The Design and Validation of Virtual Trailblazing and Guidance Interfaces for the VTrail System

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Systems Design Engineering

Waterloo, Ontario, Canada, 2009

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Wayfinding is a complex skill and the lack of tools supporting the specific sub-types of navigation hinders performance in large-scale virtual environments and consequently can slow the adoption of virtual technology for training. The VTrail System is designed to support virtual training by providing trainers (trailblazers) with the ability to create trails to guide users (trail followers) during training simulations. Without an effective interface to assist with creating trails, the task of trailblazing remains difficult.

The objective of this research was to design a default interface for the VTrail System that adheres to the basic human factors engineering guidelines of simplicity, universality, and that does not interfere with primary task performance. Two studies (trailblazing, trail following), with a total of four experiments, were performed to evaluate and modify the proposed interfaces. The first experiments in each study determined that the proposed default interfaces are simple enough to use so as to not interfere with primary task performance. The second set of experiments found that, aside from the interface components included in the default interface, novice trailblazers and trail followers did not make use of any additional wayfinding aids when users were provided with the ability to create a custom interface.

Secondary benefits included; the development of a novel approach for measuring spatial knowledge acquisition (called the SKAT), a set of criteria for qualitative analysis of trail quality in the form of the Trail Quality Questionnaire (referred to as TQQ), and improved understanding of the role individual differences, such as gender and spatial ability, in wayfinding performance. The high correlation between spatial ability score and performance on the SKAT suggests that the test provides a valid means of measuring spatial knowledge acquisition in a virtual environment. A measurable difference in the trail quality between males and females indicates that the TQQ can distinguish

between trails of variable quality. Finally, there are measurable gender performance differences, despite similar levels in spatial ability between the genders.

With the proposed interface designs the VTrail is closer to being ready to be incorporated as a support tool into virtual training programs. In addition, the designs for the VTrail System can be adapted for other platforms to support trailblazing in a range of applications, from use in military operations to providing an enhanced tourism experience. This research also serves as a starting point for future research projects on topics ranging from improving the design of the SKAT measure to understanding the effect of expertise on trailblazing performance.

Acknowledgements

I would like to acknowledge the support and guidance provide while completing this thesis. First I would like to thank DRDC-Toronto and the Ontario Centres of Excellence for partnering and supporting this research.

I would like to all the members of the examination committee (Dr. Paul Calamai, Dr. Paul Ellard, Dr. Stacy Scott, and Dr. Avi Parush) for their feedback during the comprehensive and defense examinations.

I would like to thank all the members, graduate and co-op students of the Usability and Interactive Technology (Use-IT) lab for their assistance in setting up and running the experiments, as well as Jim Wallace for volunteering to be a Trail Quality Evaluator.

Finally, I need to thank Dr. Carolyn MacGregor for providing support during this research project. I was provided the freedom to blaze my own trail, but provided with enough guidance so as to not get lost.

Dedication

This thesis is dedicated to Jenny who provided encouragement and support during my time in graduate school.

I would also like to dedicate this work to all the friends and family that did not pressure me too often to finish up quickly and get a “real” job.

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Chapter 1 Introduction

Virtual environments (VE) are computer-simulated worlds, existing and non-existing, that support user interaction (e.g. object manipulation, navigation) and provide appropriate feedback (e.g. visual, audio, tactile). Perhaps the greatest motivation for the development of VE's is the potential for training for situations where it is considered dangerous (e.g. bomb disposal), unethical (e.g. practicing surgery), or cost prohibitive (e.g. flight simulators). For example, Defense Research and Development Canada (DRDC) is currently developing large-scale virtual systems to be used for the training of military personnel for ground operations.

The creation of increasingly complex and large-scale virtual environments can affect the navigational performance of users (O'Neil, 1991). Furthermore, navigation in virtual environments is considered more challenging than in the real world due to the lack of visual depth cues and kinesthetic cues, as well as poor navigational interfaces (Satalich, 1995). As a result, the encoding of spatial information can impact performance on secondary tasks. (Meilinger, Knauff, & Bülthoff, 2008)

Addressing the navigation concerns is vital since navigation is rarely the primary task in the VE. Navigation is commonly performed to support the completion of other tasks. For example, in most 3D games the player has a quest to complete. Completion of the quest requires navigation to one destination and then finding the way back or to another location. If the navigation is not intuitive and nontrivial then the player may become distracted or frustrated. The fact that navigation in the context of video games and training environments is considered a secondary task increases the need to develop improved, usable techniques. Navigation techniques should be intuitive to reduce the cognitive demands so that the user can direct his attention and decision-making to the tasks of identifying when to change direction or in planning a path to a desired location.

To aid in creating more effective virtual training environments, the Usability and Interactive Technology (Use-IT) Lab at the University of Waterloo partnered with Defence Research and Development Canada (DRDC-Toronto) to develop a tool to support wayfinding in military training applications. The resulting concept is entitled the VTrail System. The objective of the VTrail System is to serve as a trailblazing tool by providing users with a means of adding information into the VE to aid with navigation. The specific task of trailblazing is not mentioned in the available navigation research literature; however the paths generated as a result of trailblazing are shown to improve navigation through multi-layered websites (Lida-Roger & Chaparro, 2003), and complex VE's (Ruddle, 2004). Thus, a tool designed specifically to improve trailblazing should lead to improved navigation performance.

The design and development of the VTrail System has progressed on two fronts. One front has focused on the design of the 3D directional markers (Iaboni, 2005). On the second development front, a prototype of the VTrail System software (a third-party application) was created. The first prototype of the VTrail System software allowed for the addition of virtual 3D markers into an existing, commercially available 3D game engine (Hause et al., 2006). By intercepting graphic commands from the game, adding the VTrail information into the game environment, and sending the enhanced commands to be rendered and displayed, a user can drop 3D markers to mark a path through the game environment, and then revisit those markers on subsequent journeys through the environment (provided the session has been saved). As a third-party application, the VTrail System allows for the marking of customized routes in any existing virtual environment or 3D simulation without having to add additional code of patches to the host VE program. Since the VTrail prototype was developed as a proof-of-concept for the "marker overlay" technique, the adding and dropping of markers was done through cryptic software commands. As such, the existing VTrail System prototype lacks an appropriate user interface that allows the user to easily add, manipulate and remove virtual markers. As part of the investigation into what would constitute an appropriate user-interface for trailblazing it became apparent that there is little in the way of fundamental or applied research that suggests the best way to display and support virtual trailblazing options to a user.

1.1 Research Objective

The primary objective of this research project was the design and validation of a standard interface for the use of VTrail System in an environment analogous to the real word by applying an experimental approach to establish the necessary components to aid tasks associated with virtual trailblazing. This objective was accomplished by: (1) finding out which features or tools a trailblazer and trail follower needs to perform the task effectively; (2) determining the design of the desired features to be implemented in what will be considered the standard (or default) interface; and (3) exploring the impact individual differences, such as gender and spatial ability may have on performance with specific interface components – and that may need to then be taken into account for final designs.

1.2 Application of Research

The primary application of the results from this research is the creation of a third-party wayfinding aid, the VTrail System, to be used in the current training simulators used by DRDC. However, the development of this tool is not restricted to military training applications. The VTrail System has potential to be used in two different domains, VE's, and augmented reality (AR).

The VTrail Systems is being developed as a training enhancement for a DRDC-Toronto developed VE platform called Virtual Navigation and Collaboration Platform (VNCEP). However, the VTrail System has the potential to be used in a variety of VE applications and development platforms. In the design of complex systems or buildings, virtual trailblazers can mark a path through the environment for demonstrations, virtual tours, or include notes or signs in the environment. In the entertainment industry, the VTrail can be used as a third party application to share information among players in a massive multiplayer online game (MMOG).

As a third-party application, the VTrail System will be able to provide enhanced guidance in existing complex VE's and simulations. Current navigation enhancement tools for VE's must be built into the software architecture. The VTrail System can overlay marker information on top of the environment without needing access to the original source code.

Although beyond the scope of this research project, it is worth mentioning that the deployment of the VTrail System need not be restricted to purely virtual environments, but could also be an asset in the real world if the VTrail System were to be implemented on an augmented reality platform. Augmented reality (AR) is the overlaying of computer-generated information over the real world through a head mounted display (HMD). The VTrail would be useful for military operations, search and rescue, emergency rescue, building evacuation, and tourism. However, before the VTrail System could be moved to an AR application it is critical that the user interface be carefully designed so as not to negatively impact on the primary task.

In addition to the specific user interface design aspects involved in this research project, the experimentation aspects of this research contributes to the understanding of how humans trailblaze (mark paths of interest for revisiting or for others to follow in VEs) and the user interface components needed to support such activities. The thought process a trailblazer goes through when creating a trail is not well understood. Should paths be created based on the expectations of the trailblazer or the expectations of the path follower? What are the tools necessary to perform a trailblazing task? Answering these questions will aid in the future design of trailblazing systems for environments not analogous to the real world.

1.3 Document Structure

Following this chapter this research document is structured as follows:

Chapter 2: Explores the concept of navigation and wayfinding and explores the role of trailblazing and guidance.

Chapter 3: Examines the current set of tools provided to support trailblazing in the real and virtual worlds. A discussion of limitations of current approaches is included.

Chapter 4: Explains the current state of the VTrail System and describe the design guidelines and process. An explanation for the design of the default VTrail interface and individual interface components is provided.

Chapter 5: Introduces the topic of trail quality and current approaches to evaluating trail quality. A set of criteria for qualitatively evaluating trail quality from a user perspective is proposed.

Chapter 6: Describes the experimental setup and results from a user study focused on the design of the VTrail trailblazer interface. The study consisted of two experiments and the implications of the experimental results on the interface design are discussed.

Chapter 7: Describes the experimental setup and results from the user trials focused on the design of the VTrail trail follower interface. The study consisted of two experiments and the implications of the experimental results on the interface design are discussed.

Chapter 8: Discusses some of the secondary results discovered in the process of completing the primary research objective.

Chapter 9: Summarizes the results of the interface validation studies and additional secondary results stemming from the research and proposes a set of future studies to expand on the results.

Chapter 2
Navigation, Wayfinding & Trailblazing

Navigation is the general term that is applied to any scenario in which a path is planned and then results in movement from one location to another. Because the term "navigation" can be applied to any "movement" from one location to another there is a hierarchy of navigation types, shown in Figure 1. Dourish and Chalmers (1994) identify three types of navigation: semantic (hypertext links on web pages that connect related information), social (a path marked by footprints, a tabbed page in a book) and spatial (body movements through space). Spatial navigation is the most common form of navigation and the most relevant for this research since spatial navigation involves body movement through space. For example, reaching for a book on the shelf is one form of spatial navigation as is moving from room A to room B. For the remainder of this proposal the only aspect of spatial navigation that will be considered is the movement or the perception of movement of the entire body, or viewpoint, through an environment.

