interested in determining how fast users could complete the navigation task using the navigation aids. Instead, it was made clear that the research focus was to determine how useful and effective the aids were in supporting user navigation in the virtual environment.
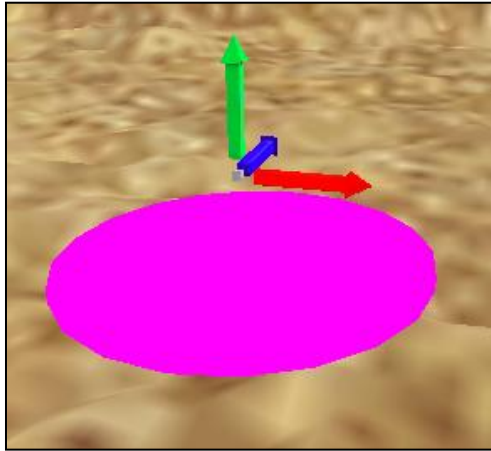
Figure 38: Target in the virtual environment
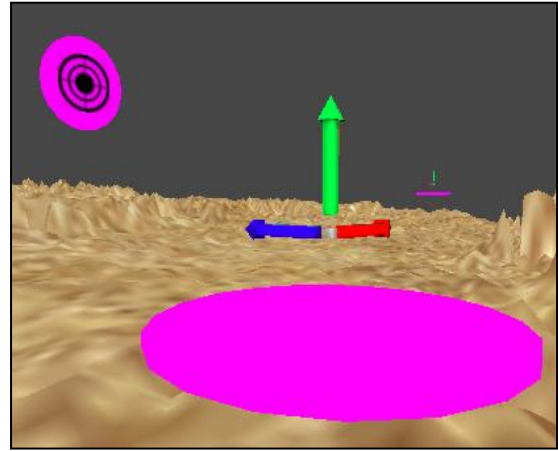
Figure 39: Target and secondary target in the virtual environment

Users were also given supporting documentation on the testing scenario. The supporting documentation contained information on the scenario's available navigation aids, visual aids, and GUI. The users were recommended to keep this document open as they navigated the world. This was recommended in order to minimize any ambiguous interpretations of the various aids and GUI components.

After completing each scenario, participants were asked to evaluate the scenario's configuration. The evaluation consisted of users completing a usability questionnaire. The questions were related to the effectiveness and usefulness of the navigations aids. Additionally, users were asked questions on the overall system framework. For instance, participants were asked questions on user-controls

reliability, supporting documentation usefulness, etc. A high level overview of the testing framework is shown Figure 40.

```
                    ┌─────────────────┐
                    │    Scenario     │
                    │  Configuration  │
                    └─────────────────┘
                             │
                             ▼
┌──────────────┐   ┌─────────────────┐   ┌──────────────┐
│  Scenario    │   │    Scenario     │   │ System User  │
│  Supporting  │───│ Navigation Task │───│    Data      │
│ Documentation│   │                 │   │  Collection  │
└──────────────┘   └─────────────────┘   └──────────────┘
                             │
                             ▼
                    ┌─────────────────┐
                    │   Post User     │
                    │  Questionnaire  │
                    └─────────────────┘
```
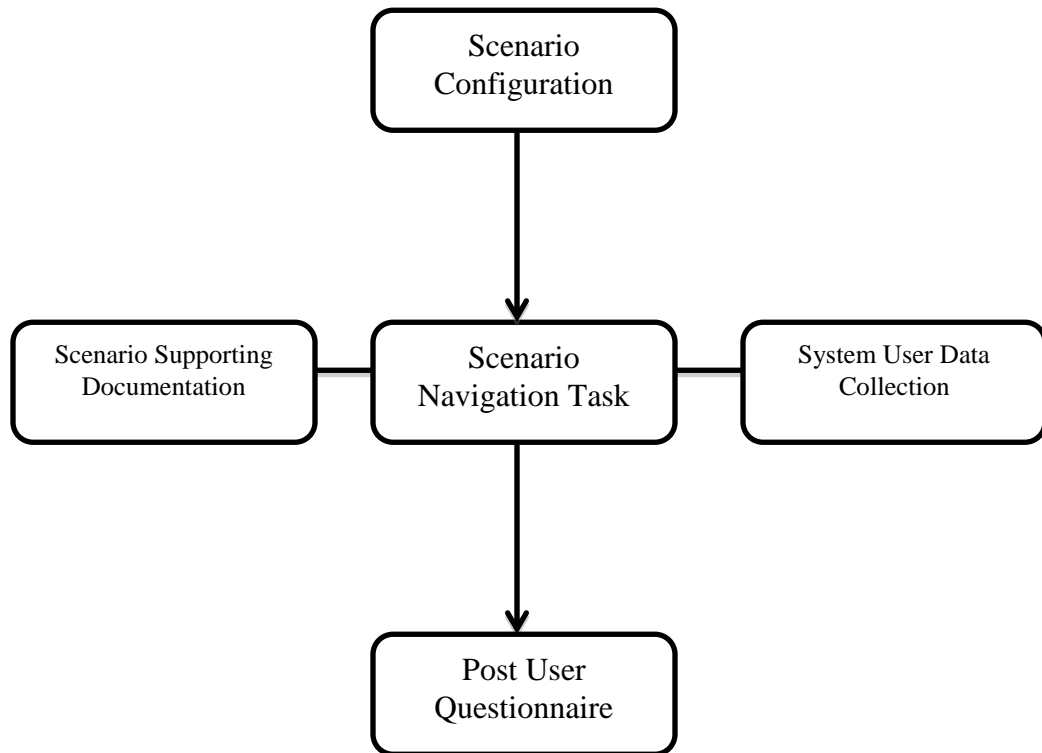
Figure 40: High-level overview of the testing procedure components used for each scenario

4.3 Participants

The participants included twenty-two computer science students (twenty-one male and one female), all of which at the moment of this research are enrolled in a game design course. Their age ranged from 19 to 31, averaging at 20. The students volunteered to participate in the research and no incentives were given to students for participating. The students were given a total of three hours to complete the usability testing and the testing was conducted in a computer laboratory of the Department of Computer Science and Statistics. The laboratory contained Apple iMacs with dual-

boot capabilities (Windows partition). Students had the flexibility of running the framework on either Mac or Windows.

In addition to the computer students, four experts (3 male and one female) were also tested. The expert pool included marine biologists, ocean engineers, and GIS developers. Their age ranged from 24 to 62, averaging at 39. The expert participants all participated remotely and were given two weeks to complete the usability evaluation. Similarly to students, the expert participants volunteered to participate in the research and there were no incentives given. The expert participants had the flexibility of using either MacOS or Windows machines to run the framework.

4.4 Scenario Configurations

The following section describes the five different scenario configurations used in the testing framework.

4.4.1 Scenario One Configuration

Scenario one was used as a learning phase. Instead of having the user directly start from usability testing scenarios— which can to lead to user time being wasted learning the controls, or to distractions—we instead encouraged users to spend as much time as they desired learning the controls and *look-and-feel* of the application. This was done to encourage users and build user confidence before entering the scenario-testing phase. Scenario one's interface is shown in Figure 41.

The first scenario's configuration consisted of a 2D map with a you-are-here dot indicator, GUI for adjusting the controls sensitivity, and buttons for resting the

user orientation and position. The participants were asked to complete a simple navigation task that simulated the task to be carried out in the remaining scenarios.

Figure 41: Scenarios one's interface

4.4.2 Scenario Two Configuration

Scenario two was the first to render the glider data set. The scenario's configuration was the same as in Scenario one with the following additions: a 2D view of the data set, a color mapping table, and a button for disabling and enabling the water surface. Scenario two's interface is shown in Figure 42.
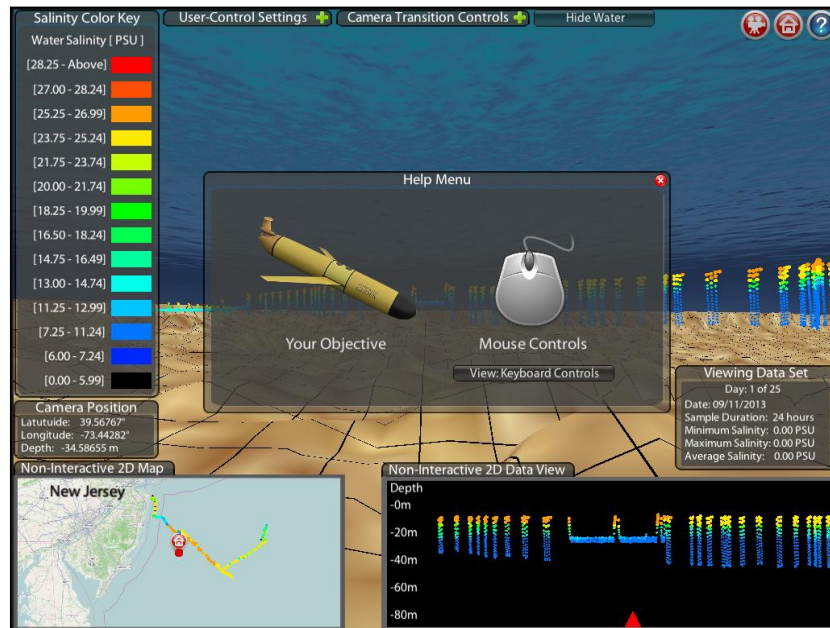
Figure 42: Scenario two's interface

Participants were asked to carry out a navigation task (explained in Section 4.2) and then asked to evaluate the configuration using a questionnaire.

4.4.3 Scenario Three Configuration

Scenario three contained a 2D map with a you-are-here arrow indicator, a 2D radar, a color lookup table, and a button for displaying a bounding box that encapsulates the data set. For this scenario, we were interested in determining if the 2D map arrow provided users with a better sense of direction than the dot indicator originally used. In order to determine if this was the case, users were asked questions (presented in Chapter 5) comparing the dot and arrow you-are-here indicators. The 2D radar had a radius of four kilometers and displayed objects of interest (such as targets, landmarks, etc.) to the user. Scenario three's interface is shown in Figure 43.
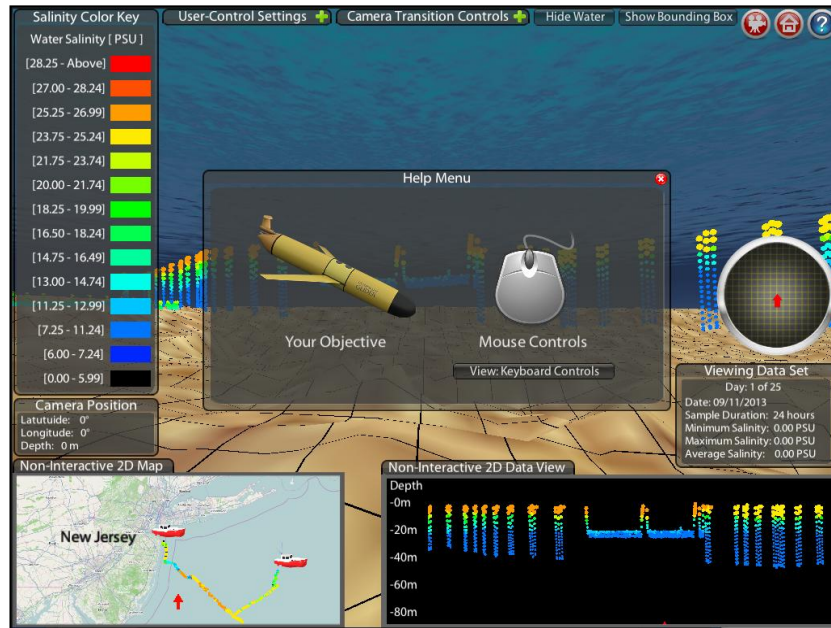
Figure 43: Scenario three's interface

Participants were asked to carry out a navigation task (explained in Section 4.2) and then asked to evaluate the configuration using a questionnaire.

4.4.4 Scenario Four Configuration

Scenario four made use of the same 2D map as the third scenario. It also included a 2D compass, a 3D user orientation window, and a bird's eye view of the virtual environment. The 2D compass pointed to the North Pole as the user navigated the environment. It was expected that users would use this navigation aid to navigate the virtual world thus possibly minimizing the need for the 2D arrow on the 2D map. In order to verify if this was the case, users were asked questions on the usefulness of the compass. The 3D user orientation window was added with the intention to support the user's ability to maintain spatial orientation in the virtual environment. Since the main user view is mostly a first-person (egocentric) view it is probably not be the best

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view for maintaining user orientation. Therefore, we were interested in determining if users found it helpful to have this 3D person view of their orientation while navigating the virtual environment. Scenario four's interface is shown in Figure 44.
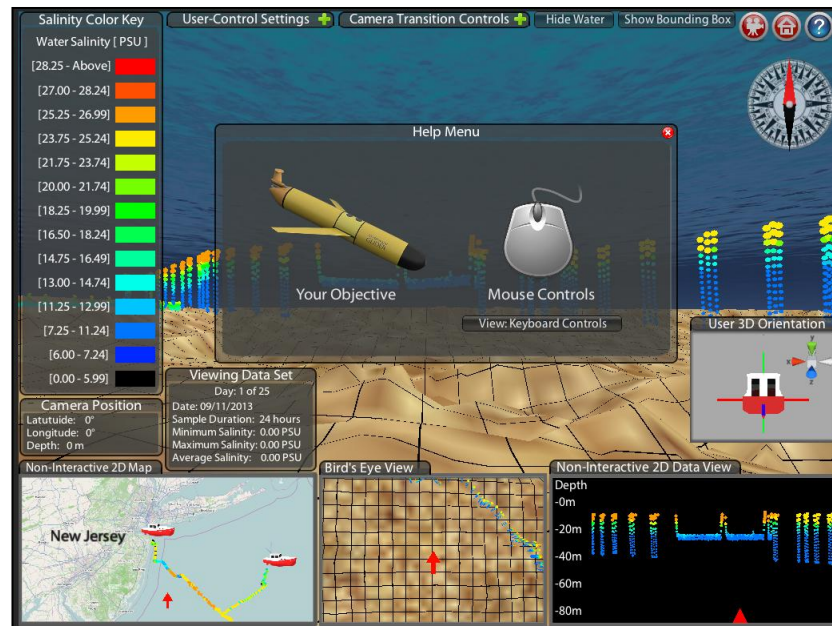
Figure 44: Scenario four's interface

Participants were asked to carry out a navigation task (explained in section 4.2) and then asked to evaluate the configuration using a questionnaire.