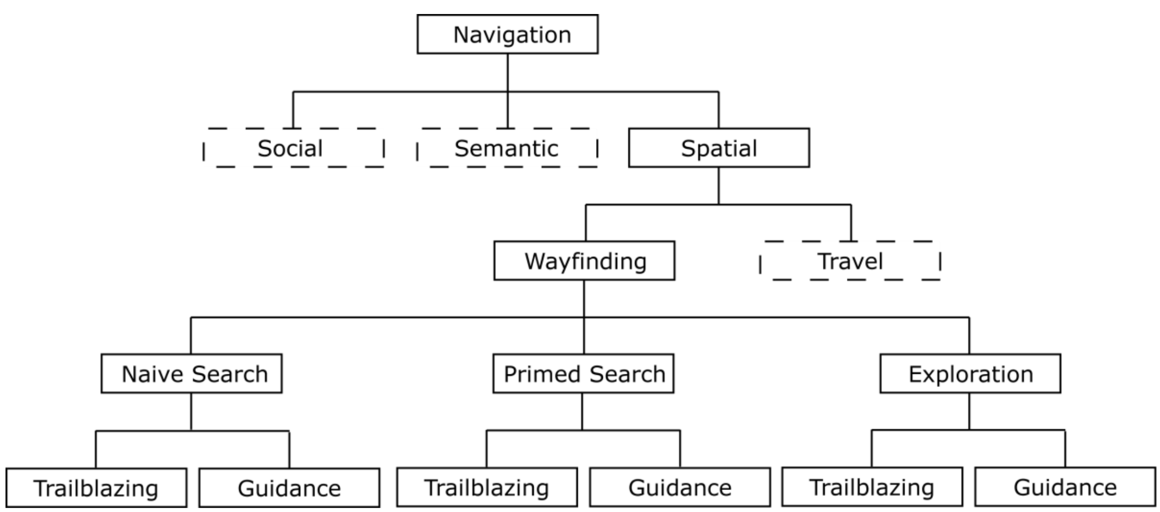

Figure 1: Breakdown of navigation task into possible sub-tasks.

Spatial navigation consists of travel and wayfinding (Bowman, Koller & Hodges, 1998). Travel, sometimes referred to as viewpoint motion control in the VE literature, is the movement of the individual's viewpoint through a 3D environment. Wayfinding is the cognitive process of determining the current location, selecting the final destination and planning a path to reach the goal. Wayfinding can be further broken down into three different types: naïve search, primed search and exploration (Darken & Sibert, 1996). A naïve search involves the individual conducting a search for an object or location with no prior knowledge of the area. In a primed search the individual has familiarity with regards to the approximate location of the target. In exploration the individual is wayfinding solely for the purpose of achieving familiarity with the surroundings. A given search and navigation task may require a combination of wayfinding behaviours. The individual may perform a primed search to narrow the possible location to a smaller region, and then perform a naïve search of the area to find the target. Search tasks can be improved by providing wayfinders with tools that support trailblazing (marking one's own path) or guidance (following someone else's path)

2.1 Trailblazing & Guidance

Simply stated, trailblazing is the act of leaving directional information in the environment. The manner in which that information is utilized determines if trailblazing is the primary or secondary task. If the trailblazer is leaving information so that others following will be able to effectively navigate the environment then the primary objective of the wayfinder is the creation of an easy to follow path. However, if the trailblazer is adding the information into the environment to aid in his own search of the environment by marking areas already explored, then trailblazing is serving a secondary function as a search tool. Ruddle (2005) found that use of paths in VE's reduced the time required to perform a naïve search. The objective of the trailblazing task will influence the manner in which a trailblazing tool is utilized. As seen among real world indigenous cultures (e.g. the Inuit), trailblazing is primarily performed to aid with seasonal migration and link remote communities

(Aporta, 2002). However, trailblazing can be a useful tool when searching or exploring an environment. The user can use a trailblazing tool to mark areas or paths previously explored and avoid retracing steps. Regardless if trailblazing is the primary or secondary wayfinding function, there are always two roles, the trail creator (trailblazer) and the trail follower. When trailblazing is the primary function then the trailblazer will create the path for others, whereas the trailblazer is often both the path creator and follower when trailblazing is performed as a secondary task. Each role has a unique set of challenges.

2.1.1 The Role of the Trailblazer

The trailblazer is responsible for adding the information into the world that will be used either by himself or others to aid in wayfinding. The challenge to the trailblazer is in deciding upon where exactly to place the marker, determining the information to be conveyed by the marker and then configuring the marker to reflect the trailblazer's decisions.

The primary responsibility of the trailblazer is to decide where and when to place markers to provide information to anyone that may be following the path. The trailblazer must decide if he will be dropping markers at regular distance intervals, or only at points where the direction of travel changes. Ruddle (2005) found that the accumulation of paths in an environment results in significant confusion and delays in path following for subsequent followers. So the frequency at which markers are placed must be moderate, but not so low as to make it difficult to locate and track the desired path. Furthermore, the physical characteristics and placement of the marker can affect the detection of the marker by the followers. For example, if the colour of the marker is similar in colour tone or hue as elements in the background then detection of the marker is likely to be slowed or compromised. Placing a marker above line of sight (approx 1.5m from the ground) may also hinder chances of detection.

Once the trailblazer selects a location for placing a marker he needs to determine the information to be conveyed by the marker. The marker may indicate a direction of travel or provide other information. For example, the trailblazer may want to bring attention to a feature in the environment, such as a landmark, or warn of danger in the area. The type of information to convey will affect the configuration and possibly other characteristics of the marker (e.g. bright red or flashing markers to serve as alerts to dangerous areas).

In the real world, there is a limited set of culturally acceptable signage that is used to convey travel guidance and advisory information; and yet within that set there is some room for variation so that guidance signs can be customized to direct a traveler to a particular destination. Likewise, the trailblazer may use multiple configurations of the same marker or a variety of marker designs to convey specific guidance or advisory information within a virtual world. One configuration may suggest a direction of travel while another may mark a path to avoid. There may be a single type of marker for default use, a standard set of markers for typical situations, and other markers that can be customized to suit the individual needs of the trailblazer.

Figure 2 expands upon Figure 1 by providing a breakdown of the sub-tasks associated within the trailblazing role. These sub-tasks will have to be taken into account when designing the VTrail user interface.

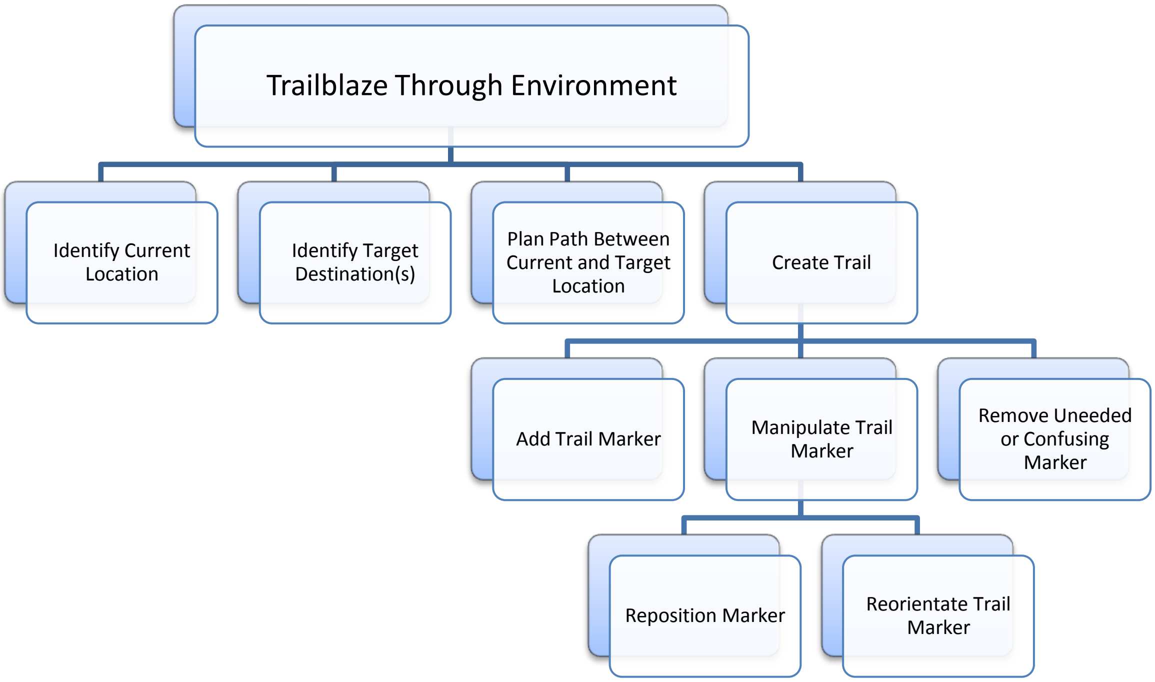

Figure 2: Task analysis of a trailblazing task

2.1.2 The Role of the Trail Follower

When following a marked path or trail through an environment the user is now performing a guidance task, and the design of a trailblazing tool needs to take into consideration the challenges of a guidance task: cue detection, cue comprehension and spatial learning.

The path created by the trailblazer is not a continuous, unbroken path but a discrete set of markers positioned to represent changes in directions. It is the responsibility of the trail follower to detect the markers and make adjustments to his heading, and direction of travel accordingly. Failure to detect the cue can mislead the follower far off the path and make it difficult to find a way back on course. Successful cue detection is influenced by the placement of the cue by the trailblazer, cue design and successful signal detection by the follower.

Once the cue is detected, the follower must also be able to comprehend the information represented by the marker. Steiner and Voruganti (2004) found that cues, such as signs, agents and paths, are easily interpreted as providing guidance information. In addition to recognizing the general intent of the marker the user must accurately comprehend and be prepared to act upon the information presented by the marker. If the marker indicates a change in heading then the follower needs to correctly interpret the new heading and adjust accordingly. Incorrect headings of a few degrees can lead to a significant difference off course if travel is continued in that direction for a long distance.

Depending on the environmental conditions, the trail follower may need to assume the role of trailblazer. In changing, dynamic, environments a path marked at one point in time may no longer be viable at a later point in time. For example, a path created through the arctic tundra can be easily erased by the snow and wind. So the users of the trail must not be too reliant on a specific path to provide a means of wayfinding through the environment. Thus, inukshuks, or stone cairns, that are built to be visible across the tundra can allow travelers to maintain general travel directions without relying on a specific path.

Chapter 3
Current Trailblazing Tools

While there is a range of tools designed to aid with wayfinding (signage, maps, compasses and Global Positioning Systems), there are few tools specifically designed to support trailblazing in VEs. A search of the literature found only 2 tools, MaPS (Movement and Planning Support) (Edwards & Hands, 1997) and Virtual Prints (Grammenos et al., 2002, 2006). Furthermore, Edwards and Hand (1997) fail to discuss the trailblazing techniques employed, and no further elaboration of the MaPS technique is available in the literature. Thus the design of the VTrail System will be influenced by the array of tools currently used in real world wayfinding, and the few tools that are used in virtual trailblazing.

3.1 Signage

One way of putting information into the world is through the design of graphic signage. In the context of navigation, a sign is a two dimensional display that provides someone with information pertaining to a particular place or thing. Signs need to be context specific so they can vary in terms of form, meaning, color, texture, and content. In unfamiliar settings signage must provide enough information to help the user make decisions, execute the decisions, and identify destinations (Arthur & Passini, 2002).

The primary role of signage is to provide orientation information. Signage designed to assist in the decision making process can provide information about the organization of the setting, the current location of the user, and the location of the destination. Examples of this type of signage include "You Are Here" maps, and floor plans. To help individuals execute navigational decisions, signage can provide directional information or guide people along a route to the destination. Examples of this type of signage include signs with arrows or use of coloured lines on the walls or floors. Finally signs should help the users identify when they have reached the destination. Signs that identify the location, either through plain-language, or pictograph, or provide warnings about hazards are examples of feedback that allows the user to assess the outcome of the decision making process.

3.2 Maps

A map is a symbolic representation of a space and provides insights into the relationships between components in that space. Typically a map is a 2D re-creation of a 3D space, however the use of computers now allows for the creation of 3D maps. The oldest known map can be found in Turkey and dates back to 6300 B.C. Despite being a part of human culture for over 8000 years map design and usage continues to be a common problem.

The challenge to cartographers is creating easy to understand 2D representation of a 3D world; and the challenge for the user is interpreting the information that is presented in a 2D exocentric perspective but is experienced in a 3D egocentric perspective. Furthermore, the process of encoding the map information into the cognitive map results in two degrees of separation between the map user's mental model and the actual environment, as illustrated by Figure 3. Consequently, the user's expectations of what will be experienced based on the map may vary greatly from what will actually be experienced in the real world. In addition, thousands of individuals with differing levels of map usage experience and each with a different navigational goal can end up using the same map, as is the case with street maps of large metropolitan cities. A cartographer cannot possibly predict all the manners in which the map will be used, so the cartographer must rely on general map design principles.

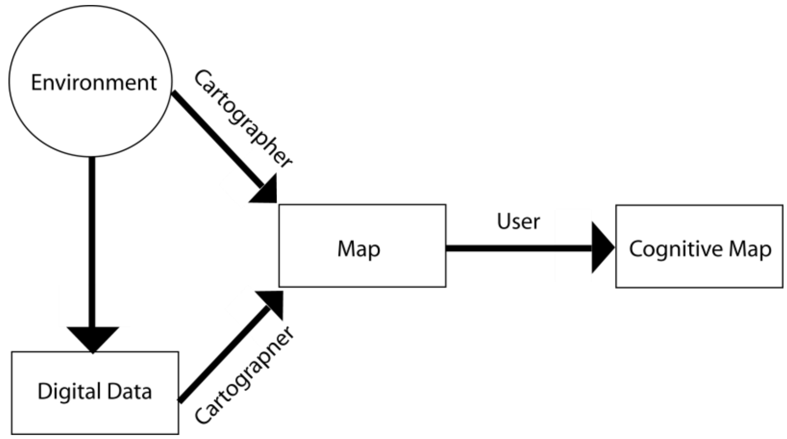

Figure 3: Representation of stages of information transfer from environment to cognitive map when learning from a map ***(Adapted from Figure 6.1: The cartographic communication process. Lloyd (2000), Understanding and learning maps in Cognitive Mapping: Past, present, and future. New York: Rutledge, p. 85.)***

While map design principles are the result of an accumulated body of research into human reading and perception, maps are now transitioning into a new medium where traditional design guidelines may no longer be valid. Laakso (2002) compared the usability of 3D maps to traditional 2D maps. While users preferred the appeal and uniqueness of the 3D maps, performance was significantly better with 2D maps which people are more comfortable using due to familiarity. Determining the acceptable design guidelines becomes more important as maps transition into new mediums

3.3 Compass

Using only a compass an expert wayfinder can successfully navigate to a desired location and back provided he keeps accurate track of the distance travelled and magnetic bearing. The usefulness of the compass is increased when used in conjunction with a map. Combining a compass with a map allows for position tracking and terrain prediction. However, since most maps are drawn based on true bearings, the compass user must account for the difference between true bearings and magnetic bearings. Accurate use of a compass requires training, so most modern navigational aids are preset to account for declination (the angle resulting from the difference between magnetic north and true north) and provide the heading in a digital format.

3.4 Global Positioning System

The Global Positioning System, originating in the 1970’s, consists of a constellation of geosynchronous satellites that provide up-to-date positioning information anywhere on Earth. By integrating GPS with Geographical Information Systems (GIS) on mobile units (cell phones, laptops, personal digital assistants, on-vehicle systems), a wayfinder can track travel progress in real-time. The majority of the GPS units are designed for use within a vehicle. However there are some models that support off-road navigation for cyclists, hikers and other wilderness related activities. GPS has some technical drawbacks in that the satellite signal can be affected by atmospheric conditions and humidity. For triangulation of location to occur, the GPS receiver must also be in line-of-sight (LOS) of at least 3 satellites (4 satellites for accurate results). This means that GPS will not work in-buildings, underground, or underwater.

The integration of GPS with maps is also a concern in human factors and user centered design research. There are at least three ways of presenting dynamic route information on a mobile navigation device: the route superimposed atop the map, directions provided by arrow pictograms with contextual information, and directional information provided in a text format (Marcus, 2000). Current portable GPS units are designed to provide route directions based on geometry, orientation and street names, but the use of landmarks, common in human wayfinding, is also being studied. Ross et al, (2004) found that use of landmarks increased user confidence in the system and reduced the number of errors. Landmark guided navigation also leads to improved navigation by elderly users (Goodman et al, 2005). Using landmarks helps to indicate specific locations on crowded streets. For example, the device could provide an image of the target destination for the user to look for rather than simply indicating that the destination is 12.5 meters South from the intersection. Unfortunately current commercially available products for supporting landmark-based navigation are still under development (Millonig & Schechtner, 2007). The fact that there is continued research into how to improve wayfinding aids illustrates that there is still a great deal of room for improvement of current tools with emerging technology.

3.5 Virtual Trailblazing

While the expression "trailblazing" is rarely used in the virtual environment and electronic multi-media literature, the concept of marking paths to aid in navigation is common. In the context of website navigation, the technique of marking a path is commonly referred to as breadcrumbs (Lida-Rogers & Chaparro, 2003). The concept behind the breadcrumb approach is from the story of Hansel and Gretel by the Grimm Brothers. In the story, Hansel and Gretel drop a trail of breadcrumbs as they explore the forest so that they can find their way out. In the context of VE navigation, the use of breadcrumbs in large-scale VE's has been explored in three different studies involving virtual breadcrumbs, virtual mapping, and virtual footprints.

3.5.1 Virtual Breadcrumbs

Darken (1993) was the first to implement a breadcrumb technique in a large-scale VE. Participants were required to perform a naïve search for a pyramid while flying around an oceanic environment with a string of islands serving as landmarks. The breadcrumb consisted of a cube, shown in Figure 4. Darken found that a key drawback of the technique was due to the limited functionality of the breadcrumbs. The cubes would be dropped everywhere the participant visited resulting in an accumulation of cubes creating visual clutter. Furthermore, encountering a previously dropped cube would only indicate to the user that he had previously visited the location and not the direction of travel. Thus it quickly became difficult for anyone to trace a previously traveled path.

Figure 4: The Breadcrumb technique. ***[Original source: Image 6. The breadcrumb tool. Darken, R. (1993). Unpublished Master's Thesis, University of Washington, p. A-106.]***

3.5.2 Virtual Mapping

Bowman et al (1999) designed a virtual mapping technique to help plan a route through a VE. Using a stylus a user could drop markers on a map of the virtual environment (See Figure 5). The motivation behind the design was to help users maintain spatial orientation as they travelled. The user would be able to compare his position on the map to the planned route to ensure that he was still on track. While this approach helped the user organize the planning process, the technique relied on the user's skill in following maps to efficiently move through the environment. The virtual mapping technique developed by Bowman et al (1999) did not take advantage of the power of a digital media that would allow one to link or "transfer" the planned route directly into the VE. This would allow users to then follow their planned route from an egocentric perspective rather than from the exocentric perspective provided by a map.

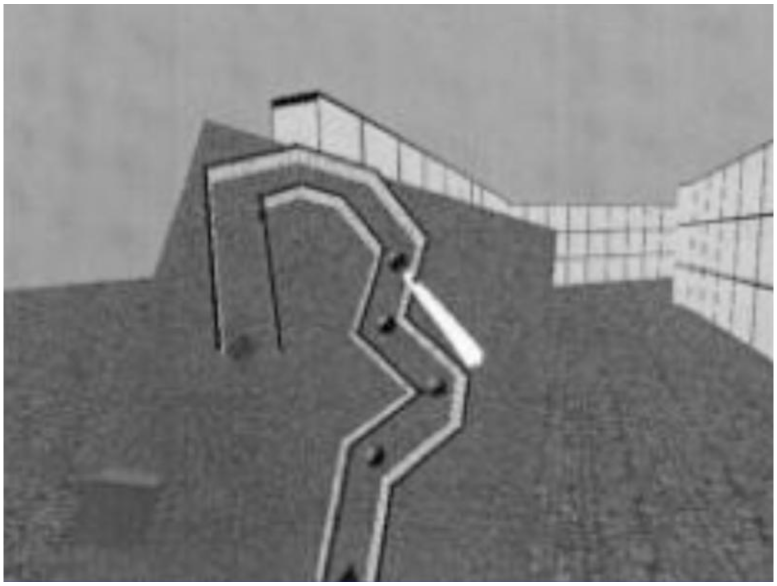

Figure 5: Route-planning technique that allows users to mark a path, through an environment by using a virtual pointer on a map, shown in the centre. ***[Original source: Figure 4. Route-planning technique using virtual map and stylus. Bowmen et al. (1999) Maintaining spatial orientation during travel in an immersive virtual environment. Presence: Teleoperators and Virtual Environments, 8(6), 628.]***

3.5.3 Virtual Prints

Most recently Grammenos et al. (2002, 2006) advanced the concept of the breadcrumb technique by redefining the design of the basic breadcrumb. First, Grammenos modified the breadcrumb to resemble a footprint or handprint (See Figure 6). This change to the marker now conveys directional information to anyone that encounters a marker in that the footprint is oriented in the direction of travel. Furthermore, the design of the Virtual Prints technique adds the dimension of social navigation.

Figure 6: Virtual footprints. ***[Orginal source: Figure 4. Example of interacting with a ViP. Gammenos et al. (2002). Virtual prints: Leaving trails in virtual environments, In Proceedings Eurographics Workshop on Virtual Environments, p.222.]***

Social navigation is most evident in the well-trodden paths that people use to create “short cuts” through the world – like the paths through the grass in parks or flowerbeds. People will continue to use these unofficial paths because a worn out path is evidence that others have used it successfully. The continued use of a path resulted in an accumulation of Virtual Prints. Infrequent use of a path resulted in the gradual disappearance of the footprints over time. A drawback of the Virtual Footprints approach is that users can become confused as to which path is preferable if more than one route had been traveled or more than one user had left behind footprints that branch off of the main path. Furthermore, not all steps taken by a user are meaningful. For example a user may have spent several minutes wandering around a room inspecting different objects resulting in a large accumulation of prints in a small area. The overlapping markers “pollute” the environment making the trail difficult to follow and not necessarily useful from a navigation perspective for other users.

3.6 Factors Influencing Navigation in Virtual Environments

A challenge in designing wayfinding aids is that individual differences are a major source of variation in performance on real world navigation tasks. In a computer generated environment the variability between subjects is greater than in analogous real world tasks (Witmer, Bailey, Knerr & Parsons, 1996) primarily due to the affect of computer experience. Previous work (Bowman, 1996; Darken & Sibert, 1996; Grammenos et al., 2006) on designing virtual wayfinding aids did not take into consideration the possible impact of individual differences. Research on the human wayfinding performance in the real world has identified two primary sources of individual differences: gender and spatial ability.

3.6.1 Gender

Gender differences on wayfinding tasks are the most consistent detectable differences. Many studies have shown consistently that humans adopt wayfinding strategies based on gender (Galea & Kimura, 1993:1999; Lawton, 1994, 1996; Lawton et al., 1996). Females tend to adopt a procedural approach and as a result use landmarks and street names to navigate. As a result, they are better at recalling object placement at a location (Choi & Silverman, 1997). Females also tend to provide right-left directions when describing a route. Males rely more on the use of a cognitive map and require fewer landmarks (Downs & Stea, 1977). In fact, men process each object independently from its particular location and make greater use of the cardinal directions (North, South, East, West) and distances when navigating (Lawton, 1994,1996; Dabbs et al., 1998). Understanding how the different genders approach wayfinding allows for the design of systems to accommodate or minimize gender differences.