4.4.5 Scenario Five Configuration

This configuration was the same as that of Scenario four, except for the addition of the snapshot tool (described in Section 4.4.4). We were interested in determining if this tool was useful for navigating the virtual world. We expected that users would prefer to use this tool for traveling over long distances. However, we must admit that this environment was not the best for determining this tool's usefulness and

effectiveness since the virtual environment was not immense and did not require users to travel back and forth between targets. Scenario five's interface is shown in Figure 45.
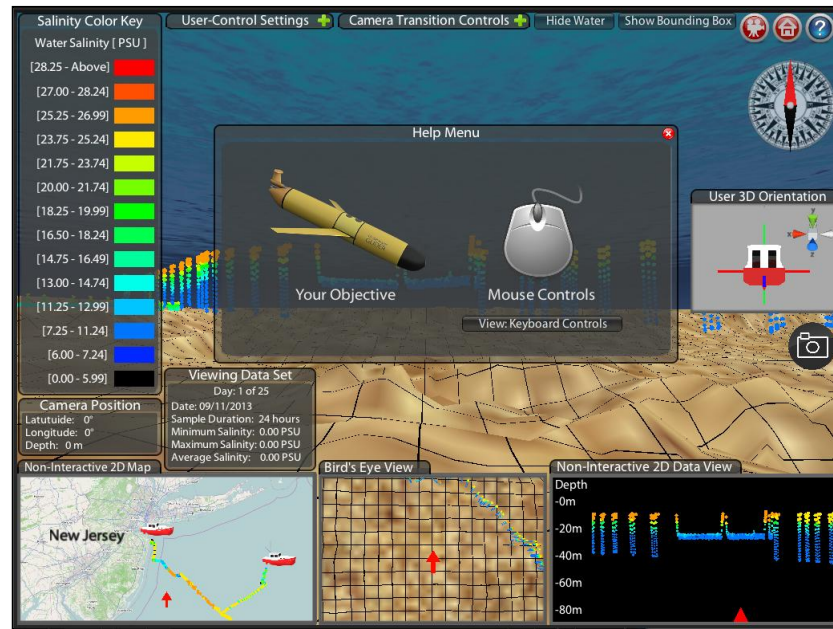
Figure 45: Scenario five's interface

Participants were asked to carry out a navigation task (explained in Section 4.2) and then asked to evaluate the configuration using a questionnaire.

4.5 User Performance Evaluations

The testing framework has the ability to record user movement in the virtual environment with a resolution of one second. While this type of data was collected on the user, we did not the record the time it took a user to complete each navigation task. Therefore, we do not have a quantitative metric such as task completion time. Due to testing limitations and constraints (explained in Section 4.6) we instead use the user

movement data to support the qualitative data recorded in the user questionnaires. In addition to recording the user movement, the framework also has the ability to record the number of times the reset orientation and reset-to-home button were pressed during the execution of the scenario. This information was used to support the statistics done on the qualitative data collected in the user questionnaires.

4.6 System and User Complexities

A current limitation of the framework is that the controls are not adaptive to different hardware and system configurations. The controls sensitivity levels are set manually (by the users) through the framework's GUI. As stated before, the framework has the ability to run on Mac and Windows desktop and laptop computers. The framework controls support both a conventional mouse and laptop trackpad for mouse movement.

Due to development time constraints, the adaptive controls will have to be added in a later phase of this research. Once this aspect of the framework is completed, quantitative data such as task completion times can and be tested more effectively (since the controls would be more uniform/stable across different hardware and system configurations).

CHAPTER 5

Results and Analysis

5.1 Demographics

This section presents the demographic information collected prior to the usability evaluation. As stated in Chapter 4, there were a total of twenty-six participants. The participants consisted of four experts and twenty-two undergraduate students. From the twenty-six participants, two were women (one student and one expert) and the rest were male. The experts consisted of biologist, GIS developers, and ocean engineers. The students participating in this experiment were all computer science majors currently engaged in a video game development course. The student and expert age groups are summarized in Figure 46 (One student did not respond to this question).

(a)   (b)
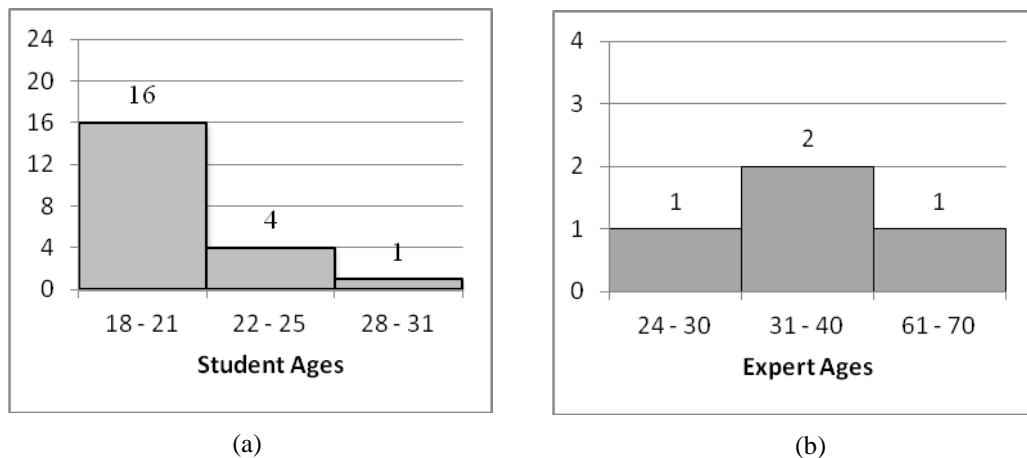
Figure 46: (a) Age distribution of the student group; (b) Age distribution of the expert group

Participants were asked questions on their familiarity with existing geovisualization tools, level of expertise with the tool most familiar to them, and preferred navigation control for that tool. The students' and experts' responses are presented in Figures 47, 48, and 49.

(a)   (b)
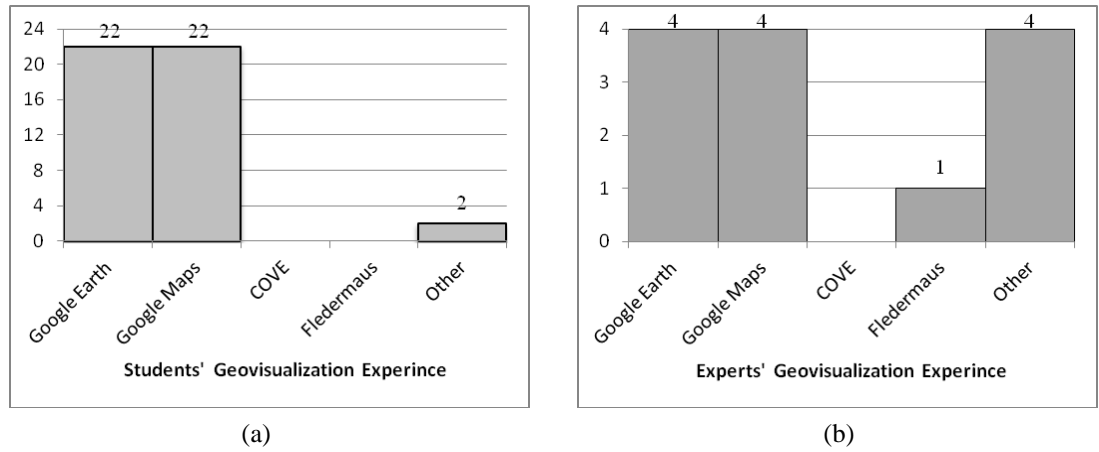
Figure 47: (a) Geovisualization tool experience distribution of the student group; (b) Geovisualization tool experience distribution of the expert group

(a)   (b)
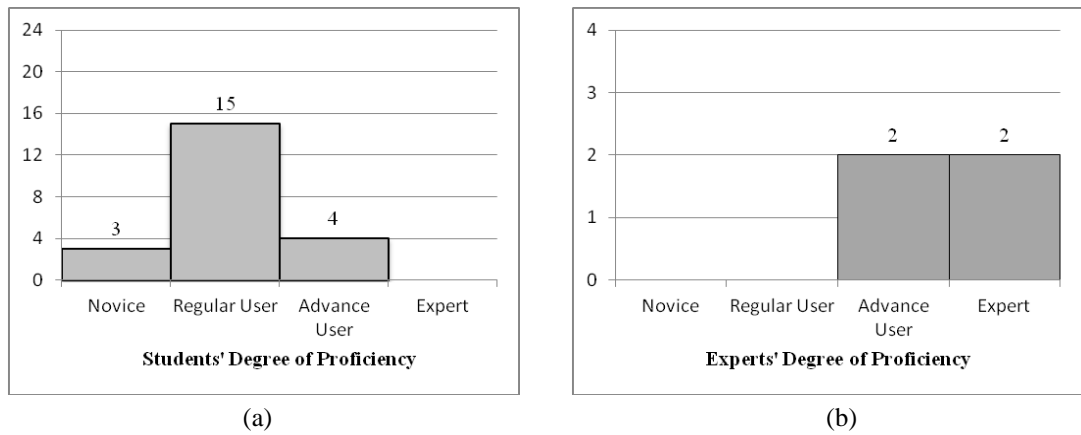
Figure 48: (a) Geovisualization proficiency distribution of the student group; (b) Geovisualization proficiency distribution of the expert group

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(a)   (b)
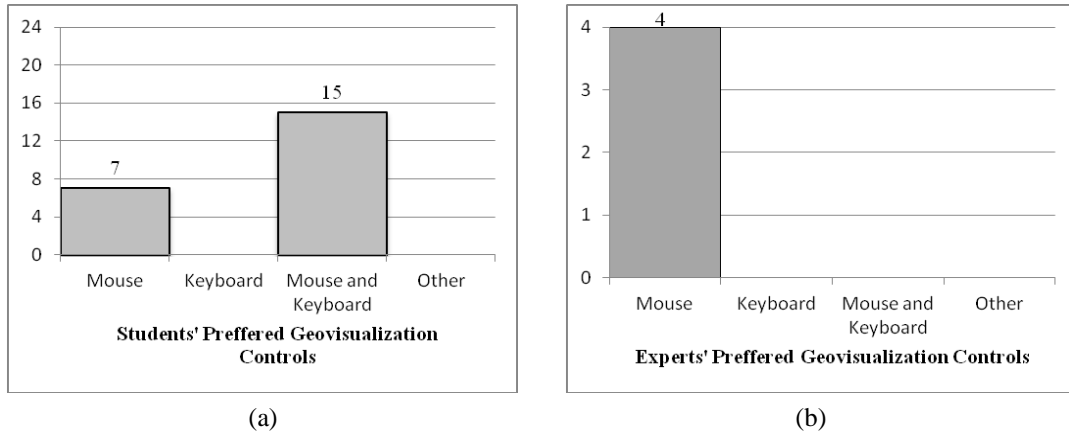
Figure 49: (a) Geovisualization preferred controls distribution of the student group; (b) Geovisualization preferred controls distribution of the expert group

In addition, participants were asked questions on their degree of experience with video games (see Figure 50). This included questions on the type of game genres they had experience with (see Figure 51), the average number of hours spent playing video games per week (see Figure 52), and a question on their preferred gaming platform (see Figure 53).

(a)   (b)
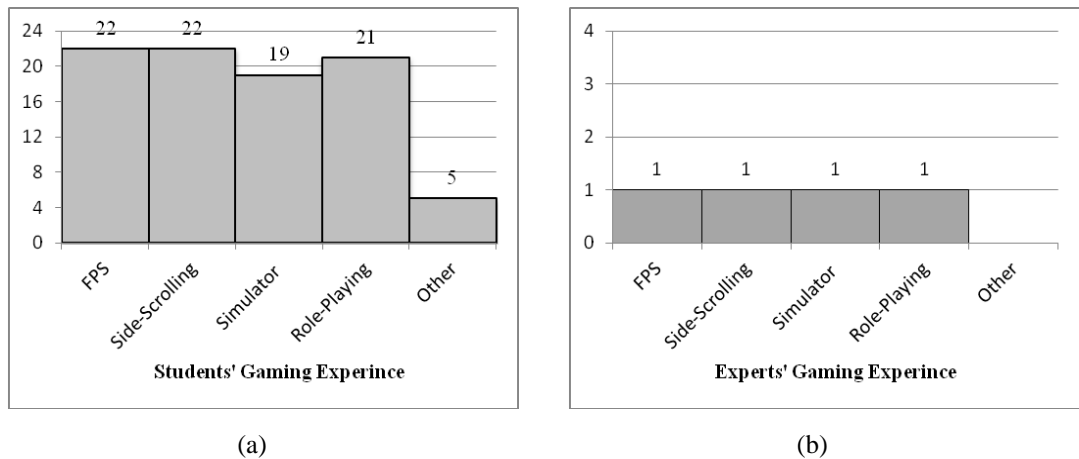
Figure 50: (a) Gaming experience distribution of the student group; (b) Gaming experience distribution of the expert group
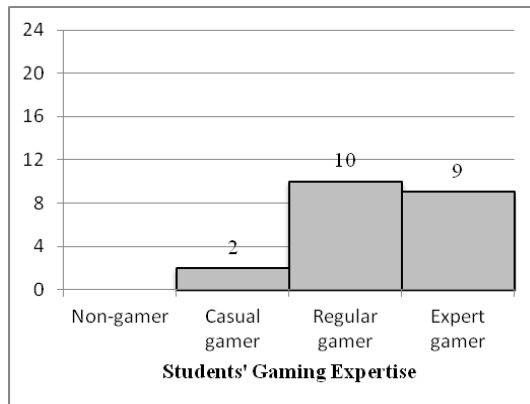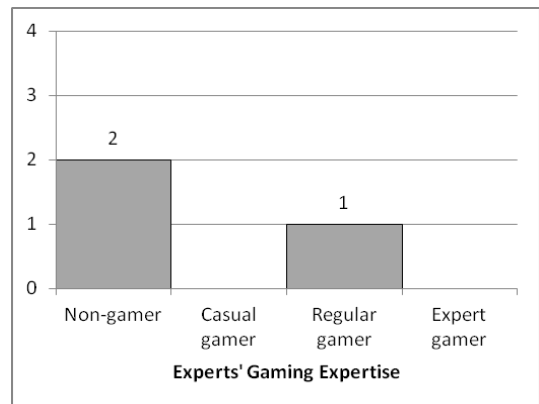
Figure 51: (a) Gaming expertise distribution of the student group; (b) Gaming expertise distribution of the expert group
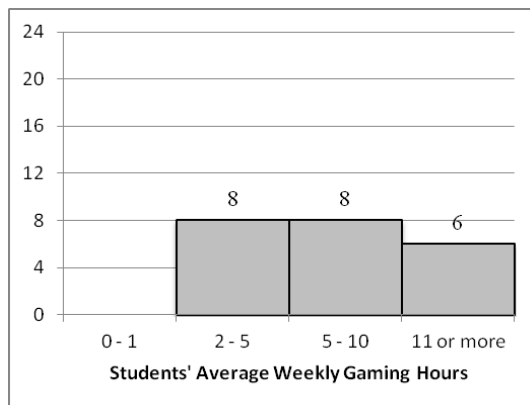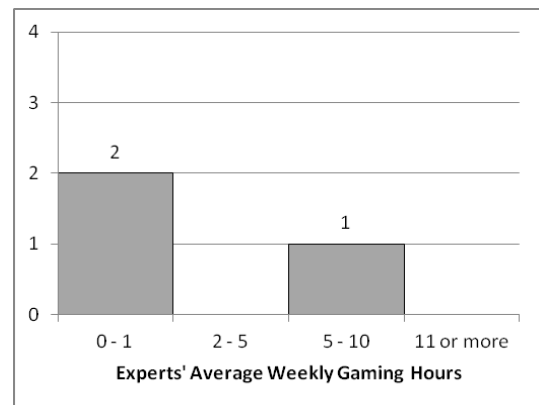
Figure 52: (a) Average weekly gaming hours distribution of the student group; (b) Average weekly gaming hours distribution of the expert group
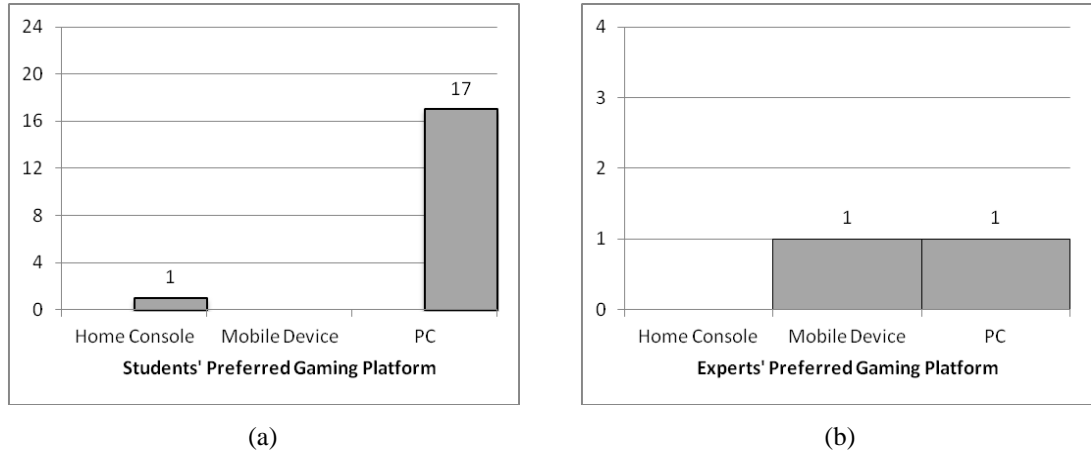
Figure 53: (a) Preferred gaming platform distribution of the student group; (b) Preferred gaming platform distribution of the expert group

From the demographics, we found that every single student participant was familiar with both Google Earth and Google Maps. More than 60% of the students classified themselves as regular users of the geovisualization tool they use the most. We also found that 68% of the students prefer the combination of keyboard and mouse as the dominant navigation control in the geovisualization tool most commonly used by them. All experts indicated that they had experience with both Google Earth and Google Maps. In addition, all experts indicated that they had experience with other geovisualization tools such as OpenStreetMap, Fledermaus (covered in Chapter 3), Arc GIS, and various world-mapping services. Moreover, the experts selected the mouse as their dominant navigation control in the geovisualization tool they used most commonly.

Through the demographics questionnaire we found that more than 86% of the students had some level of experience with first-person shooter, side scrolling, simulator, and role-playing game genres. Moreover, 45% of the students classified themselves as regular gamers and another 40% classified themselves as expert gamers,

with the remaining students classifying themselves as casual gamers. Interestingly enough, each student participant averages two or more hours a week playing video games, with almost a third of the students indicating they average 11 or more. However, let it be stated that the sample was very biased since all the students were enrolled a game development course.

In contrast, only one expert indicated having experience with any of the game genres. The remaining experts did not answer the question related to game genre experience. One of the experts who did not respond to the game genre question did however classify himself as a non-gamer, with an average of zero to one hour of video game playing per week. Moreover, the expert with the gaming experience classified himself as a regular gamer with an average of five to ten hours a week playing video games.

We must note that due to the number of student participants being significantly larger than that of expert participants, we encountered some difficulties performing in-depth statistics on sub-categories of the participants. Initially we wished to carry out a detailed statistical analysis of sub-categories by comparing the participants' performance (i.e., task completion times) using varying age ranges, different gender, technical background, etc. However, due to time constraints and project deadlines for the expert audience we could not obtain a larger expert pool. Therefore, we have tried our best to conduct a useful and meaningful evaluation of the participant sample pool we had available to us. The remaining information presented in this document provides salient information gathered from the post questionnaires that can hopefully

shed light on the successes and failures of different navigational aids and the visualization tool we created.

5.2 User Questionnaires

The usability evaluation of the framework uses Likert scales and Likert-type questions to obtain qualitative data from the participants. The following section provides background information on Likert scales and the types of statistical procedures that can be carried out with the data collected by these types of questionnaire.

5.2.1 Likert Scale Questionnaire

A Likert scale is a psychometric response scale mainly used in questionnaires to obtain a participant's preference or level of agreement with a statement or set of statements [27]. When using Likert scales, participants are asked to determine their level of agreement with a given statement by way of ordinal data. Commonly used Likert scales include five, seven, and nine-point scales ranging from "strongly disagree" to "strongly agree". It is often recommended that odd-point scales be used since they offer a natural middle, which can be denoted as "neutral" or "undecided." An example of intermediate scales for a five-point Likert scale includes: "strongly disagree," "disagree," "undecided," "agree," and "strongly agree." Table 2 presents an example of Likert-type questions that belong to a Likert scale.

Table 2: An example of overall user satisfaction Likert-type questions

#	Statements		1	2	3	4	5	
1	This configuration was helpful for learning the controls of the application	Strongly Disagree						Strongly Agree
2	The supplemental materials (PDFs/Docs) were very helpful	Strongly Disagree						Strongly Agree

A weak point of Likert scales is that, while the participant data are generally treated as ordinal, we cannot presume that participants perceive the difference between neighboring levels to be identical [21]. For instance, we cannot assume that all participants perceive the difference between "strongly disagree" and "disagree" as being the same as the difference between "undecided" and "agree".

5.2.2 Analyzing Likert Data

Research has shown that improper statistical procedures are often carried out on the Likert scale data due to a misinterpretation of the data itself [21]. A Likert scale is made up of multiple questions that are grouped by researchers to quantitatively measure a character or personality trait. However, questions that are grouped together and do not form a composite scale (unconnected questions) are known as Likert-type questions. Understanding the difference between Likert-type and a Likert scale is important when determining how to correctly analyze the data.

Table 3: An example of Likert-type questions related to ease of use

#	Statements		1	2	3	4	5	
1	The controls were easy to use	Strongly Disagree						Strongly Agree
2	The computer had issues starting up	Strongly Disagree						Strongly Agree

Table 3 demonstrates two Likert-type questions; one question is related to the usability of the controls and one question is related to hardware reliability. If the Likert questions are unique and unconnected then researchers should analyze them as Likert-type items. This includes using frequency charts, computing modes and means, etc. A Likert scale made up of connected questions (composition of questions when combined measure a particular trait) can be analyze them using means, standard deviations, etc. It is also possible to report on individual items from a Likert scale, however in each case one should only use Likert-type statistical procedures on that data [21].

5.3 Scenario Analysis

The following sections will present the analysis of the usability evaluations for each of the five scenarios. We will present what we believe is salient information related to the usability of the navigation aids, the overall user satisfaction, etc.

5.3.1 Scenario One (Learning Phase)

Before presenting the qualitative data collected from the questionnaires, we would like to present the time spent by participants in Scenario one. There was no time limit imposed on the users. However, participants were asked to spend somewhere between four to five minutes in each scenario. We believed this was an

adequate amount of time to properly evaluate the scenario configuration. The time spent by students and experts in Scenario one is shown in Figure 54.

(a)   (b)
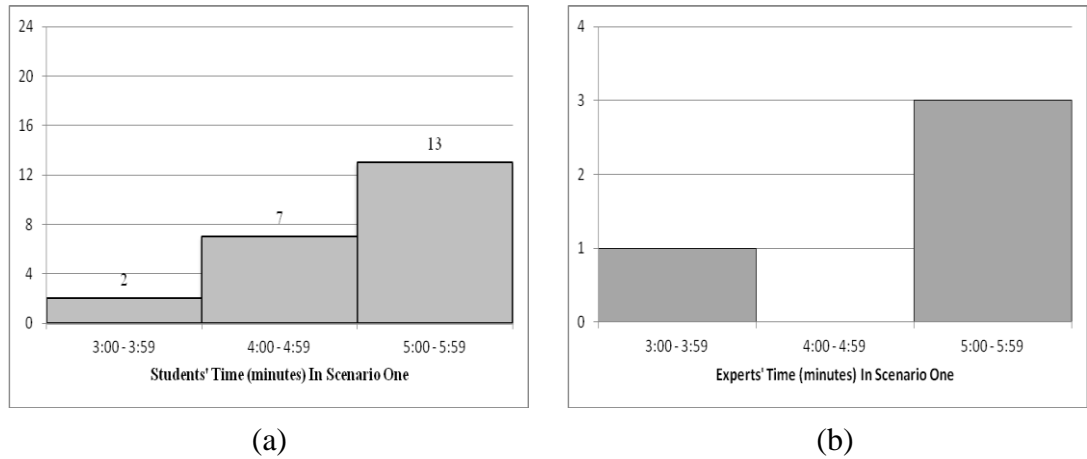
Figure 54: (a) Distribution of the student group for time spent in Scenario one; (b) Distribution of the expert group for time spent in Scenario one

The quantitative data collected shows that only two of the twenty-two students spent less than four minutes in the scenario. This meant that more than 90% of the students spent four to five minutes evaluating the scenario. Moreover, the entire expert pool spent more than five minutes evaluating the scenario.

The descriptive statistics reveal that more than 80% of the participants agreed or strongly agreed that Scenario one was helpful for learning the controls. More than 85% of the participants found the supporting documentation helpful. This was a satisfying result since it meant that Scenario one did a satisfactory job of introducing the participants to the testing framework. Table 4 demonstrates two Likert-type questions related to the overall user satisfaction.

Table 4: Descriptive statistics of the overall user satisfaction using two Likert-type questions

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1						
	#	0	1	4	12	9
	%	0%	4%	15%	46%	35%
Q.2						
	#	0	0	4	10	12
	%	0%	0%	15%	38%	46%
Q.1 – This configuration was helpful for learning the controls of the application						
Q.2 – The supplemental materials (PDFs / Docs) were very helpful						

Participants were asked questions related to their ability to understand the scenario's configuration. We created Likert-type questions with the goal of determining if the participants understood the navigation task, the purpose of the each navigation aid, and that of each GUI component. Table 5 contains the results of the Likert-type questions related to the learning of configuration elements.

Table 5: Descriptive statistics of the overall user satisfaction using two Likert-type questions

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	0	2	5	10	9
	%	0%	8%	19%	38%	35%
Q.2	#	0	0	2	7	17
	%	0%	0%	8%	27%	65%
Q.3	#	0	1	1	6	18
	%	0%	4%	4%	23%	69%
Q.4	#	0	0	1	3	22
	%	0%	0%	4%	12%	85%
Q.5	#	0	0	3	5	18
	%	0%	0%	12%	19%	69%

Q.1 – The navigation task was simple to complete

Q.2 – I understood the purpose of the 2D map in this scenario

Q.3 – I understood how to reset my orientation using the *reset* button

Q.4 – I understood how to return to the home location in the virtual environment using the home button

Q.5 – I believe I can quickly learn how to use the controls

The questionnaire results revealed that more than 70% of the participants found the navigation task simple to complete. Some of the student participants stated that they experienced some minor issues traveling in the world using Apple's Magic Mouse®. It was noted during the development stage of the framework that varying hardware and system configurations could lead to differing navigation experiences.

Users were asked to manually set the controls' sensitivity using the framework's GUI to fix any issue.

Close to 90% of the student participants felt they understood the purpose of the 2D map and felt they understood how to use the orientation-reset and home button. This was a satisfying statistic because it meant that participants were aware of how to reorient themselves upon getting disorientated or lost. For the experts, two of the participants felt that the navigation task was not easy to complete. Both of these test experts were running the framework on Windows machines. One expert indicated that completing the navigation task was tedious since it seemed that the framework was not responding correctly upon reaching a target. In addition, another expert expressed having had trouble using the combination keys for the controls in Windows. While, both of these experts encountered technical difficulties at times, another expert experienced no difficulties on their Windows machine.