One approach found to minimize gender performance differences is to increase the field of view provided to the users (Tan, Czerwinski, & Robertson, 2006). A larger field of view increases the optical flow information and leads to similar performance levels between the genders. Hubona and Shirah (2004) suggested that providing information that is textual in addition to spatial information could create "gender neutral" interfaces.

3.6.2 Spatial Ability

Spatial ability influences how well a person can acquire spatial knowledge, although it is not clear which aspect of spatial knowledge accounts for the differences (Malinowski & Gillespie, 2001). During a dual task, individuals with a high spatial ability will experience impaired acquisition of spatial knowledge if the concurrent secondary task is spatial in nature, whereas spatial learning for individuals with low spatial ability is impaired by secondary tasks that are non-spatial (Garden et al., 2001). Performance on mental rotation tests has been shown to predict performance in learning a novel environment (Bailey, 1994; Darken & Sibert, 1996).

An alternative to creating universal interfaces is the creation of specific interfaces that are suitable for user groups (defined by gender, spatial ability) (Bowman, 2006). However, the development of user specific interfaces requires a better understanding of how individuals handle a task.

Chapter 4
Design of the VTrail Interface

Recognizing the need for a tool designed specifically to aid with virtual trailblazing, the Use-IT Lab began the development of the VTrail System. The preliminary research was carried out in collaboration with DRDC-Toronto as part of a research contract funded through the Ontario Centres of Excellence CRESTech/ETech program. The envisioned solution (VTrail System) was intended to provide a means of marking and configuring desirable routes for trainees to follow within a VE training environment to maximize learning, and minimize disorientation.

During the initial stages in the conceptualization and design of the VTrail System a series of design guidelines were adopted.

I. Use of the system must not hinder the performance of the primary task, since wayfinding is frequently a secondary task.

II. VTrail must be the simplest design possible to ensure ease of use, ease of learning, and reduce the amount of interface real estate to avoid cluttering the visual field.

III. Create a system that supports effective trailblazing and trail following regardless of an individuals' gender, spatial ability or wayfinding experience.

4.1 Previous VTrail Related Research

Prior to this research project, research and development into the design of the VTrail System focused primarily on establishing an effective design for the virtual markers to be used as an integral part of the VTrail System (Iaboni and Ma, 2004; Iaboni, 2005), A series of controlled experiments were carried out to establish and refine the geometric design for a directional marker that can be readily detected within a VE, quickly interpreted for directional information, and scaled to fit any VE using a simple algorithm.

The starting point for establishing an “implicit” 3D directional marker was to start with a circle as it only depends on its radius to establish its 3D counterpart – in contrast to the construction of a 3D arrow which would have variables related to the angle of the chevron, as well as the length, width, thickness, and construction of the arrow shaft (i.e. rectangular versus cylindrical). To create a shape that implied directionality, the circle was protruded along the diameter until participants could reliably identify whether the shape was pointing to the left or to the right that occurred when the ratio of radius to protrusion was approximately 1.7 (Iaboni and Ma, 2004). The 2D design was then converted to a 3D design, the VTrail marker, and tested under controlled experiments to determine the effectiveness of the marker design in aiding navigation performance when compared against 2D arrows (signs) and 3D arrows (Iaboni, 2005) The resulting VTrail marker design can be seen in Figure 7.

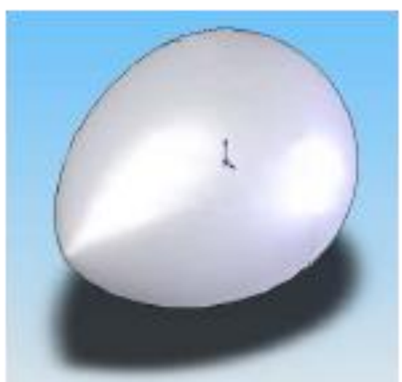

Figure 7: The current design for the VTrail marker (Iaboni, 2005)

While the VTrail marker design was being tested, an initial proof-of-concept was developed for the software that allows for the VTrail markers to be “virtually” dropped onto the graphics of an existing VE without altering the source code of the VE. Using the Chromium framework (Humphreys et al., 2002) the VTrail System software intercepts API commands to the graphics library, adds the VTrail information and passes the modified stream on to the user's computer display. Currently, a user who is familiar with the control codes developed by the software designer can drop a marker into the world and manipulate the marker's orientation so that it points in particular direction to indicate a marked path or to point at a specific object within the VE to indicate a landmark of interest. Each marker is assigned a default name (e.g. "Marker 1"), and a bar at the top of the screen indicates the approximate location to the next marker in the sequence. A representation of what the marker looks like within the 3D video game Quake® is shown in Figure 8.

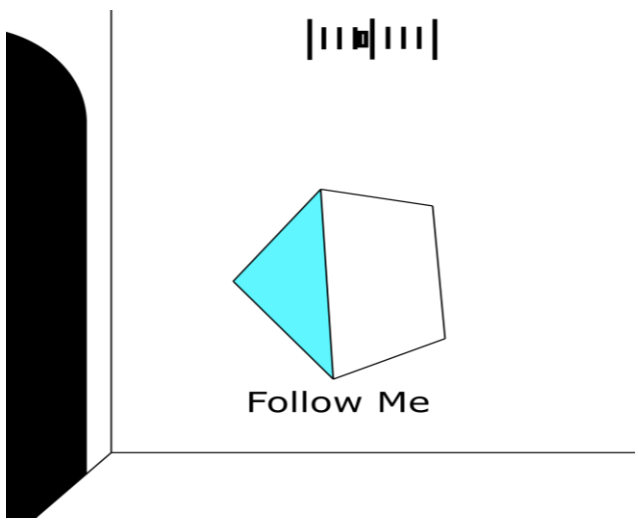

Figure 8: A low-fidelity representation of the initial VTrail interface due to poor resolution of original image.

Prior to this research the VTrail System interface relied on a series of control codes that must be memorized as the system lacked a sufficient user interface to allow someone to easily drop markers into a VE for the purposes of virtual trailblazing. For the VTrail System to become a useful third-party software application it needed to have an interface that can be used effectively by people who are responsible for development of training scenarios.

4.2 Trailblazing and Trail Following Tools

As a starting point for the proposed research, preliminary designs for the VTrail interface were created based on scenario-based task analyses performed on a typical military ground troop training scenario provided by DRDC-Toronto. A task analyses results in the creation of a descriptive model consisting of objects and relationships (Diaper, 2004). Objects may be physical (e.g. keyboard, computer, person), but can also represent intangibles (e.g. social political structures). The objects of a model are connected to each through relationships. Objects with no relationships have no influence on the system and thus can be ignored. A scenario is a description that contains actors and information about the actors: environment description, goals, limitations, and capabilities. Combining scenarios with a task analyses is a powerful design tool that captures and identifies tasks and artefacts (Carroll, 2001). By applying an object-oriented task analysis to the military ground troop scenario, the key tools and behaviours to be included for both the trailblazer and trail follower modes have been identified.

The military ground troop scenario provided by DRDC-Toronto required the trailblazer to navigate to three locations within a large-scale environment within a specified time frame while avoiding potential enemy locations. A list of the identified objects (tools) and associated behaviours for the military scout (i.e. the trailblazer) and the troops (i.e. trail followers) can be found in Table 1. One design decision drawn from the object-oriented task analysis was that the interface used by the trailblazer and the trail follower could be similar. One exception is the ability to add, remove and manipulate markers was restricted to the trailblazer depending on the training or educational goals set for a particular VE application.

Based on the results from the task analysis, the artefacts that would be included into the design of the VTrail interface were sub-divided into three groups; trail related, user related, and mini-map.

Table 1: Examples of identified tasks and artefacts necessary to support Trailblazing and Trail following for the DRDC Training scenario.

Trailblazers (Scouts)		Trail Followers (Troops)	
Task	Artefact(s)	Task	Artefact
Add trail information	VTrail Marker	Follow Trail	VTrail Markers
Determine location of target	Map	Relocate Trail if lost	Map
Determine direction to target	Compass	Heading back to Trail	Compass

4.2.1 Trail Information

Trailblazing and trail following can be facilitated by providing additional information regarding the structure of the trail. In the VTrail interface the trail information is provided through interface components such as the marker information display, information repository, and marker cameras. The features that are associated with the trail information are grouped together and placed on the bottom of the screen to avoid obstructing the user's view.

Marker Information

Although the trail is visually presented to the user with the 3D directional markers, details regarding the marker are available to aid the user. The following marker information is presented to the user: identification, location, and orientation.

Marker identification is currently generated automatically when placed by the trailblazer, and corresponds to the marker's position in the trail sequence, i.e. the first trail marker is "Marker 1", and the tenth marker is "Marker 10".

The coordinates of the marker are provided in case the user needs to find the way back to the trail or decides to head directly to a specific marker location. In the current training scenarios users are restricted to planer motion, so the X and Y Cartesian coordinates are sufficient. The Z-axis coordinates can be included for environments where the user is able to move vertically.

Although users are generally accurate with interpreting the direction implied by a marker (Iaboni, 2005), the exact heading is provided to ensure accurate following of the trail. A small error of a few degrees can result in a large deviation from the trail over long distances. If the user is not restricted to planar movement then the display provides both a pitch angle that can be used to indicate if the user must go up or down a set of stairs.

Information regarding the closest marker to the current position of the user is displayed unless the user scrolls through the list of markers. To scroll through the marker information the user is provided with buttons with arrow icons.

Information Repository

Making use of the VTrail information repository to embed information into the directional markers can enhance a trail. Embedded information can be warnings or task instructions. To add information to the selected marker the user clicks the button labeled “Information”, which opens a window where the user can add/create the content. When satisfied, clicking the “Done” button closes the window. To modify the content, the user can reopen the information window and add or remove content. Although the goal is to support all forms of multimedia, the current VTrail only supports text consisting of 200 characters or less. Furthermore, only the first 20 characters of the message are visible on the main VTrail interface as a preview. To view the remainder of the message, the user must access the information repository by clicking on the button labeled “Information”. The information repository preview is restricted to reduce clutter on the interface.

Marker Camera

The marker camera provides users with the ability to preview the environment from the position and perspective of the selected marker. When users can teleport between locations, previewing a target location prior to travelling reduces spatial disorientation (Elvins, 1998). If markers are used as a warning, a camera allows the trail followers to preview the danger prior to arriving at the marker location. To reduce the number of controls and thus the complexity of the feature, the users have no control of the marker camera, which is fixed in the direction represented by the marker.

4.2.2 User Information

To make use of the marker information the user must be aware of his current status. User status consists of two pieces of information: the user's position, and the user's orientation. The user information components are placed at the top, center of the screen to facilitate rapid updating of position or heading. Placement of the user information adjacent to the trail information facilitates comparisons between current position and the desired position. However, there is the concern that placing information that is similar in appearance in close proximity may result in misreading during a quick glance to update spatial information.

Position

In the real world, an individual's exact position on the planet is determined using a GPS receiver. The user's position can be represent using three different formats; Degrees/Minutes/Seconds (DMS), Degrees Decimal Minutes (DDM), and Universal Transverse Mercator (UTM). In DMS a reading of N47° 37' 12" W122° 19' 45" indicates that the north/south position is 47 degrees, 37 minutes and 12 seconds north of the equator; while W122° 19' 45" places the east/west position at 122 degrees, 19 minutes and 45 seconds west of the Prime Meridian. To calculate the distance between two waypoints the GPS co-ordinates must be converted into the respective longitudes and latitudes in degrees, and calculated using the formula show in Equation 1 ("Distance calculation: How to calculate the distance between two points on the Earth", 2009). Due to the complex nature of interpreting GPS co-ordinates, a standalone GPS receiver is insufficient for accurate navigation in the real world.