In order to evaluate the usefulness of the 2D map with the you-are-here dot indicator a Likert scale with more than four questions was used. The results revealed that all but one of the participants agreed or strongly agreed that the 2D map dot gave them a good sense of position of the world (spatial awareness support). The high percentage was not a surprise since past research has shown that 2D maps are effective tools for enhancing spatial awareness [4]. However, the questionnaire results revealed that almost 60% of the participants did not believe that this version of the 2D was useful for providing a sense of orientation in the environment. This result was somewhat expected since the 2D map dot provided no directional information to the participant. The students' and experts' responses are shown in Figure 55 and 56

respectively. Table 6 presents the results of two Likert-type questions related to the usefulness of the 2D map.
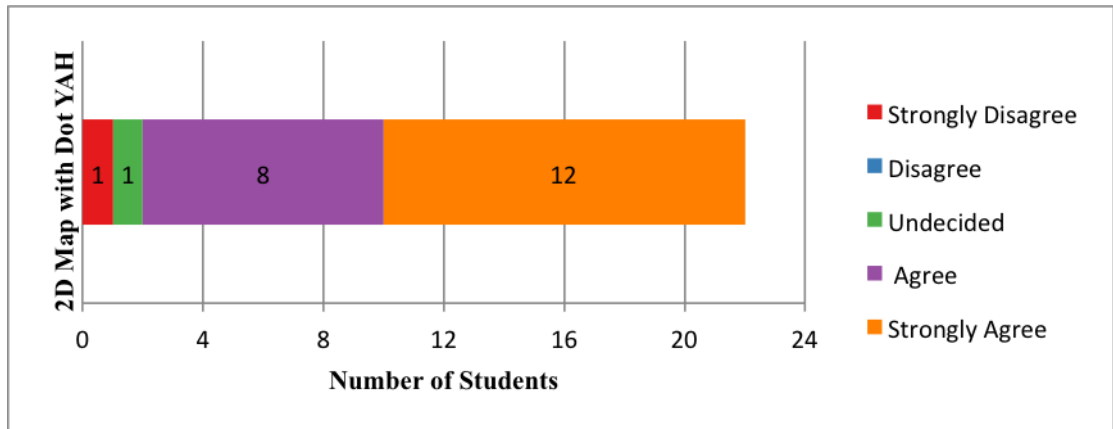
Figure 55: Students' response to the Likert scale measuring the 2D map's usefulness
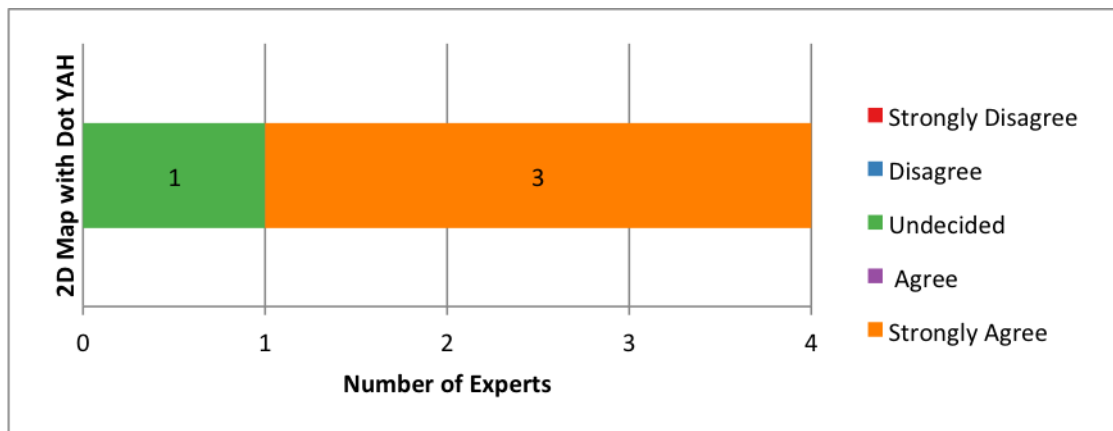
Figure 56: Experts' response to the Likert scale measuring the 2D map's usefulness

Table 6: Descriptive statistics of the Likert scale measuring the 2D map with dot usefulness

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	0	0	2	10	14
	%	0%	0%	8%	38%	54%
Q.2	#	9	2	4	8	3
	%	35%	8%	15%	31%	12%

Q.1 – The you-are-here red dot on the 2D map gave me a good sense of position in the world

Q.2 – The you-are-here red dot on the 2D map gave me a good sense of orientation in the world

Most of the critical comments received about the 2D map were related to the lack of direction indicated by the dot. Several participants suggested that the dot be replaced with an arrow. One participant stated that determining heading direction was a guessing game since the dot gave no inclination of direction in the environment.

A strong interest in this research was to determine how useful a scenario's configuration was at reducing the likelihood of the user both getting lost and disorientated in the environment. However, we like to admit that determining the exact moment a user becomes disorientated is not an easy task, either be it quantitatively or qualitatively. How does one quantitatively calculate the moment a user gets lost or disorientated in the world? What about asking the user to remember the number of times they got lost or disorientated in the word? Our framework does not calculate when a user gets lost or disorientated in the world. Instead, we use Likert-scales and

Likert-type questions to obtain information from the user related to getting lost and disorientation (a qualitative approach). Table 7 presents three orientation-related Likert-type question and their results.

Table 7: Descriptive statistics of the Likert scale used to assess orientation problems

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	2	10	9	4	1
	%	8%	38%	35%	15%	4%
Q.2	#	2	16	6	2	0
	%	8%	62%	23%	8%	0%
Q.3	#	2	8	10	4	2
	%	8%	30%	38%	15%	8%
Q.1 – I found myself getting disorientated in the environment often						
Q.2 – I found myself getting lost in the environment often						
Q.3 – The controls contributed to me getting lost/disorientated						

We initially expected to see a large number of participants experience difficulties with orientation and spatial awareness, since it was the first time participants were exposed the framework. However, the questionnaire revealed that only 15% of the participants (one expert and three students) felt they got disorientated often in the environment. This percentage was expected to be higher due to lack of visual aids, and navigation aids available in this scenario. However, we believe these numbers are skewed due to the overwhelming number of participants experience with

virtual environment navigation (e.g., in video games). It is likely that the majority of participants felt comfortable navigating using this egocentric view, since our framework used a first-person camera view, which is similar to ones found in FPS games.

Interestingly enough, the descriptive statistics reveal that less than 10% of the participants felt they got lost often the environment. We expected this percentage to be higher as well. However, one possible reason for this low percentage is likely due to the availability of the 2D map in the scenario and to the small dimensions of the world, in my opinion. Another possible explanation for the low percentage of participant's getting lost in the environment could be related to the participant's perception of the word "often." Does "often" mean two, three, or four disorientations? We could have asked participants to keep a tally on the number of times they got disorientated in the world but that would have likely introduce more of a cognitive load on the user (likely resulting in longer evaluation times). Similarly, we could have included a button "I am lost" that users could press during moments of disorientation. However, it would be difficult to determine if users hit the "I am lost" because they were still lost or got lost again in the virtual environment.

5.3.2 Scenario Two (2D Map with Dot + Visual Aids)

This scenario is the first to display a geospatial data set to the participants and it contains additional visual aids to support the understanding of the data being represented in the virtual environment. Participants were asked Likert-type questions related to the usefulness of the 2D map, their understanding of visual aids, and their views on the usefulness of the aids for observing the data sets.

Figure 57: (a) Distribution of the student group for time spent in Scenario two; (b) Distribution of the expert group for time spent in Scenario two

The quantitative data collected shows that 50% of the students spent less than the recommended four-to-five minutes in this scenario, as shown in Figure 57. While there is no statistical backing to prove this, the change in evaluation time is likely due to Scenario two's similarity to Scenario one. As for the expert testers, there was no significant change in the time spent in the scenario. The corresponding student and expert times spent in the virtual environment is displayed in Figure 57.

The descriptive statistics for Scenario two reveal that 90% of the student participants and 100% of the experts found that this scenario configuration effectively supported their navigation in the virtual environment (see Table 8). The questionnaire results also showed that nearly 80% of the student participants agreed that the color mapping of the data and lookup table were easy to understand (see Figures 58 and 59). We also found that seven of the twenty-two students felt they did not understand the 2D data view presented in the scenario. Problems understanding the 2D data view are

likely a result of demographic or system issues. These issues are presented in Chapter 6.

Table 8: Descriptive statistics of the overall user satisfaction Likert-type questions

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	0	0	1	14	11
	%	0%	0%	4%	54%	42%
Q.2	#	1	1	1	6	17
	%	4%	4%	4%	23%	65%
Q.1 – This configuration was helpful for learning the controls of the application						
Q.2 – The supplemental materials (PDFs / Docs) were very helpful						

Q.1 – The color mapping of the data set was easy to understand

Q.2 – I understood the purpose of the 2D data view
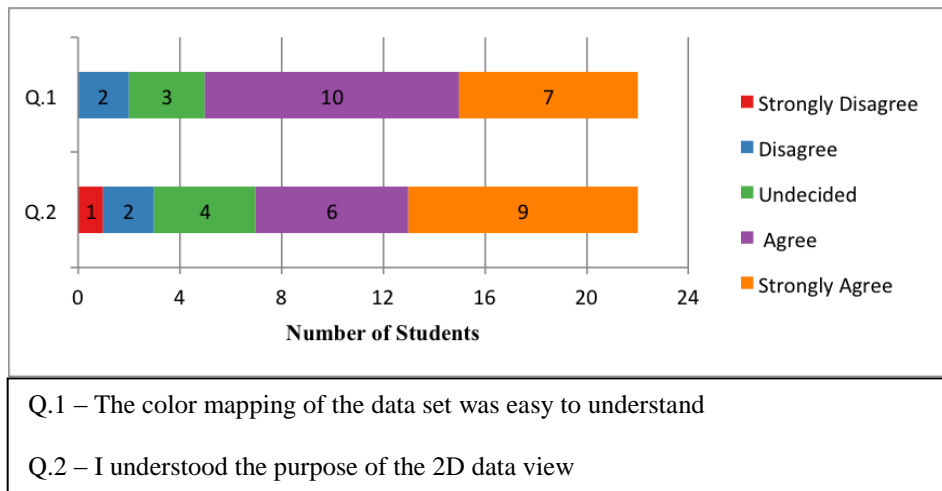
Figure 58: The students' response to the Likert-type questions related to the 2D data view's usefulness

Q.1 – The color mapping of the data set was easy to understand

Q.2 – I understood the purpose of the 2D data view
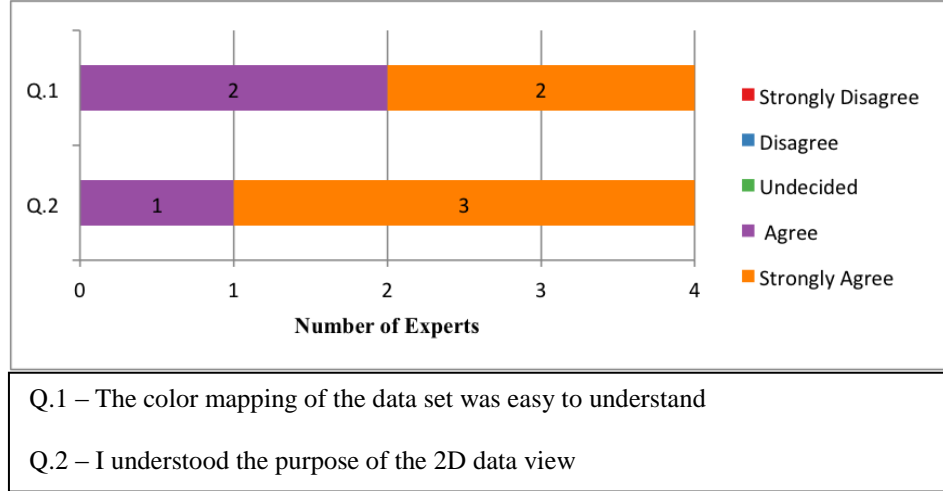
Figure 59: The experts' response to the Likert-type questions related to the 2D data view's usefulness

In order to measure the usability of the 2D map, terrain gridlines, and 2D data view, we used a collection of Likert-type questions. We expected the usefulness of the 2D map for navigation to be similar to that of Scenario one. Also, the gridlines were expected to act as visual landmarks during navigation, thus helping participants maintain spatial awareness in the environment. Moreover, we expected the 2D data view to help participants gain insight on the geospatial data set being represented in the underwater environment.

The descriptive statistics revealed that all participants agreed or strongly agreed that the 2D map helped them maintain a sense of position in the environment. This result was expected for reasons explained in Section 5.1.1. However, there was still a strong negative reaction for the effectives of the 2D map to provide a sense of orientation in the world, with 44% of the participants believing it was not helpful. An encouraging statistic was related to the usefulness of the gridlines for perceiving

74

distance in the virtual environment, with more than 70% of the participants agreeing it was helpful to them. This was an encouraging statistics for us since, as we mentioned in Chapter 4, the resolution of the terrain is low (approximately four kilometer between each data point), therefore it lacks detail and does little to act as a visual landmark on its own. Table 9 presents the results of four Likert-type questions related to the overall usefulness of 2D map, 2D data view, and terrain gridlines.

Table 9: Descriptive analysis of the Likert-type questions related to overall usefulness

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1						
	#	0	0	0	7	19
	%	0%	0%	0%	27%	73%
Q.2						
	#	8	3	6	3	6
	%	30%	12%	23%	12%	23%
Q.3						
	#	1	1	4	14	6
	%	4%	4%	15%	54%	23%
Q.4						
	#	1	2	7	10	6
	%	4%	8%	27%	38%	23%

Q.1 – The 2D map's you-are-here red dot gave me a good sense of position in the world

Q.2 – The 2D map's you-are-here red dot gave a good sense of orientation in the world

Q.3 – The terrain (bathymetry) grid lines heightened my perception of distance in the world

Q.4 – The 2D view helped me understand the relationship between depth and salinity concentrations

We would like to mention that our questionnaire did not contain questions concerning the usefulness of the water surface. However, we received several comments from both students and experts related to the water surface. Several participants commented that the water surface worked well as a visual landmark for maintaining orientation and giving them a sense of being under water.

Table 10: Descriptive analysis of Likert-type questions related to orientation

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	9	10	4	3	0
	%	35%	38%	15%	12%	0%
Q.2	#	14	9	2	1	0
	%	54%	35%	8%	4%	0%
Q.3	#	10	7	6	2	1
	%	38%	27%	23%	8%	4%
Q.1 – I found myself getting disorientated in the virtual environment often						
Q.2 – I found myself getting lost in the virtual environment often						
Q.3 – The controls contributed to me getting disorientated/lost						

We concluded this scenario's evaluation by asking Likert-type questions on orientation, as shown in Table 10. The descriptive statistics reveal that nineteen of twenty-six participants felt they did not experience disorientations in the environment. This was an increase from Scenario one, which is likely related to the participant's second exposure to the framework. Another statistic that points in that direction is that in Scenario one, six of the twenty-six participants felt that the controls contributed to

their getting lost or disorientated in the world. However, in Scenario two, the number was down to three participants. It is probable that as participants were repeatedly exposed to the framework they became more comfortable with the controls and visualization tool.

There was also an increase in the number of participants who felt they did not get lost in the environment. In Scenario one, eighteen of the twenty-six participants indicated they did not get lost in the environment. In Scenario two, this number jumped to twenty-three out of twenty-six. It is likely that as the participants are repeatedly exposed to the same environment they will develop a cognitive map of the environment, thus reducing the chances of getting lost. Research has shown that cognitive maps—mental representation of an environment developed through wayfinding—can help users better navigate the same virtual environment [2].