(Equation 1) $$\boldsymbol{Distance} = \mathbf{acos}(\mathbf{sin}(\boldsymbol{lat1}) * \mathbf{sin}(\boldsymbol{lat2}) + \mathbf{cos}(\boldsymbol{lat1}) * \mathbf{cos}(\boldsymbol{lat2}) * \mathbf{cos}(\boldsymbol{lon1} - \boldsymbol{lon2}))$$

Where lat1, lon1 is the latitude and longitude (in radians) of position one and lat2, lon2 is the latitude and longitude (in radians) of position two.

In a virtual world a user's position can be represented in Cartesian notation. If the user is restricted to planer movement then the user's position on the vertical axis can be ignored. One corner of the environment represents the origin and the players' position is represented by his position along the positive X and Y axes. Use of Cartesian notation not only facilitates the approximation of the distance between two points but also can facilitate travel between two points. For example, a user is located at (89, 45) and wants to travel to (119, 37). By moving around the user can determine which direction results in a positive change on the X-axis, and negative change on the Y-axis. By providing a compass, the processes of determining which direction to travel by moving around can be eliminated.

Heading

A compass typically provides an individual's heading but can be difficult to use for an inexperienced wayfinder. As part of the design work on the Futuristic Infantry Navigation Device (FIND), researchers at Human Systems Inc. compared user performance with several bearing indicator designs on a HMD to use of physical compass (Kumagai & Massel, 2005). These designs included a level indicator, magnitude arrows, crosshair arrows, moving pointer/fixed dial, fixed pointer/moving dial, and rolling compass. Examples of these interfaces are shown in Figure 9. Results showed improved performance and preference for all HMD designs except the level indicator when compared to the physical compass.

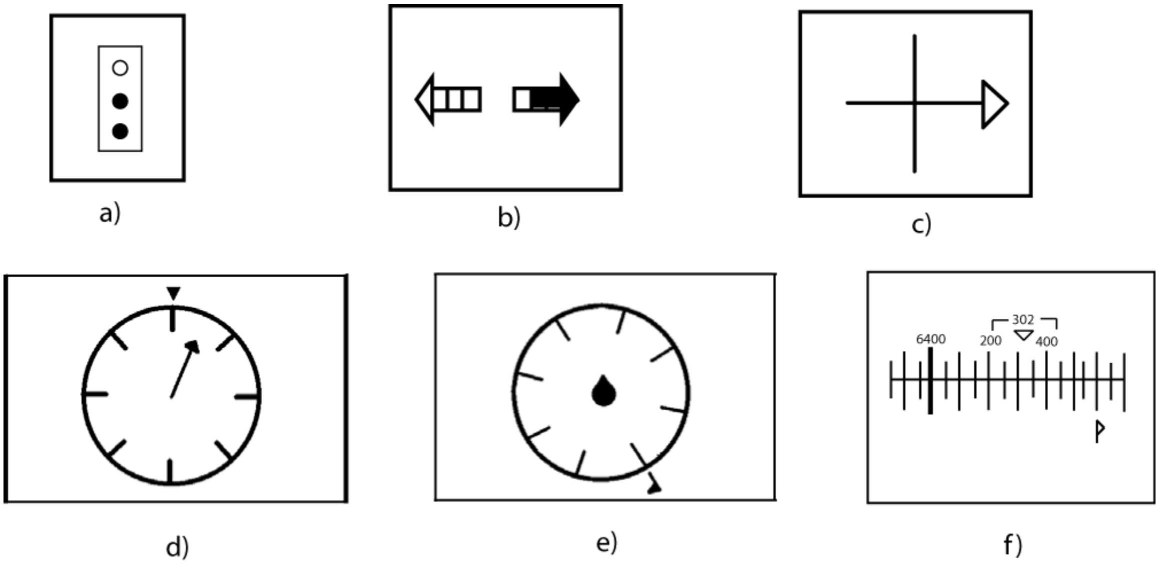

Figure 9: Wayfinding HMD aids tested for FIND, a) level indicator, b) magnitude arrows, c) crosshair arrows, d) moving pointer/fixed dial, e) fixed pointer/moving dial, f) rolling compass. [Composite image created examples from original source: Figures 5 -10. Kumagai & Massel, (2005). ***Alternative visual displays in support of wayfinding, p. 14-18]***

The initial prototype of the VTrail implemented in Quake included a bearing indicator similar to the rolling compass without any numerical values indicating heading. A virtual bar on the rolling compass presented markers in the environment; and the opacity of the bar approximated the distance to marker. For the current implementation of the VTrail interface the rolling compass design was modified to eliminate the analog graphical elements so that bearing was represented only by a single digital value. The advantage of this approach was that the user's current bearing was represented by an exact digital value, which is easy to match up with the heading information indicated by the marker. The modification was made to maintain simplicity of the design and reduce occupied screen real estate.

The heading can be presented in degrees, with north represented by 0°/360°, or a combination of cardinal directions and degrees. For example, 35° can be represented as N35°E. For the initial design the heading information was presented in degrees since participants are assumed to be more comfortable working degrees instead of cardinal directions. The cardinal format provides the general direction of travel (i.e. North, South, East, and West) without the additional cognitive processing required to convert from the degree format. However, the degree format is the simplest to identify and interpret; and general direction of travel can be inferred when combine with the mini-map.

4.2.3 Mini-map Design

Maps are common and powerful tools for wayfinding; but there are a variety of issues to deal with when designing a map, such as scaling and orientation. Taking a map of a large environment and scaling down while retaining the relevant information is difficult. There are techniques for modifying the detail provided by the map as the user zooms in or out (Bartram et al., 1995); however, VNCEP does not currently support this behaviour. Instead, the mini-map will provide a constant level of detail for a smaller region. Instead of trying to provide the users with a map representative of the entire environment, users have an exocentric view of approximately 50m around the current user position.

Another concern with map design is selecting an appropriate orientation, forward-up or north-up. Forward-up maps result in improved performance on egocentric tasks and north-up are better for exocentric tasks, but computer games primarily use north–up maps (Darken & Cevik, 1999). Participants with high spatial abilities could use either map interchangeably but in general users preferred using north-up maps. Since forward–up maps aid in selecting directions and the trail eliminates the need to make a decision about which way to turn, then a north-up map is preferred. Furthermore, since the compass is designed to provide heading in degrees, using north-up orientation sets a fixed point from which the user can determine their orientation if judgments about cardinal directions are necessary.

4.3 VTrail Customization Support

The goal is the development of a default interface that is suitable for users with various levels of experience and accommodates individual differences. In addition, the current system was designed to support a user's desire to modify the interface to fit personal preferences. With a click of the "tab" keyboard button the user enters VNCEP's Graphical User Interface (GUI) mode. In GUI mode the user can reposition interface components features by clicking on a box in the corner of the GUI element and dragging to the desired position. The mini-map element also supports resizing, and zooming (50m, 75m, 100m above the surface). However, the text size and colour is fixed and can not be changed.

The user can modify the number of interface components or the properties of the components by entering the customization screen, shown in Figure 10. In the current design of the screen the user is provide with a list of interface components that can be activated or deactivated by clicking on the corresponding checkbox. When a feature is activated, a button appears on the left side of the customization screen, and clicking the button brings up the property screen for the component. For example, under the compass component the user can decide if they want the bearing displayed in degrees or cardinal directions.

Figure 10: VTrail feature selection screen

4.4 Proposed VTrail Interface Design

The combination of the interface components described above resulted in the default VTrail interface shown in Figure 11. However, the design was subject to change depending on the results from user studies.

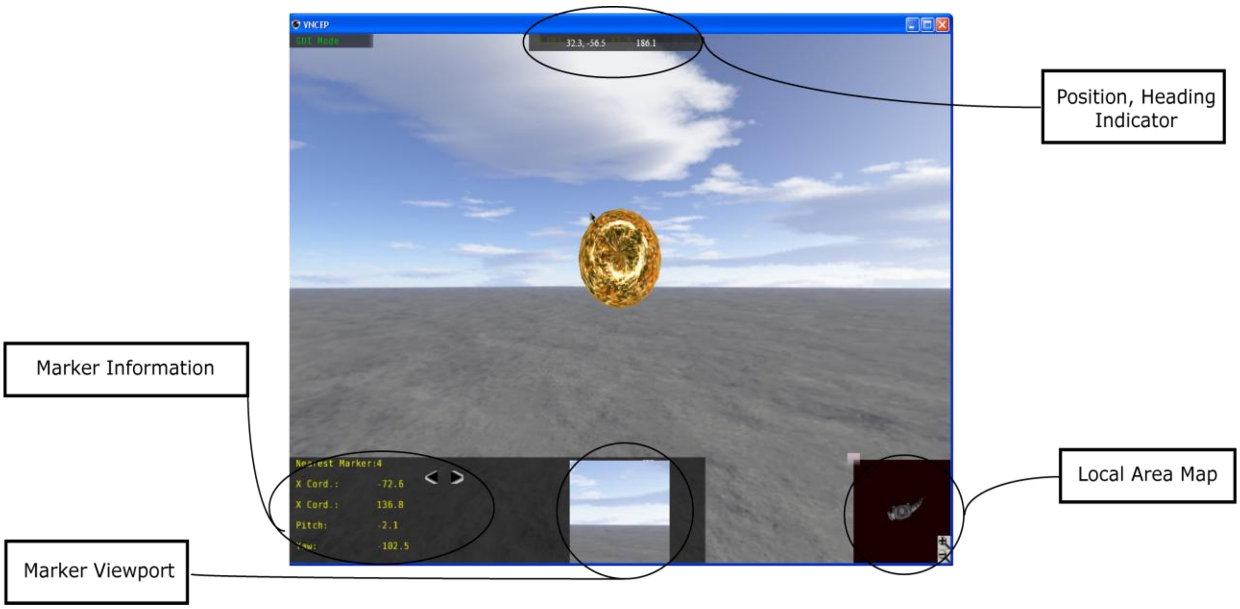

Figure 11: Layout for the proposed default VTrail Interface

4.5 Interface Validation Approach

The structure of the user trials used for the validation of the VTrail default interface is shown in Figure 12. There were two studies (trailblazing and trail following), each consisting of two experiments (minimum interface vs. default; customizable interface vs. default). Each experiment used an equal number of male and female participants to account for possible gender issues. Only a small number of participants were recruited for the validations studies (12 participants in the first trailblazing and trail following experiments, and 16 in the second trailblazing and trail following experiment) due to the exploratory nature of the research. In exploratory interface validation experiments it is possible to extract results with a small number of participants (4-8). Nielsen &

Landauer (1993) recommended no more than 5 participants, whereas more recently Faulkner (2003) suggested around 15 participants for results with sufficient statistical power. The number of participants was increased from 12 to 16 to determine if near significant results in the first experiment regarding gender would reach significance.

The structure of each experiment was similar and is shown in Figure 13.

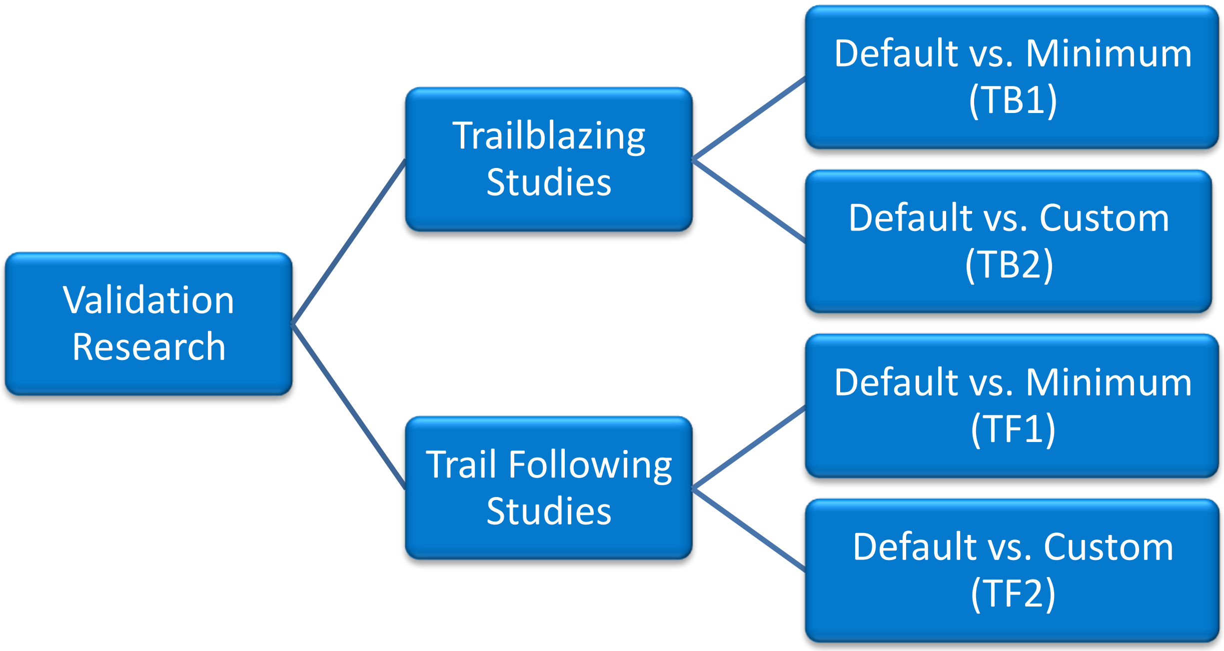

Figure 12: Structure of validation studies for the VTrail interface

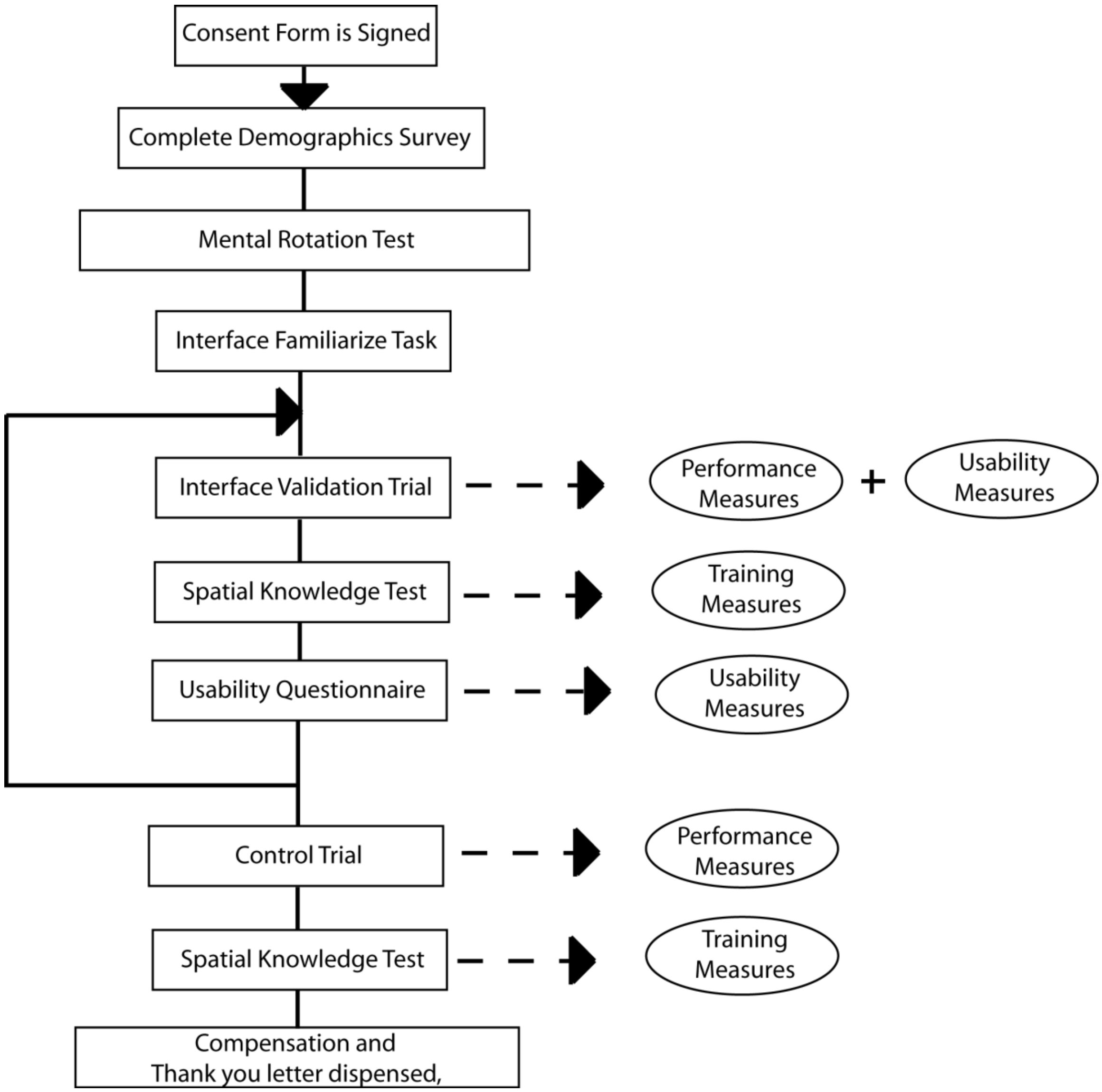

Figure 13: Structure of the experimental trials and points during study where dependent variables were measured for the trailblazing and trail following studies.

Chapter 5
Evaluating Trail Quality

An important step in evaluating the effectiveness of the VTrail interface is to determine the quality of the trails that are generated. However, this raises the question of how to evaluate trail quality. There are two approaches: quantitatively based on graph theory; and qualitatively based on users' perspectives.

5.1 Graph Theory

The quantitative approach to evaluating trails can be traced to the Traveling Salesman Problem (TSP). The TSP is used extensively in planning and logistics, as well as in routing of data packages and genome sequencing (Gutin & Punnen, 2006). The TSP is a graph consisting of nodes and edges, where a node can represent a geographical location in the context of spatial navigation; and each node is connected by one or more edges, representing a cost of moving from one node to another. An edge may have a different cost associated with the direction of travel. For example, assume that cost is a measure of energy expended to move between locations. If one location is at the bottom of a hill and the other is at the top of the hill, then the cost of traveling up the hill will be greater than down the hill. Solving the TSP provides the solution to visiting every node in the graph with the lowest cost.

There are problems with using the TSP as a basis of evaluating trail quality. First, the TSP is known to be NP (nondeterministic polynomial time) complete; it becomes increasingly more difficult to resolve as the number of nodes increases. Expecting a trailblazer to find an optimal solution while trailblazing is unrealistic, and assumes that the trailblazer is aware of all the costs of moving between locations. Second, the TSP does not take into consideration the design of the trail from the user's perspective. Using virtual ant colonies Dorigo and Gambardella (1997) have replicated behavior of real world ant wayfinding; but a virtual simulation of human navigation may not capture the nuances in human behavior, such as assigning trust in the trail quality.

Another computational approach to evaluating trail quality was suggested by Ruddle (2006). Trails were generated while the user explored the environment. Path segments that were traveled more frequently resulted in trails with increased widths, adding a social navigation dimension to the design of the trail, similar to a well-worn path in a flowerbed. Upon returning to the virtual world a couple of weeks later participants were able to complete the task much quicker using the generated trail. Ruddle (2006) suggests trail quality is indicated by the amount of time the participant adheres to the path and does not venture off. The problem with using this approach is that trail evaluation requires multiple users to test the trail. Developing an approach to evaluating trail quality prior to usage is ideal.

5.2 Real World Approach

The Inuit were able to travel around the barren landscape of Canada's arctic for generations by relying on trails. These trails may not be the optimal trails based on graph theory, but are appropriate due to the nature of the Inuit language. Inuit wayfinders rely on the description of wind patterns, snowdrifts, astronomical phenomena, and animal behaviour (Aporta, 2004). When these sources of information are not sufficient Inukshuit are constructed to guide the wayfinders. From generation to generation the trails remained the same, with minor seasonal variation due to the weather effect on the trailblazer. Since there are numerous ways of describing how to travel between two locations there is a large variation in the amount of landmark knowledge possessed by each individual. Therefore, only trails that are easy to verbalize and rely on more commonly known landmarks and features are included into oral tradition and passed down to the next generation.

More recently, trails are used extensively to guide people safely through national parks. The objective of the trail is not to quickly guide the users through the environment, but to provide enjoyment of the natural setting. The trail designer repeatedly goes through the process of designing, and testing before construction of the trail and associated facilities begins. The process is slow, but the designer needs to take into consideration environmental considerations like erosion, water drainage, animal habitats, and usage considerations like the trail grade, signage and user experience. Trails that are popular with users and are sustainable are maintained; and unpopular trails are allowed to grow over.

5.3 Proposed Approach

The decision to go with a strictly qualitative approach to assessing trail quality for this study was based on the fact that a quantitative approach to assessing trail quality does not take into consideration the structure of the trail as experienced from the user's perspective. Instead, a qualitative approach based on Parks Canada's Trail Manual (1978) was devised.

Since the study focuses on trails generated in a virtual environment, criteria from the Parks Canada guide, such as physical concerns like soil erosion and trail grade, are not relevant. However, the underlying design principles of park trails can be transferred over to the virtual realm. The following criteria were included in the design of the Trail Quality Questionnaire (TQQ): path usefulness, path completeness, path length, marker placement, marker orientation, marker frequency, marker usage, and overall user experience.

The first step in the design of a trail is to determine the intended use of the trail. The trail could be used to aid exploration, or guide an individual or group of users to complete specific tasks. Therefore, an important step in the assessment of the virtual trail is in determining if the trail helps the user achieve the desired outcome.

The completeness of the trail is a measure of how well the trail supports task completion. There are different ways of structuring a trail depending on the purpose of the trail. For example, a trail from point A to point B may only need to be linear and one-directional construction. A trail that requires users to return to the starting location can either be constructed in the form of a loop, or support bi-directional travel along a single route. Regardless of the structure, the trailblazer must provide sufficient guidance to reach the final destination. An incomplete trail can result in the user getting lost.

When evaluating the length of a trail it is tempting to compare the actual length to the shortest solution. However, the shortest solution may not be the best trail. The length of the trail needs to match the objective of the trail. A trail for exploring the environment may cover the entire environment whereas a trail between locations may need to be short. The trail length criterion on the TQQ asks the evaluator to consider whether the provided trail is too short, too long, or approximately the right length to accomplish the desired objective.