5.3.3 Scenario Three (2D Map with Arrow + 2D Radar + Visual Aids)

This scenario replaces the dot on the 2D map with an arrow. This scenario also introduces the radar navigation aid. In addition to the navigation aids, this scenario contains the same visual aids found in Scenario one. Participants were asked Liker-type questions on the usefulness of the 2D map with an arrow and radar for navigating about the virtual environment. Figure 60 presents the time spent by both experts and students in Scenario three.
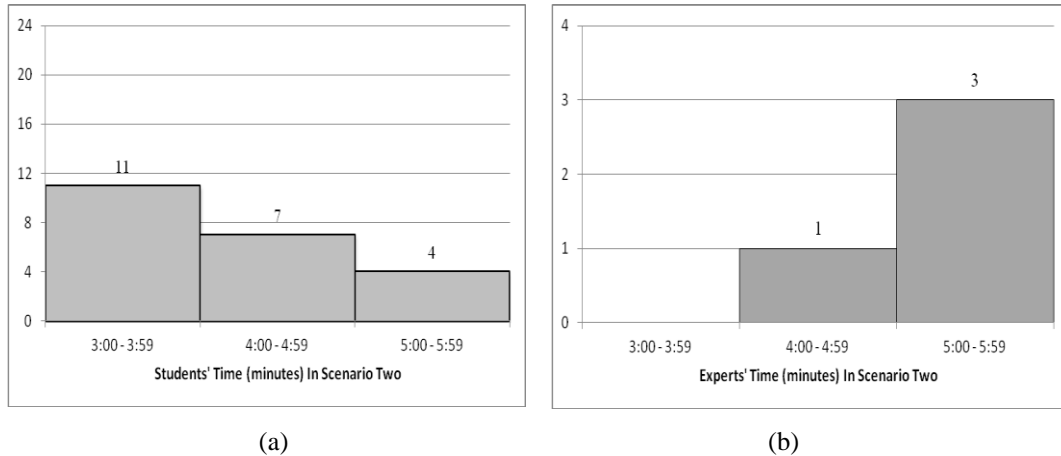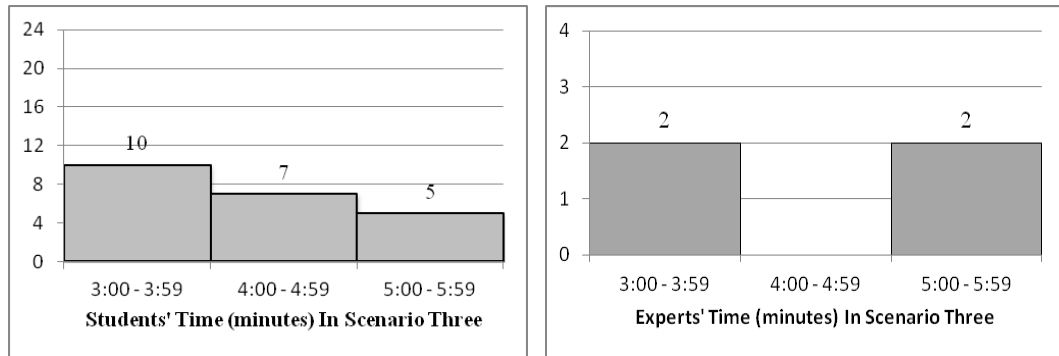
Figure 60: (a) Distribution of the student group for time spent in Scenario three; (b) Distribution of the expert group for time spent in Scenario three

The descriptive statistics shown in Table 11 reveal that more than half of the participants strongly believed that this scenario configuration effectively supported their navigation in the environment. In addition, nearly half of the participants (48%) strongly believed Scenario three was more effective than Scenario two in supporting navigation.

While there was favorable support for Scenario three, critical participant feedback included statements such as "I have found the interface to be cluttered for my liking" and "GUI overload". We must agree that as the scenarios progress, the scenario interfaces do get somewhat cluttered. There are two reasons for this. First, we wanted to test as many navigation aids as possible. Second, we were also interested in determining when users felt there was too much assistance, such that it negatively impacted navigation performance.

Table 11: Descriptive analysis of the Likert-type questions related to overall usefulness

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	0	0	2	11	13
	%	0%	0%	8%	42%	50%
Q.2	#	1	0	3	10	12
	%	4%	0%	12%	38%	46%
Q.3	#	0	0	4	7	15
	%	0%	0%	15%	27%	57%

Q.1 – This configuration effectively support supported my navigation in the world

Q.2 – I found this scenario's configuration more effective than the last configuration

Q.3 – The supplemental materials (PDFs / Docs) were very helpful

The modification of the 2D map to use an arrow was received with positive feedback. Fifteen of the twenty-two students strongly agreed that arrow gave them a good sense of orientation in the environment. Thirteen of the twenty-two students strongly believed that the arrow was more helpful than the dot. One student stated that the arrow removed the orientation guessing-game problem he experienced in Scenario one. Figure 61 presents the students' responses to three Likert-type questions related to the usefulness of the 2D map (with arrow).

We have to admit that a problem with Likert-type question Q.3 (in Figure 61) is that it is somewhat vague. What is the meaning of "more helpful?" How is the arrow more helpful than the dot? This question should have been rephrased to say something along the lines of: "I felt that the arrow was more helpful at providing a sense of

orientation in the world as opposed to the 2D map dot." While the original question does shed light on the participants' preference for the arrow, the question should have explicitly used the word orientation to help us understand why users thought it was more helpful. Therefore, we can only assume that more than half of the participants prefer the arrow because it provides directional information.

Q.1 – The 2D map arrow gave me a good sense position in the world

Q.2 – The 2D map arrow gave me a good sense of orientation in the world

Q.3 - I found the 2D map arrow more helpful than the red dot during navigation in the environment
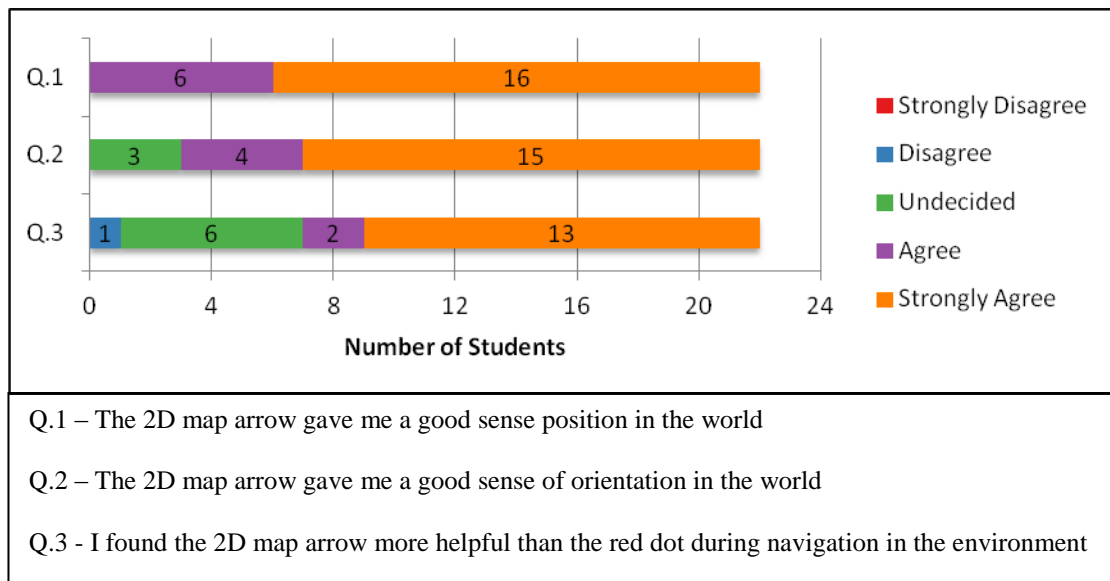
Figure 61: The student's response to the Likert-type questions related to the usefulness of the 2D map with arrow

As for the experts, the replacement of the 2D map dot with an arrow was not so well received. Two of the four experts strongly agreed that the 2D map arrow gave them a good sense of orientation in the world. However, interestingly enough, the experts had different views on Likert-Type question Q.3 (Figure 62). Two experts disagreed that the 2D map arrow was more helpful than the 2D map dot. There were no additional comments provided by the experts on why they answered so to this question. One expert who preferred the 2D map arrow mentioned that the arrow was easy to use for determining in which direction they were heading.

Q.1 – The 2D map arrow gave me a good sense position in the world

Q.2 – The 2D map arrow gave me a good sense of orientation in the world

Q.3 - I found the 2D map arrow more helpful than the red dot during navigation in the environment
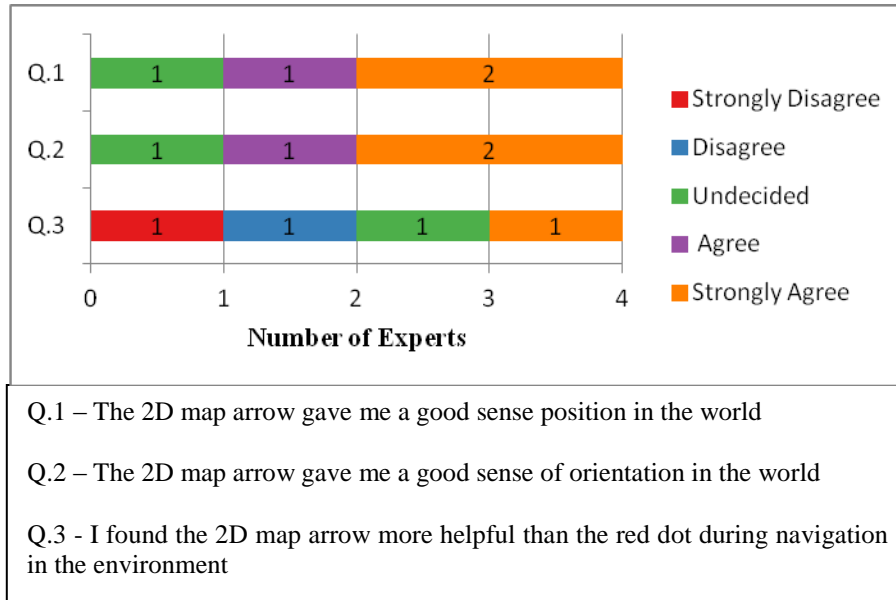
Figure 62: The experts' response to the Likert-type questions related to the usefulness of the 2D map with arrow

We also asked Likert-type questions related to the usefulness of the 2D radar. The results reveal that ten of the twenty-two students found the radar useful during navigation. However, when asked whether they believed the 2D radar was unnecessary—since all of the objects of interest are almost always visible on the 2D map—, thirteen of the twenty-two students agreed. As stated in the questions, the 2D map's resolution is much smaller than that of the virtual environment. Therefore, there are instances where all the objects of interest are visible on the same map. For this reason, we expected a large number of participants to find the 2D unnecessary.

However, if the 2D map's resolution were greater, then using a 2D radar would probably make more sense. As past research has shown [6], a 2D radar can be an effective tool for navigating large virtual environment, since it can provide users with information on objects of interest that are not visible in the users current view-port.

The students' and experts' responses to two Likert-type questions related to the radar usefulness is shown in Figure 63 and 64 respectfully.
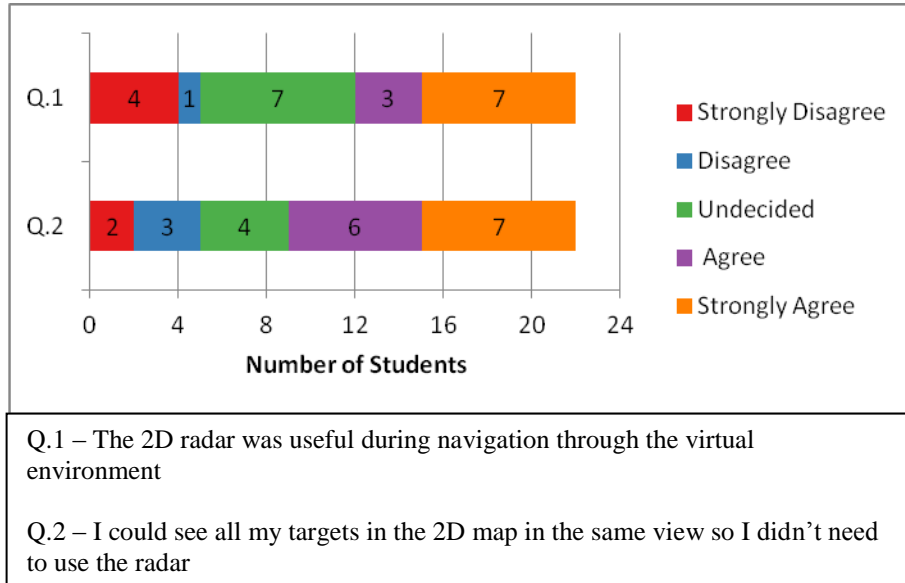
Figure 63: The students' response to the Likert-type questions related to the 2D radar usefulness
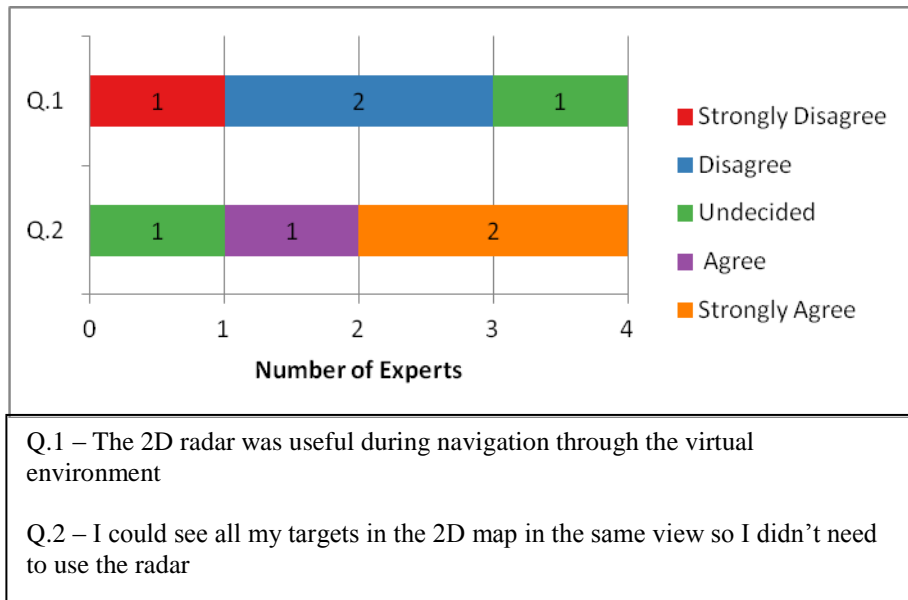
Figure 64: The experts' response to the Likert-type questions related to the 2D radar usefulness

The questionnaire results of the experts are similar to that of the students: All experts found the 2D radar not to be useful in this scenario. Two of the four experts agreed that they did not use the radar since all the objects of interest were shown on the 2D map. We again concluded this scenario evaluation by asking Likert-type questions related to orientation. The results are presented in Table 12.

Table 12: Descriptive analysis of the Likert-type questions related to orientation

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	11	9	2	4	0
	%	42%	35%	8%	15%	0%
Q.2	#	12	6	5	3	0
	%	46%	23%	19%	12%	0%
Q.3	#	11	7	6	1	1
	%	42%	27%	23%	4%	4%
Q.4	#	4	2	6	8	5
	%	15%	8%	27%	31%	19%

Q.1 – I found myself getting disorientated in the environment often

Q.2 – I found myself getting lost in the environment often

Q.3 – The controls contributed to me getting lost/disorientated

Q.4 – The configuration effectively helped me avoid getting lost

5.3.4 Scenario Four (2D Map + 2D Compass + Orientation View + Visual Aids)

This scenario replaces the radar navigation aid with a compass. It also introduces a bird's eye view, and a user orientation display. In addition to the navigation aids, this scenario contains the same visual aids as in the last scenario to support the understanding of the data being represented in the virtual environment. Participants were asked Liker-type questions on the usefulness of the compass, bird's eye view display, and user orientation display for navigating about the virtual environment.

The time spent by both student and experts was similar to those to that of Scenario one and Scenario two. Figure 65 presents the time spent by students and experts in Scenario four.

(a)   (b)
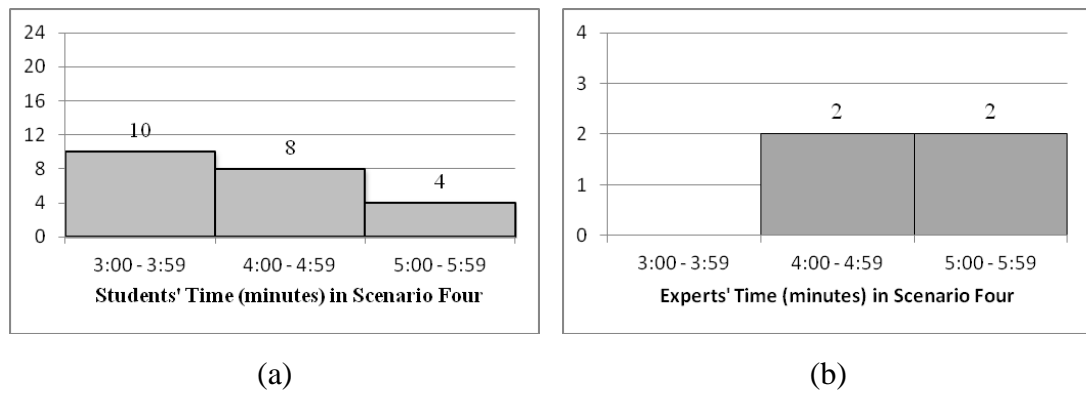
Figure 65: (a) Distribution of the student group for time spent in Scenario four; (b) Distribution of the expert group for time spent in Scenario four

The descriptive statistics reveal that this scenario was also considered effective for supporting user navigation by 92% of the participants. Twelve of the twenty-six participants strongly felt that this scenario configuration supported their navigation more effectively than the previous scenario. A positive statistics from the analysis is

that, as in Scenario one through Scenario three, none of the participants felt the scenario was ineffective for supporting navigation.

The 2D compass's usefulness was measured using two Likert-type questions. The results revealed that, as was the case with the 2D radar, several participants felt it was unnecessary. Seven of the twenty-two students felt strongly about the 2D compass being unnecessary. One expert participant stated that there was no real need for a compass since one can always tell the North direction by looking at the 2D map. While this might be the case in our environment, since there are clear visible landmarks on the map, research has shown that 2D compasses are helpful for navigating large environment with lacking visual aids. Figure 66 and 67 present the students' and experts' responses to Likert-type questions related to the usefulness of the 2D compass.

Q.1 – The 2D compass was very helpful during navigation in the environment

Q.2 – The 2D compass is not necessary since I have a 2D map
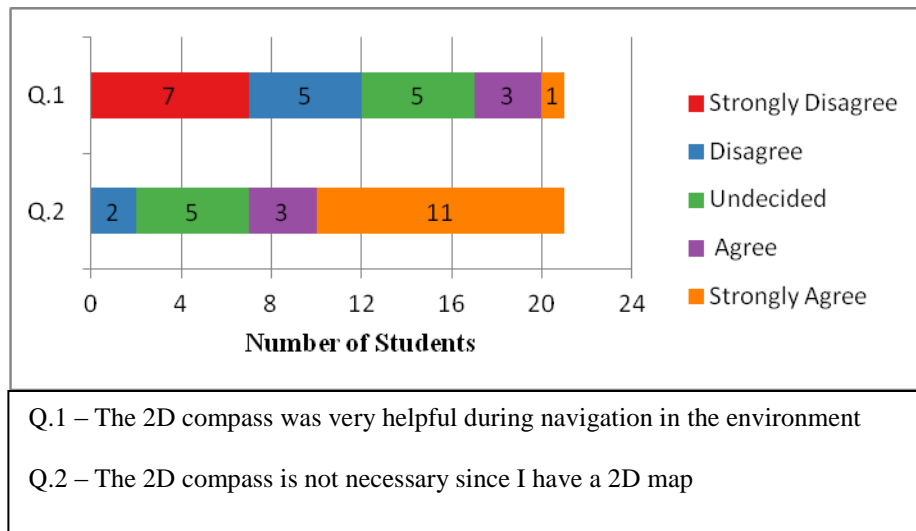
Figure 66: The students' response of the Likert-type questions measuring compass usefulness

Q.1 – The 2D compass was very helpful during navigation in the environment

Q.2 – The 2D compass is not necessary since I have a 2D map
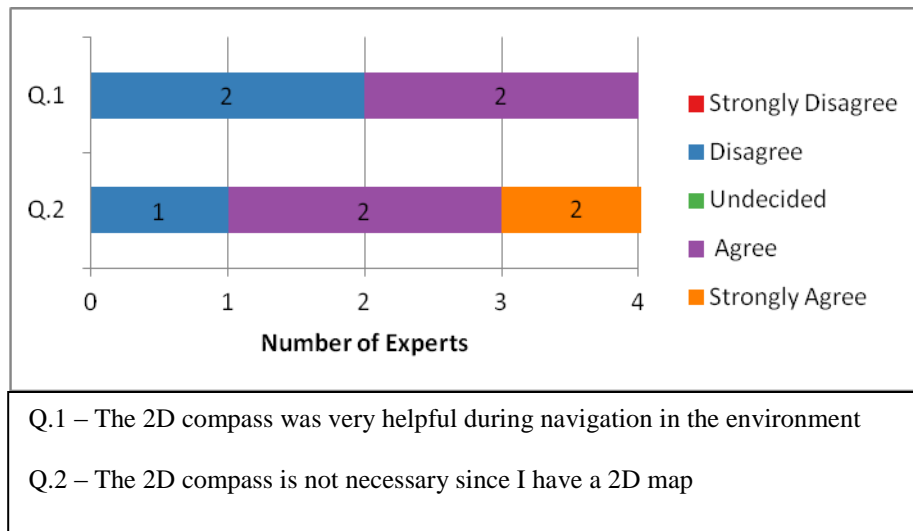
Figure 67: The experts' response of the Likert-type questions measuring compass usefulness

While a large number of students and experts did not find the 2D compass useful in this scenario, we believe the 2D compass could be more useful in other scenarios. In Scenario four, New Jersey was clearly visible on the 2D map and acted as a visual landmark that could be used to maintain a sense of position in the world. Due to the 2D map North-up orientation users—most likely—had the ability to determine the North, East, West, and South direction. However, had the data been visualized somewhere in the middle of the North Atlantic Ocean with no clear landmarks visible on the 2D map (e.g., only water was shown on the 2D map), the users could have potentially found the 2D compass more useful while navigating the environment. However, even in this situation, because the 2D map orientation is based on a traditional North-up map, users might still not find the 2D compass useful during navigation since they always know that North is up on the 2D map.

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The usefulness of the 3D orientation window was measured through a collection of Likert-type questions. This view was in place to help users maintain spatial orientation as they navigated. While it was not expected for this view to greatly benefit expert gamers with experience in virtual navigation, it was instead directed toward users who might have issues navigating in an egocentric first person view. The results show that seven of the twenty-two students agreed to some extent that the 3D orientation window was helpful for maintaining orientation, while the rest were unsure or felt the window was not helpful. One student stated that the view helped him keep track of his orientation in situations where no visual landmarks were in sight. Some students mentioned that the view was a little difficult to understand. All of the participants of who felt strongly about this navigation aid not being helpful were self-classified expert gamers. The students' response to two Likert-type questions is presented in Figure 68.

Q.1 – The User 3D Orientation window was very helpful in maintaining orientation during navigation

Q.2 – The 3D boat used in the User 3D Orientation was a good choice for showing the camera's orientation
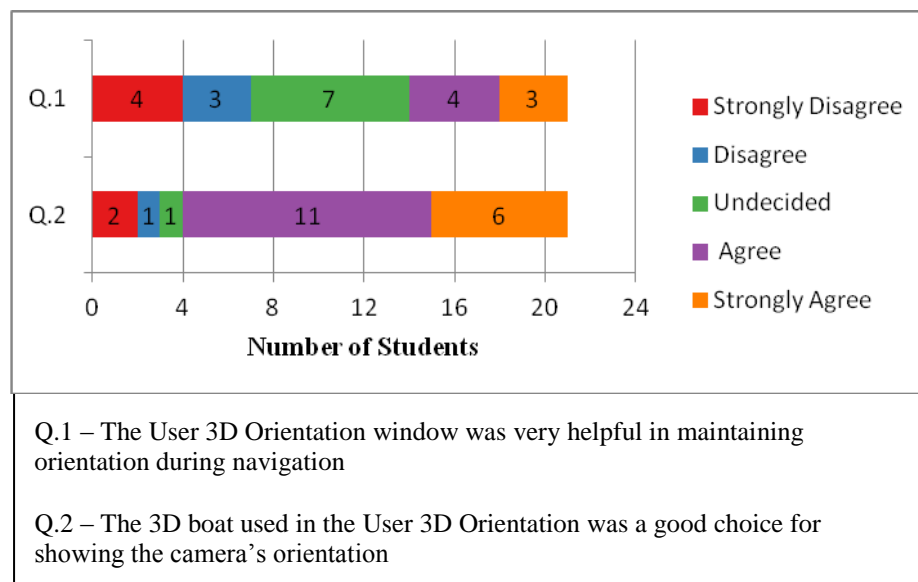
Figure 68: The students' response to the Likert-type questions related to the 3D orientation window usefulness

Two of the three experts agreed to some to level that this 3D orientation window was helpful for maintaining a sense of orientation. However, one expert mentioned that the orientation view was confusing to understand. The experts' response to two Likert-type questions is presented in Figure 69.

Q.1 – The User 3D Orientation window was very helpful in maintaining orientation during navigation

Q.2 – The 3D boat used in the User 3D Orientation was a good choice for showing the camera's orientation
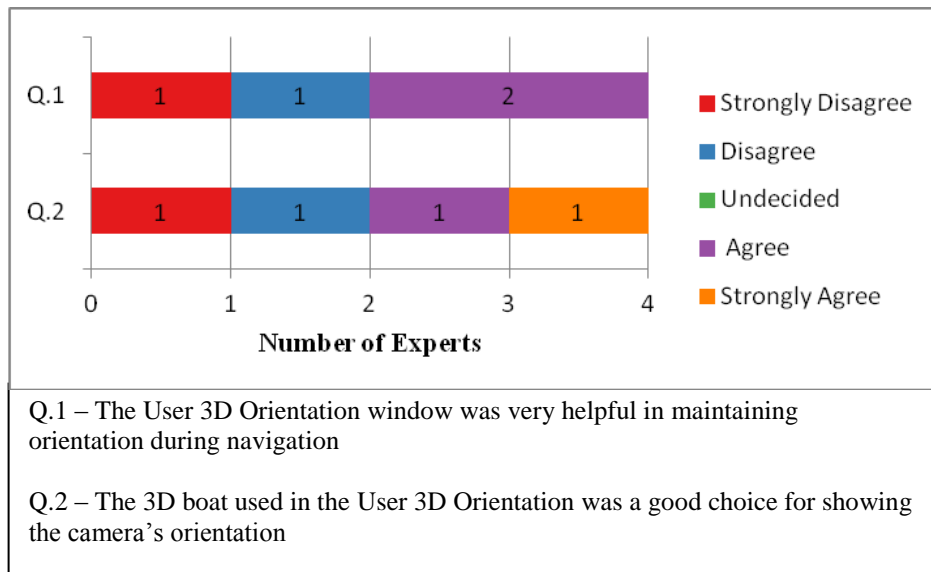
Figure 69: The experts' response to the Likert-type questions related to the 3D orientation window usefulness

The choice of using a boat to display the user's orientation was made due to the boat's non-rotational symmetric shape; it was surprisingly well liked by a majority of the participants as a good model to use for representing the user's orientation. We were initially weary that using a boat to represent the user's orientation might look a bit odd to the user. In all, of the twenty-six participants all but five thought the boat was a good choice for showing the camera's orientation.

We used a collection of Likert-type question (presented in Figure 70 and 71) to assess the usefulness of the bird's eye view The bird's eye view was in place to give

users a different view of themselves in the world with the hopes it would allow participants to see more of the world from a higher view-point. Typically, bird's eye views are used to support survey knowledge and route knowledge, since they allow users to see more of the world (including landmarks) thus allowing users to develop a cognitive map. The descriptive statistics revealed that six of twenty-two students did not find the bird's eye view useful for navigating. While thirteen of the twenty-two students found the view helpful to some degree.