Successful use of the trail is dependent on trail followers being able to detect signage, or directional markers, so marker placement is critical in evaluating trail quality. The VTrail is already configured to place the markers approximately 1.5 metes off the ground as recommended by Parks Canada (1976). Effective placement requires that markers be positioned in a manner that ensures detection by approaching trail users. Since a lack of contrast between the marker and the background could make the trail marker hard to notice, the trailblazer may need to assess the placement of the markers from the perspective of someone approaching the marker. Parks Canada (1976) also recommends that markers are placed so that trail followers can see from one trail marker to the next, particularly in environments with low visibility

In addition to having the correct placement, the directional markers must be correctly orientated to successfully guide the user to the next marker along the trail. Within a confined environment where the user has only a few possible routes to take from a marker, such as hallways in a building, exact marker orientation will not hinder effective wayfinding. However, when travelling in a large open space travelling a few degrees off from the trail can result in a significant deviation over large distances.

Decreasing the interval between markers can reduce dependence on accurate marker orientation. The strategy of placing markers only at points where a change of direction occurs can result in long straight paths. For straight paths Parks Canada (1976) recommends that a marker should be placed every 100 meters. Rather than expecting trailblazers to adhere to a fixed interval between markers, the marker frequency metric is used to ensure that participants are not adding too many markers such that the environment is cluttered, or too few, making the trail difficult to follow.

The marker usage criterion is included to evaluate how well the trailblazer made use of the available markers. The markers provided with the VTrail are not only capable of providing directional information. Trailblazers have the option of embedding information into the markers and can use the markers to identify points of interest such as the starting location, the final location. Although the measure title appears to suggest that this criterion may not be useful beyond assessment of trails generated using the VTrail System, the measure can be easily renamed to “signage usage” to be applicable to any trail.

The final measure included is used to gauge the trail follower’s overall impression of the trail. This measure encompasses a variety of factors such as the enjoyment of following the trail, and the level of trust in the trail reliability.

Chapter 6
Validation of Trailblazing Interface Design

The purpose of conducting the validation experiments was to ensure that the proposed trailblazing interface design adhered to the design principles proposed at the beginning of the research project, see Section 4.1.

To ensure that final interface was the simplest design that results in effective trailblazing a study comprising a set of two experiments was conducted. The first experiment examined performance on a trailblazing task using the proposed default VTrail interface compared to an interface that mimicked trailblazing with only a compass and map, the oldest, and most common tools for wayfinding. The objective of the first study was to determine if there were features in the default interface that hindered trailblazing performance. The first experiment also provided insight into the set of components included as part of the interface. The second experiment compared trailblazing performance between the proposed default interface, modified based on results from the first experiment, and an interface created by the users.

While a detailed and separate study can be performed on the design and validation of each individual component of the VTrail interface, the decision was made to test the interface in its entirety because of possible interactions between components. For example, use of only a map can result in a cognitive map that is orientation-specific (Presson & Hazelrigg, 1984) and wayfinding with only a compass is difficult (Goldiez, Ahmad, & Hancock, 2007). Feedback of user preferences on the design of individual interface components was captured through a usability questionnaire.

The third design objective was to create an interface that supports trailblazing performance regardless of individual differences. The interface validation experiments were designed to determine if the default VTrail interface would result in effective trailblazing by individuals of different genders and spatial abilities.

6.1 Trailblazing Experiment One

6.1.1 Objective

The primary objective of Trailblazing Experiment One (TB1) was to address design concerns, such as: are there features currently included in the standard interface that increase the complexity of the design without any improvement to trailblazing; are there features that need to be added to improve trailblazing performance?

This study compared performance on creating trails to guide a user to multiple targets in the environment using either an interface with a basic set of features (map and compass) or the proposed default interface.

Hypothesis TB1.1: Use of the proposed default interface will result in higher quality trails compared to the minimum interface design.

Rational: The default interface is specifically designed to support trailblazers whereas the map and compass are tools used to support navigation in general.

Hypothesis TB1.2: Use of the proposed default interface design will result in participants completing the trailblazing task in a shorter period of time while traversing a shorter distance.

Rational: The additional information provided to the user of the default interface will facilitate planning, implementation and review of created trails.

Hypothesis TB1.3: It is expected that users will prefer using the default interface versus the minimum interface.

Rational: The default interface is expected to provide better support for trailblazing making the task less difficult.

Hypothesis TB1.4: Males are expected to outperform females in trailblazing performance.

Rational: A gender difference is expected to be found in this study due to a difference in spatial ability between males and females, as predicted by a standardized mental rotation test, and previous findings in literature (Malinowski & Gillespie, (2001); Tlauka et al., 2005).

6.1.2 Measures and Material

Measures

The experiment was setup as a within-subject design (2 x 3) with 2 independent variables and 3 categories of dependent variables. The two independent variables were gender (male, female) and interface design (minimum, default, control), while spatial ability was used as a covariate. Spatial ability will be studied as a covariate as it may help explain individual differences in performance.

There were three types of dependent measures used in the assessment and comparison of the proposed interfaces: performance, usability and spatial knowledge acquisition. For this study the task performance metrics were time, distance traveled and trail quality. Trail quality was assessed based on the criteria and methodology described in Chapter 5. A questionnaire, see Appendix G, captured user preference data. The questionnaires were based on a 5-point Likert scale, where 1 represents “strongly disagree” and 5 represents “strongly agree”. For example, one question asks the participant to rate the usefulness of each tool provided. Participants were also asked to rate the overall interface. Space was provided for the participant to add additional feedback.

Accumulated observational data from the “think aloud” protocol and recorded observations during the trials provided additional insight into the effectiveness and usability of the components of the interface designs.

Material (Common)

The virtual world was generated using the Virtual Navigation and Collaboration Experimentation Platform (VNCEP) supplied by DRDC. VNCEP ran on Pentium™ 4 PC desktop computer with a 3.4 GHz processor and 3 GB of RAM. The computer used Windows™ XP operating system with a Quadro™ FX 3450/4000 SDI (256 MB) from NVIDIA™. The large projection screen display was an 81" Fakespace® ImmersaDesk with 1280 by 1024 resolution at a 75Hz refresh rate. Non-stereoscopic vision was used to reduce possibility of simulator sickness.

Movement through the environment was similar to controls in popular first person computer games. Participants used the "W", "A", S", and "D" keys on the keyboard to translate through the environment. The participant's walking speed was set to 1.5 m/s, but a participant could increase his speed to 4.5 m/s by pressing the "Shift" key. Participants controlled their viewpoint through the mouse. Translating the mouse forward allowed participants to look up and translating the mouse backwards moved the viewpoint down. Left and right mouse movements controlled the viewpoint in their respective directions. The left mouse button was used to drop the trail markers and the right mouse button removed the marker nearest to the user. The marker design was based on an earlier study by Iaboni and Ma (2004), and is shown in Figure 14. Travel was coupled with the gaze of the user, so users could only travel in the direction they were facing. Participant movement was restricted to a single plane to simplify control and environment design.

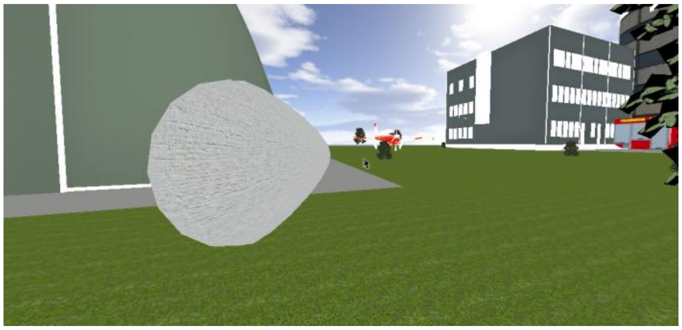

Figure 14: Directional trail marker used in Trailblazing Study One (TB1).

The experimental environments consisted of three large-scale, approximately 300m x 300m, environments. Since there are no self-reported differences in wayfinding strategies between indoors and outdoors (Lawton, 1994), the environments represented an outdoor rural setting. A rural environment was preferred over an urban environment because of the increased complexity of selecting a direction at a decision point. In an urban environment the decision may be constrained by the structure of the decision point (e.g. a 4-way intersection forces a choice between 3 directions). The environments were constructed in the form of a 3x3 matrix, consisting of nine square tiles each 100m x 100m. To reduce possible experimental bias due to the design of the world, the environments were created from a random arrangement of the nine tiles. Each tile contained a large feature (e.g. a building), a smaller feature (e.g. windmill), and assorted vegetation (e.g. trees and bushes). Participants were not able to enter the buildings. An exocentric view of an archetypal rural landscape is shown in Figure 15. Lighting simulated daytime levels.

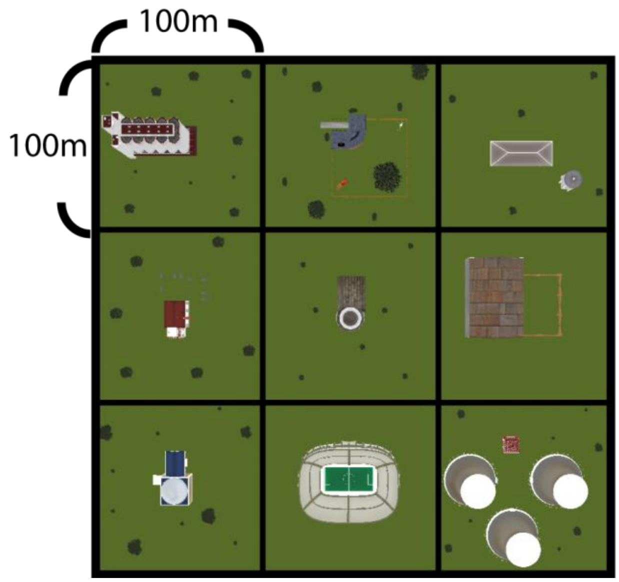

Figure 15: Exocentric view of one of the study environments.

Three sets of 5 delivery items were created for the study. Each delivery item corresponded to a location in the environment, however the participant was expected to determine which location was the most appropriate. Table 2 provides a list of the three sets of delivery items and corresponding delivery locations used in the study.

6.1.3 Participants

Twelve participants (6 male, 6 female) were recruited from the University of Waterloo population (undergraduate, graduate, staff). All participants had normal (20/20) or corrected to normal vision with no visual impairments like colour blindness, and all participants were right handed. Participants that ranked computer gaming experience lower than 3 on a 5-point Likert scale were thanked for their time and dismissed from the study. Participants were monetarily compensated ($10/hour) for their time.

Table 2: Sets of delivery items, provided to participants and expected target locations, not provided to participants.

Set Number	Item	Intended Target Location
1	Telescope	Observatory
	Football	Stadium
	Headstone	Church
	Uranium Rod	Nuclear Power Plant
	Fog Lamp	Lighthouse
2	Children's Toys	House with playground
	Branding Iron	Stables
	Referee Whistle	Stadium
	Lottery Tickets	Gas Station
	Astronomy Charts	Observatory
2	Cross	Church
	Car Engine Oil	Gas Station
	Wheat	Grain Silo
	Horseshoes	Stables
	Fog Horn	Lighthouse

6.1.4 Procedure (Common)

Upon arrival at the Use-IT Lab the participant was seated at a table approximately one meter in front of a large (81") projection screen. The participant was provided with an information letter describing the main objectives, the benefits of participating and the potential minimal risks of participating in a computer-based experiment (see Appendix B). After reading the information letter the participant was asked to sign a consent form, see Appendix C, and complete a background questionnaire, see Appendix F. The background questionnaire collected information on demographics (age, gender, computer experience, wayfinding experience), vision, and computing gaming experience. Participants completed the cube-comparison test (Elkstrom, French, & Harman, 1976). The cube-comparison test is a pencil and paper measure of mental rotation ability, which has been linked to wayfinding ability (Blanjenkova, Motes, & Koshevnikov, 2005).