While the bird's eye view found favor with the student participants, only one of the experts (with background playing video games) found the bird's eye view useful. One critical statement received on the bird's eye view was that the view wasn't large enough to display more of the world to be effective. While this point is well taken, one reason for having a small bird's eye view was related to the resolution of the framework. Making the bird's eye view larger would have resulted in major design changes to the scenario interface, likely costing one of the other navigation aids to be eliminated. This scenario's evaluation was concluded by asking Likert-type questions related to user orientation. The results are presented in Table 13.

Q.1 – The bird's eye view was very helpful during navigation in the virtual environment

Q.2 – The bird's eye view gave me a good sense of spatial awareness

Q.3 – The bird's eye view furthered my perception of distance in the environment
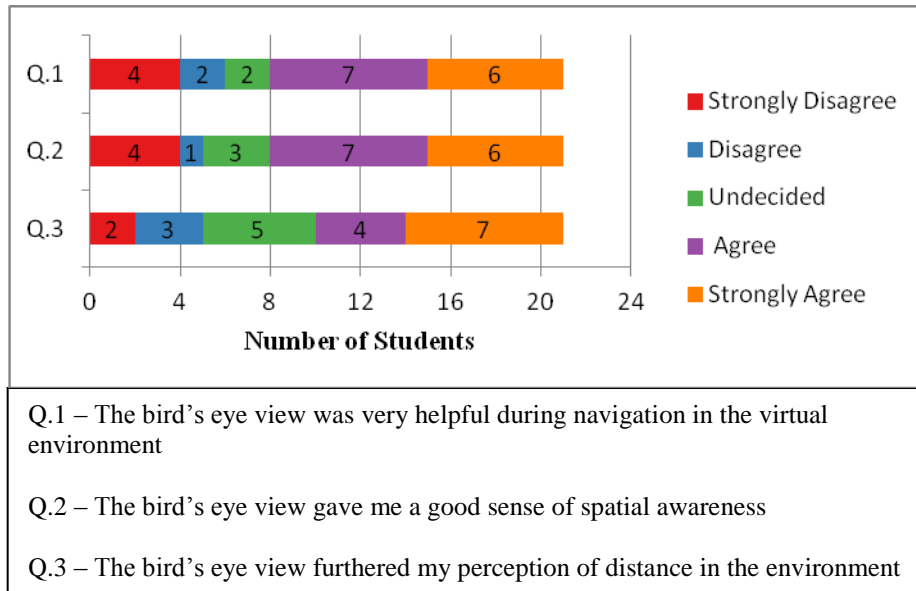
Figure 71: The students' response to the Likert-type questions related to the bird's eye view usefulness

Q.1 – The bird's eye view was very helpful during navigation in the virtual environment

Q.2 – The bird's eye view gave me a good sense of spatial awareness

Q.3 – The bird's eye view furthered my perception of distance in the environment
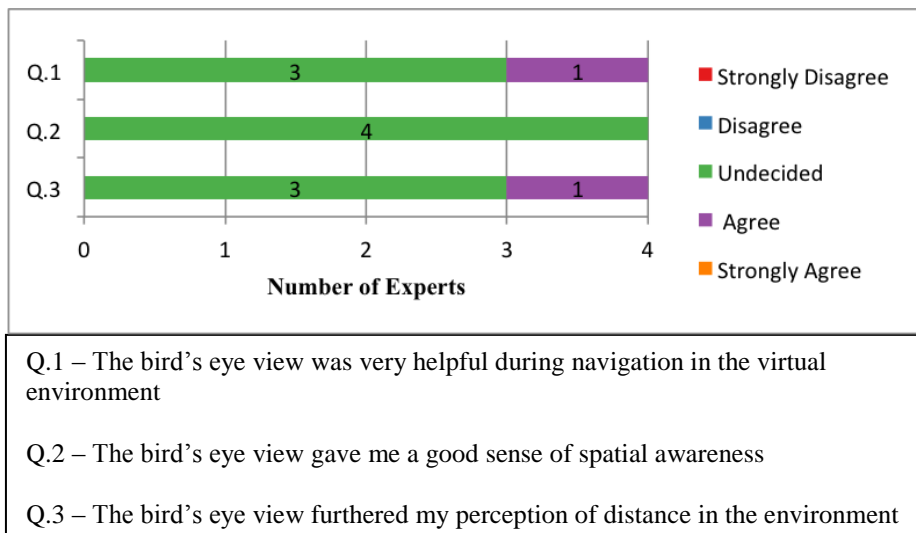
Figure 70: The experts' response to the Likert-type questions related to the bird's eye view usefulness

Table 13: Descriptive analysis of the Likert-type questions related to orientation

		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q.1	#	17	5	2	1	1
	%	65%	19%	8%	4%	4%
Q.2	#	19	2	3	2	0
	%	73%	8%	12%	8%	0%
Q.3	#	18	2	1	3	2
	%	69%	8%	4%	12%	8%
Q.4	#	2	4	4	6	10
	%	8%	15%	15%	24%	38%

Q.1 – I found myself getting disorientated in the environment often

Q.2 – I found myself getting lost in the environment often

Q.3 – The controls contributed to me getting lost/disorientated

Q.4 – The configuration effectively helped me avoid getting lost

5.3.5 Scenario Five (2D Map + 2D Compass + Orientation View + Snapshot)

This scenario uses the same configuration of navigation aids but also introduces a new aid, the snapshot tool. Participants were asked Liker-type questions on the usefulness of the snapshot tool for navigating about the virtual environment. The time spent by participants in Scenario five was similar to that of previous scenarios.

Since the scenario was exactly the same as Scenario four with the exception of the snapshot tool we expected participants to find this scenario as effective in

supporting navigation. The descriptive statistics reveal that more than 70% of the participants found the scenario to be effective. Three Likert-type questions were used to evaluate the usefulness of the snapshot tool, the student and expert results are presented in Figure 72 and 73 respectfully.

Q.1 – I found the snapshot tool was very helpful for navigation

Q.2 – I used the snapshot tool to minimize my travel time

Q.3 – I believe the snapshot tool is an effective tool for navigating large environments
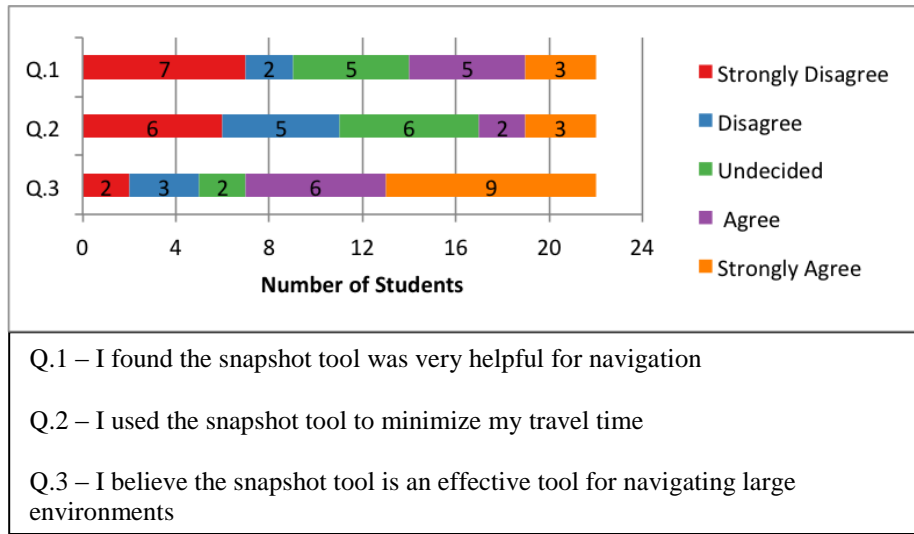
Figure 72: Students' response to the Snapshot tool usefulness Likert-type questions

Q.1 – I found the snapshot tool was very helpful for navigation

Q.2 – I used the snapshot tool to minimize my travel time

Q.3 – I believe the snapshot tool is an effective tool for navigating large environments
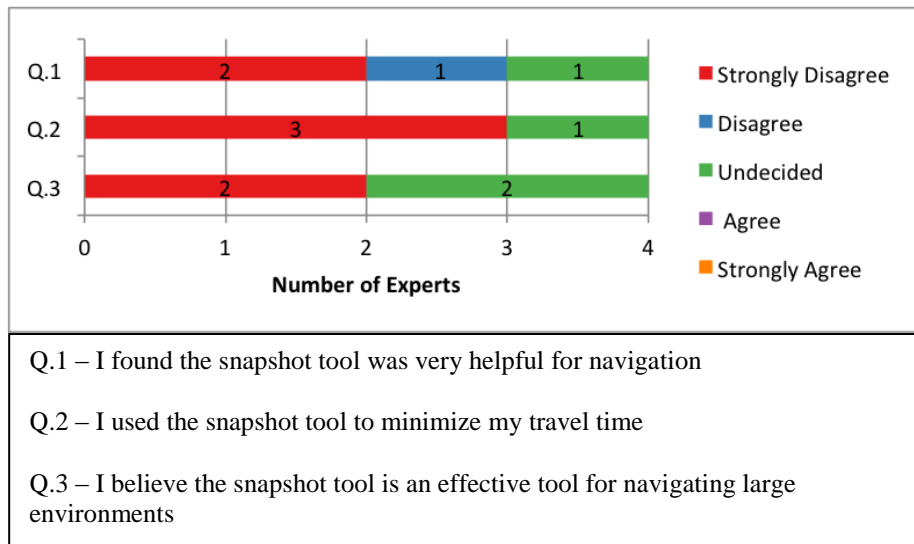
Figure 73: Experts' response to the Snapshot tool usefulness Likert-type questions

We asked the participants three Likert-type questions to assess the usefulness of the snapshot tool. To our dismay we found that 59% of the participants found the tool not helpful or had no feelings toward the tool. In addition 50% of the participants felt the snapshot tool did not minimize their travel time. There are a few reasons why participants most likely had these views. The snapshot tool was designed with a large environment in mind. However, because our virtual environment is scaled (due to visualization purposes mentioned in Chapter 3), participants could travel several kilometers with a single scroll of the mouse. Therefore, the snapshot tool was not very helpful in this smaller environment. If our environment had been scaled to a lesser degree then the snapshot tool would have likely been more helpful in reducing travel time. In fact, many of the participants stated that the tool would serve more purpose in a larger environment in Additional Comment section of the questionnaire.

Moreover, we believe the snapshot tool would be more useful in situations that required the user to travel back and forth between targets or locations of interest. The snapshot could potentially minimize the need for users to manually navigate back and forth between the targets (e.g., take a snapshot at the target locations). Also, in this situation the snapshot tool would also reduce the cognitive effort of the user. For instance, using the snapshot tool would remove the need to remember where and how to travel back to a target or location of interest. While the snapshot tool was not well received by participants in Scenario five, we believe it would provide more use in a larger-scale environment and situations that required users to travel back and forth between targets or locations of interest.

Conclusion and Future Work

The framework created for this research was used to investigate the usefulness of various navigation aids, visual aids and visualization tool. A usability evaluation of the framework was conducted and both qualitative and quantitative data were collected from twenty-six participants (four experts and twenty-two students). Through the usability evaluation we measured the level of agreement of users with the usability of navigation aids such as the 2D compass, 2D radar, 2D maps, bird's eye view, 3D orientation window, and snapshot tool. In addition, we also measured the level of agreement for the usability of visual aids such as a color lookup table, terrain gridlines, and 2D data view.

From the descriptive statistics conducted on the evaluation data, (Chapter 5) we found that some navigation aids were much appreciated (e.g., the 2D map with arrow), while other aids were heavily rejected (e.g., the snapshot tool). In addition, we found that some of the scenario configurations yielded positive user satisfaction, while other scenario configurations were found inefficient or awkward (i.e., the combination of 2D radar and 2D map). The following summarizes some of the results from the usability evaluations:

1. **2D map with you-are-here dot** – More than three quarters of the participants felt this map did a good job of providing spatial information in both Scenario one and Scenario two. The biggest complaint was in regard to the map dot, which most participants agreed lacked the ability to provide a sense of orientation in the world.

2. **2D map with you-are-here arrow** – More than three quarters of the participants felt that this map did a good job of providing spatial information and directional information. Also, more than one third of the participants felt that the 2D map with arrow was more helpful during navigation than the 2D map with you-are-here dot. Most of the additional user comments revealed that the arrow was easy to both understand and use. One participant stated that the arrow removed the guessing game of determining the heading direction experienced when using the 2D map with dot.

3. **2D radar** - Nearly half of the participants indicated that the 2D radar was not really useful in this environment, since the environment was not very large and all of the objects of interest were always visible on the 2D map. The participants also suggested that the combination of a 2D radar and 2D map (with low resolution) does not work well since all objects of interest are visible on the 2D map.

4. **2D compass** – As with the 2D radar, participants stated that the 2D compass was not very useful in this environment. Some participants suggested that because the 2D map was available to them they did not really need to use the 2D compass to navigate.

5. **3D orientation window** – More than a third of the participants felt that the orientation window was not needed for navigation, but more than half of the participants felt it did a good job of displaying their orientation. More than half of the participants were very satisfied with the choice of a 3D boat (non rotationally symmetrical) model to represent the user orientation. One

participant stated that the 3D orientation window was helpful in situations where no visual landmark (terrain or water) was in sight. Other participants mentioned that the orientation window was confusing to understand.

6. **Bird's eye view** – A large number of participants felt that the bird's eye view gave them a better understanding of distance in the environment since they had the ability to see the terrain gridlines from above. Some participants indicated that the bird's eye view was not large enough to help develop spatial awareness, and while others believed it did nothing to help them navigate.

7. **Gridlines** – The draped gridlines were well received by participants. The lines were in place to work as a visual landmark. Some participants strongly felt that the gridlines helped them perceive distance.

8. **2D data view** – from the descriptive statistics, this orthographic view was informative and helped most users understand the relationship between depth and salinity values. However, one third of the participants indicated that they did not understand this view's purpose.

9. **Snapshot tool** – the snapshot was not as helpful as we had hoped. More than 60% of the participants felt that the snapshot tool was better served for larger environments.

From the usability evaluations we were able to gain insight on the participants in the evaluation. We found that some navigation aid combinations, such as the combination of a 2D map and a 2D radar or 2D compass were not very well accepted by participants. The critical comments from the participants reveal that it was not

necessary to have additional navigation aids such as the 2D radar and 2D compass if all the objects of interest are visible on the 2D map.

As stated in Chapter 5, the lack of user need for the 2D radar and 2D compass is likely due to the testing configuration. For instance, had the data set been further out from shore (e.g., in the middle of the Atlantic ocean) it is very likely that the 2D map alone would not be as helpful. In this scenario, having additional navigation aids such a compass (for sense of direction) and orientation window (sense of orientation) could potentially be very useful in combination with the 2D map.

In addition, several participants expressed that the GUI was too cluttered and at times distracting. However, from the usability evaluation we did find that minor modifications, such as replacing the you-are-here dot with a you-are-here arrow and providing external views (bird's eye view) resulted in positive user feedback.

We would like to present some improvements and modifications that can or should be made to help strengthen the analysis of the various navigation and visual aids.

1. **Demographics** – We would like to carry out a usability evaluation using a larger number of experts in the field of geospatial sciences. Our research was very biased, since our demographics included many more students than experts. We would like to get more feedback on the usefulness of navigation aids from experts. In addition, we would also like to carry out a usability evaluation with students from the environmental sciences. Testing students who are familiar to geovisualization concepts, such as analyzing and

comparing attributes, which would allow us to create navigational tasks more related two gaining insight on the data.

2. **Quantitative testing** – Due to time constraints, we were not able to create adaptive controls—controls that adjust to specific system and hardware configurations. Therefore, we avoided defining quantitative metrics such as *task completion time*—the time it takes users to complete a task. However, we do have the ability to collect quantitative data on the user such as the time spent by users in the environment, their positions over time, and GUI interactions (number of times user interacts with a component). In future stages, we would like to collect quantitative data such as completion times, and evaluate the data using quantitative statistical procedures to further evaluate the usefulness and effectiveness the navigation and visual aids.

Appendix A

A.1 Demographics Questionnaire

1. What is your gender?

   ☐ Male
   ☐ Female

2. What is your age? _____

3. On average, how many hours per week do you spend using computers?

   ☐ 0 – 1
   ☐ 2 – 5
   ☐ 5- 10
   ☐ 11 or more

4. Are you familiar with any of the following geographic visualization tool? If so, select the ones that apply. You can use the *other* option to add other geovisualization tools you are familiar with:

   ☐ Google Earth
   ☐ Google Maps
   ☐ COVE
   ☐ Fledermaus
   ☐ Other:

If you answered Question 4, please answer the following questions:

   4.1 What is your level of experience with the visualization tool you know most:

   ☐ Novice
   ☐ Regular user
   ☐ Advanced user
   ☐ Expert

4.2 If the tool you know the most allows for user navigation (i.e., navigating a map or virtual world) which of the following user control / controls are predominately used:

☐ Mouse
☐ Keyboard
☐ Mouse and keyboard combination
☐ Other: _____

5. Do you have experience playing video games? If so, select the game genres that you have experience with:

☐ First-person shooters (FPS)
☐ Side-scrolling games
☐ Simulator games
☐ Role-playing games (RPG)
☐ Other:

If you answered Question 5, please answer the following questions:

5.1 What is your level of expertise with video games; select the option that best applies to you:

☐ Non-gamer
☐ Casual gamer
☐ Regular gamer
☐ Expert gamer

5.2 On average, how many hours per week do you spend playing video games?

☐ 0 – 1
☐ 2 – 5
☐ 5- 10
☐ 11 or more

5.3 What type of console do you most play on; select the option that best suits you:

☐ Home console (Xbox, PlayStation, Wii)
☐ Mobile device
☐ PC

LIST OF REFERENCES

[1] "How much water is on, in, and above the Earth?" 14 Mar. 2014. U.S Geological Survey (USGS). 18 Mar. 2014. < http://water.usgs.gov/edu/earthhowmuch.html>.

[2] Bowman, D., Davis, D., Hodges, L., and Badre, A., "Maintaining Spatial Orientation During Travel in an Immersive Virtual Environment," in *Presence: Teleoperators and Virtual Environments*, vol. 8, no. 6, pp. 618–631, 1999.

[3] Darken, R., Allard, T., and Achille, L., "Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces: An Introduction," in *Presence: Teleoperators and Virtual Environments*, vol. 7, no. 2, pp. 101–107, 1998.

[4] Darken, R., and Cevik, H., "Map Usage in Virtual Environments: Orientation Issues," in *Proceedings of IEEE Virtual Reality,* Houston, Texas, 13 − 17 March, 1999, pp. 133–140.

[5] Poupyrev, I., Weghorst, S., Billinghurst, M., and Ichikawa, T., "A Framework and Testbed for Studying Manipulation Techniques for Immersive VR," in *Proceedings of the ACM symposium on Virtual Reality Software and Technology*, Lausanne, Switzerland, 15 − 17 September, 1997, pp. 21–28.

[6] Chittaro, L., and Burigat, S., "3D Location-Pointing as a Navigation Aid in Virtual Environments," in *Proceedings of the Working Conference on Advanced Visual Interfaces*, Gallipoli (Lecce), Italy, 25 − 28 May, 2004, pp. 267–274.

[7] Medina, D., Moline, M., Clark, C., and Wood, Z., "Real-Time Visualizations of Ocean Data Collected by the NORUS Glider in Svalbad, Norway," in *Proceedings of the International Offshore and Polar Engineering Conference,* Maui, Hawaii, 19–24 June, 2011, pp. 870 – 875.

[8] Woronuk, D. *Investigating 3D Geovisualization for Fire Incident Command.* Diss. Texas State University, 2008.

[9] Grochow, K. *COVE: A Visual Environment for Multidisciplinary Ocean Science Collaboration*. Diss. University of Washington, 2011.

[10] Dykes, J., MacEachren, A.M., and Kraak, M.-J. *Exploring Geovisualization*, Chapter 29: Exploring Geovisualization, San Diego: Elsevier, 2005.

[11] Bleisch, S. "3D Geovisualization – Definition and Structures for the Assessment of Usefulness." In: *International Society for Photogrammetry. Remote Sensing and Spatial Information Sciences*, Melbourne, Australia, 25 August – 01 September. 2012. pp. 129–134.

[12] Stanney, K., Mourant, R., and Kennedy, R. "Human Factors Issues in Virtual Environments: A Review of the Literature." Presence: Teleoperators and Virtual Environments, vol. 7, no. 4, pp. 327–351, 1998.

[13] Minocha, S., and Hard, C., "Designing Navigation and Wayfinding in 3D Virtual Learning Spaces," in *Proceedings of the 23rd Australian Computer-Human Interaction Conference*, Melbourne, Australia, 23–27 November, 2009, pp. 211–220.

[14] Wolbers, T., and Hegarty, M. "What Determines Our Navigational Abilities?" Trends in Cognitive Sciences, vol. 14, no. 3, pp. 138–146, 2010.

[15] Elmqvist, N., Tudoreanu, M., and Tsigas, P., "Evaluating Motion Constraints for 3D Wayfinding in Immersive and Desktop Virtual Environments," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Florence, Italy, 05–10 April, 2008, pp. 267–274.

[16] Ware, C., *Information Visualization*, Chapter 1: Foundations for an Applied Science of Data Visualization, Waltham, MA: Morgan Kaufmann, 2013.

[17] "Unity - Game Engine." n.d. Unity Technologies. 05 March. 2014. <http://unity3d.com>

[18] "Makai Voyager." n.d. Makai Ocean Engineering, Inc. 10 February. 2014. <http://voyager.makai.com>

[19] "Fledermaus." n.d. QPS Hydrographic and Marine Software Solutions. 15 February 2014. <http://www.qps.nl/display/fledermaus/main>

[20] "Ocean Explorer." 11 February. 2014. Ocean Explorer NOAA. 02 March. 2014. <http://oceanexplorer.noaa.gov/explorations/11midatlantic/background/seafloormapping/media/seafloormapping_fig2.html>

[21] Shneiderman, B., *Designing the User Interface,* Boston, MA: Addison Wesley, 2004.

[22] "Exploring Ocean Data with Google Earth." 10 February. 2011. The Science Education Resource Center at Carleton College. 15 March. 2014. <http://serc.carleton.edu/eyesinthesky2/week12/ocean_data_google_earth.html>

[23] "What Are Autonomous Underwater Vehicles?" n.d. Marine-Knowledge. 20 March. 2013. <http://www.marine-knowledge.com/ocean_engineering/what-are-autonomous-underwater-vehicles.html>

[24] OpenStreeMap. n.d. OpenStreetMap. 20 March. 2013. <http://www.openstreetmap.org/>

[25] Boone, H., Boone, D., "Analyzing Likert Data," in *Journal of Extension*, vol. 50, no. 2, 2012. 02 Mar. 2007 <http://www.joe.org/joe/2012april/tt2.php>.

[26] Bowman, D., Kruijff, E., LaViola, J., Poupyrev, I., *3D User Interactions: Theory and Practice*, Boston, MA: Addison-Wesley, 2005.

[27] Bertram, D., "Likert Scales", Online posting. n.d. CPSC 681 – Topic Report. 15

Mar. 2014. <http://www.al-huda.net/2012/PA/2014/topic-dane-likert.pdf>

[28] "Direct Mapping". 2004–2010. Mapping European Seabed Habits. 10 April. 2014

<http://www.searchmesh.net/default.aspx?page=1763>

BIBLIOGRAPHY

Bertram, D., "Likert Scales", Online posting. n.d. CPSC 681 – Topic Report. 15 Mar. 2014. <http://www.al-huda.net/2012/PA/2014/topic-dane-likert.pdf>

Bleisch, S. "3D Geovisualization – Definition and Structures for the Assessment of Usefulness." In: *International Society for Photogrammetry. Remote Sensing and Spatial Information Sciences*, Melbourne, Australia, 25 August – 01 September. 2012. pp. 129–134.

Boone, H., Boone, D., "Analyzing Likert Data," in *Journal of Extension*, vol. 50, no. 2, 2012. 02 Mar. 2007 <http://www.joe.org/joe/2012april/tt2.php>.

Bowman, D., Davis, D., Hodges, L., and Badre, A., "Maintaining Spatial Orientation During Travel in an Immersive Virtual Environment," in *Presence: Teleoperators and Virtual Environments*, vol. 8, no. 6, pp. 618–631, 1999.

Bowman, D., Kruijff, E., LaViola, J., Poupyrev, I., *3D User Interactions: Theory and Practice*, Boston, MA: Addison-Wesley, 2005.

Chittaro, L., and Burigat, S., "3D Location-Pointing as a Navigation Aid in Virtual Environments," in *Proceedings of the Working Conference on Advanced Visual Interfaces*, Gallipoli (Lecce), Italy, 25 – 28 May, 2004, pp. 267–274.

Darken, R., Allard, T., and Achille, L., "Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces: An Introduction," in *Presence: Teleoperators and Virtual Environments*, vol. 7, no. 2, pp. 101–107, 1998.

Darken, R., and Cevik, H., "Map Usage in Virtual Environments: Orientation Issues," in *Proceedings of IEEE Virtual Reality,* Houston, Texas, 13 – 17 March, 1999, pp. 133–140.

"Direct Mapping". 2004–2010. Mapping European Seabed Habits. 10 April. 2014 <http://www.searchmesh.net/default.aspx?page=1763>

Dykes, J., MacEachren, A.M., and Kraak, M.-J. *Exploring Geovisualization*, Chapter 29: Exploring Geovisualization, San Diego: Elsevier, 2005.

Elmqvist, N., Tudoreanu, M., and Tsigas, P., "Evaluating Motion Constraints for 3D Wayfinding in Immersive and Desktop Virtual Environments," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Florence, Italy, 05–10 April, 2008, pp. 267–274.

"Exploring Ocean Data with Google Earth." 10 February. 2011. The Science Education Resource Center at Carleton College. 15 March. 2014. <http://serc.carleton.edu/eyesinthesky2/week12/ocean_data_google_earth.html>

"Fledermaus." n.d. QPS Hydrographic and Marine Software Solutions. 15 February 2014. <http://www.qps.nl/display/fledermaus/main>.

Grochow, K. *COVE: A Visual Environment for Multidisciplinary Ocean Science Collaboration*. Diss. University of Washington, 2011.

"How much water is on, in, and above the Earth?" 14 Mar. 2014. U.S Geological Survey (USGS). 18 Mar. 2014. < http://water.usgs.gov/edu/earthhowmuch.html>.

"Makai Voyager." n.d. Makai Ocean Engineering, Inc. 10 February. 2014. <http://voyager.makai.com>.

Medina, D., Moline, M., Clark, C., and Wood, Z., "Real-Time Visualizations of Ocean Data Collected by the NORUS Glider in Svalbad, Norway," in *Proceedings of the International Offshore and Polar Engineering Conference,* Maui, Hawaii, 19–24 June, 2011, pp. 870 – 875.

Minocha, S., and Hard, C., "Designing Navigation and Wayfinding in 3D Virtual Learning Spaces," in *Proceedings of the 23rd Australian Computer-Human Interaction Conference*, Melbourne, Australia, 23–27 November, 2009, pp. 211–220.

"Ocean Explorer." 11 February. 2014. Ocean Explorer NOAA. 02 March. 2014. <http://oceanexplorer.noaa.gov/explorations/11midatlantic/background/seafloormapping/media/seafloormapping_fig2.html>.

OpenStreeMap. n.d. OpenStreetMap. 20 March. 2013. <http://www.openstreetmap.org/>.

Poupyrev, I., Weghorst, S., Billinghurst, M., and Ichikawa, T., "A Framework and Testbed for Studying Manipulation Techniques for Immersive VR," in *Proceedings of the ACM symposium on Virtual Reality Software and Technology*, Lausanne, Switzerland, 15 – 17 September, 1997, pp. 21–28.

Shneiderman, B., *Designing the User Interface,* Boston, MA: Addison Wesley, 2004.

Stanney, K., Mourant, R., and Kennedy, R. "Human Factors Issues in Virtual Environments: A Review of the Literature." Presence: Teleoperators and Virtual Environments, vol. 7, no. 4, pp. 327–351, 1998.

"Unity - Game Engine." n.d. Unity Technologies. 05 March. 2014. <http://unity3d.com>.

Ware, C., *Information Visualization*, Chapter 1: Foundations for an Applied Science of Data Visualization, Waltham, MA: Morgan Kaufmann, 2013.

"What Are Autonomous Underwater Vehicles?" n.d. Marine-Knowledge. 20 March.

2013. <http://www.marine-knowledge.com/ocean_engineering/what-are-autonomous-

underwater-vehicles.html>.

Wolbers, T., and Hegarty, M. "What Determines Our Navigational Abilities?" Trends

in Cognitive Sciences, vol. 14, no. 3, pp. 138–146, 2010.

Woronuk, D. *Investigating 3D Geovisualization for Fire Incident Command.* Diss.

Texas State University, 2008.