Two researchers were present during the study. One researcher was responsible for recording observations while the other researcher was responsible for running the study. Test scripts were used to reduce experimental variation. The participant was given an opportunity to learn how to use the VTrail interface during a familiarization in an environment similar to the experimental environment.

Upon completing the familiarization task, participants began the experimental trials. During the experimental trials participants were asked to use a “think aloud” protocol. The participant completed three (minimum/default/control interfaces) trials.

For the minimum and default trials the participant was asked to create a trail that would help someone quickly deliver five packages to the appropriate locations, with only one package per location. At the beginning of each trial the trailblazer was provided one of the three lists of delivery items at random. The experimental trial began once the user started to move through the environment. Once the participant was satisfied with the trail they could terminate the trial.

In the control condition the participant was asked to complete the delivery task without the benefit of any additional information provided via the interface. The participant had to memorize the list of five items to be delivered to ensure the task was similar to the trail following task. Upon locating all five locations, the participant was required to return to the starting location. Once the participant was back at the starting point the control trial was complete.

Half of the participants completed the default trial first and the other half completed the minimum condition first, and the control trial was always the third trial for both groups. Due to the differences in the task between the control trial and the minimum and default trials, the control trial was not included in the analysis for assessing the performance of the proposed trailblazing interfaces. The control trial was included to determine if there were any sample population differences between the participants in this study and the participants selected for a planned study on trail following, as well as used in the assessment of the reliability of the spatial knowledge acquisition test discussed further in Chapter 8.

At the end of each trial the participant was asked to complete the spatial knowledge acquisition test, template shown in Appendix E, where the participant attempted to recreate the environment they had just explored using tile pieces provided by the researcher. There were 6 distracter tiles, (i.e. tiles of building not in the environment). Participants were also asked to indicate where they believed the starting position was on the map of the environment that they had created. The spatial knowledge test was followed by a subjective usability questionnaire on the interface they had used. After completing the three trials the participant was thanked and provided with a general feedback letter outlining the benefits of the research.

6.1.5 Results

The results of the pre-trial mental rotation test were analyzed to determine if there were any differences in spatial ability due to gender. The mean female spatial score was 29.2, (SD = 6.94), compared to a mean male score of 26.83 (SD = 7.14), but the results were not significantly different ($p > 0.05$). All experimental results are evaluated as reaching significance at an alpha level of 0.05.

Performance Results

A 2 x 2 mixed design analysis of covariance (ANCOVA) design was used to examine the time spent and distance traveled with the between-factor of Gender (male, female) and the within-factor of Interface (minimum, default). The covariate was the spatial score based on the mental rotation test .

Analysis of the time data found that interaction between interface and gender approached significance, $F(1,9) = 4.03$, $p = .08$. Table 3 shows the means and standard errors for the interaction between interface and gender. The main effect of spatial ability was significant, $F(1,9) = 11.6$, $p < .01$. There was a negative correlation, $r(24) = -.708$, $p < .05$, between spatial ability and time spent trailblazing. Gender was nearly significant, $F(1,9) = 4.53$, $p = .06$, with males completing the task faster (M = 604.2s, SD = 267.2) than females (M = 804.7s, SD = 316.3).

Table 3: Means (Standard Deviation) for interaction between gender and interface for time performance (seconds).

	Interface	
Gender	Minimum	Default
Male	588.8s (204.2)	619.6s (338.1)
Female	973.3s (308.9)	636.0s (228.7)

Analysis of the distance data found a significant interaction between interface and gender, $F(1,9) = 6.20$, $p < .05$. Summary of the interaction results is shown in Table 4. The main effect of gender was nearly significant, $F(1,9) = 4.60$, $p = .06$. On average males traveled 1081.3m (SD = 701.1) while females traveled 1561.0m (SD = 690.8). Spatial ability was also a significant predictor of distance traveled, $F(1,9) = 15.14$, $p < .005$. Lower spatial scores resulted in further distances traveled, $r(24) = -.70$, $p < .05$. Interface was not a significant factor.

Table 4: Means (Standard Deviation) for interaction between gender and interface for distance performance (meters).

Gender	Interface	
	Minimum	Default
Male	898.7m (350.5)	1263.9m (926.0)
Female	1832.4m (749.1)	1289.6m (530.6)

Trail Quality Results

To determine trail quality four graduate members of the Use-IT lab (2 male, 2 female) received an hour-long training session involving a description of the TTQ and practiced evaluating trails to ensure consistency. Trail evaluators then independently assessed all of the trails in a random order. The inter-rater reliability for the raters was found to be Cronhbach = 0.88, $p < .001$. The final trail quality score was the average of individual evaluator scores. Summary of the trail quality scores is shown in Table 5. There were no significant results.

Table 5: Means (Standard Deviation) for trail quality, out a maximum possible score of 50, measured in Trailblazing Experiment One (TB1).

Gender	Interface	
	Minimum	Default
Male	31.25 (8.6)	32.7 (7.1)
Female	31.63 (6.7)	34.33 (6.9)

Usability Results

Usability data was analyzed using Friedman's test. Results indicate that the participants significantly, $\chi^2(1, n=12) = 6.00$, $p < .05$, preferred using the default interface ($M = 4.00$, $SD = 0.60$) compared to the minimum interface (M = 3.50, SD = 0.67). There was no difference between the interfaces for task difficulty, ease in learning, and ease of use.

The usability questions pertaining to the individual features were analyzed with a Chi-Square Test. Ratings from 1 to 2 were collapsed into a single value, "0", representing "Exclude from interface", while ratings from 3 to 5, were collapsed into a single value, "1", representing "Include feature with interface". The difference in the ranges used in the collapse of the usability questionnaire data ensures that interface components, not currently considered essential to the interface but potentially beneficial, are not removed from contention without first re-evaluating the component design.

The results of the Chi-Square tests indicate that the Marker Position component, χ^2 (1, N= 12) = 5.01, $p < .05$, and Marker Camera, χ^2 (1, N= 12) = 6.13, $p < .05$, achieved significance, and further analysis indicates that participants found the marker position information useful, but the marker cameras of little use.

Spatial Knowledge Results

A 2 x 2 mixed design analysis of covariance (ANCOVA) design was used to analyze the TIS, TLS, and TOS Spatial Knowledge Acquisition Test (SKAT) data with the between-factor of Gender (male, female) and the within-factor of Interface (minimum, default). Spatial ability was included as a covariate. For a discussion of how spatial knowledge acquisition was measured and details on the SKAT see Chapter 8. Summary for all three data measures (TIS, TLS, and TOS) is provided in Table 6.

For the TIS data the interaction between interface and gender approached significant, $F(1,9) = 3.96$, $p = .08$.

Based on analysis of the TLS and TOS data there were no significant or nearly significant main effects or interactions.

Table 6: Means (Standard Deviations) of TIS, TLS and TOS data for TB1

SKAT Measure	Gender	Interface	
		Minimum	Default
TIS	Male	6.83 (2.04)	7.08 (1.50)
	Female	7.75(0.69)	6.25 (1.75)
TLS	Male	2.75(4.40)	2.92 (4.69)
	Female	2.00 (5.54)	2.08 (4.59)
TOS	Male	-1.17 (2.23)	-0.67 (2.21)
	Female	-1.50 (2.81)	-0.33 (1.69)

6.1.6 Discussion

The objective of TB1 study was the validation of the design of the default VTrail interface according to the design guideline of simplicity set at the start of the research project. TB1 investigated the effect of providing additional information, the default VTrail interface, on trailblazing performance compared to using only a map and compass. To ensure a universal design, individual factors such as gender and spatial ability were included in the analysis.

The interaction between interface and gender for both the time and distance measures suggests that the design of the VTrail is on the right track. One of the design objectives for the VTrail is to support trailblazing by users regardless of individual differences. Females using the minimum interface were significantly slower, and traveled much further compared to males using the minimum interface. However, when using the default interface, performance was not statistically different between the genders. While the absence of a statistical difference does not “prove” a case, the fact that significant differences were found between the genders in the minimum interface condition suggests that there was enough power in the experimental design to reveal major differences in performance.

The concern that providing additional information with the default interface cluttered the visual field and possibly distracted the user is resolved. The lack of a significant performance differences between the two interface designs suggests that the current set of features provided on the default interface does not significantly hinder performance of a trailblazing task.

As hypothesized, users did prefer using the default interface compared to the minimum interface. One participant commented that having the map information on the main screen and not having to toggle between the first person and map views made the experience less frustrating. There was no difference between the interfaces in terms of ease of use and ease in learning. This indicates that the current set of tools provided by the default interface does not result in a noticeable difference in difficulty as perceived by the user. The results suggest that the design of the VTrail is on the right track; however, there is room for improvement.

Modifications to Default Interface Design

Observations of participant behaviour and participant feedback resulted in a number of recommendations for improvements to the design of individual interface components and screen layout.

The marker camera feature was considered by users to provide little or no support. While being able to view a location prior to teleporting reduces disorientation (Elvins, 1999), the ability to teleport was not provided in this study and so, in hindsight, this feature would have limited use from the user’s perspective. However, other applications may allow users to jump between locations and so future VTrail interfaces may incorporate this feature that can then be customized to the needs of the specific application.

The redesign of several other interface components is required. Users found that knowing the marker position was useful, but only for one particular marker, the one representing the starting location. However, providing this information is only useful if the user knows where he is in the environment, and participants indicated that the user position interface component was not helpful in determining dynamic location. This finding suggests that the user needs a means of facilitating trailblazing back to the starting position. Instead of creating a separate interface component, this information can be added to the mini-map as an arrow icon on the edge of the map indicating the approximate straight-line direction to the start. When the starting location beacon icon in located in the top left corner of the North-up map, the user must head northwest from the current position.

Similar to the positional data, participants did not find providing the detailed orientation information of the marker and the user to be of much use. Since the trailblazer never needed to follow his own trail and had no idea where the next marker in the trail would be located, knowing the orientation of the marker did not necessarily help with trailblazing. As a result the heading component is replaced with an arrow located at the center of the mini-map that rotates to indicate direction of travel. Since the mini-map is always north up, a user can approximate his heading.

That the mini-map was not viewed as an essential component was surprising since the mini-map was the only means of gaining a birds-eye view of environment – a perspective useful for constructing a mental map of the world. It is possible that the mini-map, located in the lower right corner of the display, was not in a convenient location for rapid glances. In the next version of the default interface the mini-map is repositioned to the top left of the screen where the contrast between the bright blue sky in order to make the mini-map feature more noticeable when compared to its original location against the dark green ground in the lower right corner of the screen.

Given the typical participant behaviour of generating the trail as the environment is explored, there is a need for real-time summary of the trail details as the user creates a trail. A "Trail Details" component would provide information regarding the trail length, estimated travel time, and the number of marked points of interest.

In addition to feedback regarding the design of the interface, users provided feedback for improving the VTrail System. Participants expressed interest in having another marker. To use the current marker to indicate noteworthy locations required manipulation that participants found time-consuming. An additional marker specifically for rapid and easy marking of points of interest is necessary. Therefore, the revised default interface consists of the modified mini-map, the trail summary component, and the information repository, and an enlarged view is shown in Figure 16. The components that were removed from the default design will still be accessible to users through the customization menu if more detailed information is required.

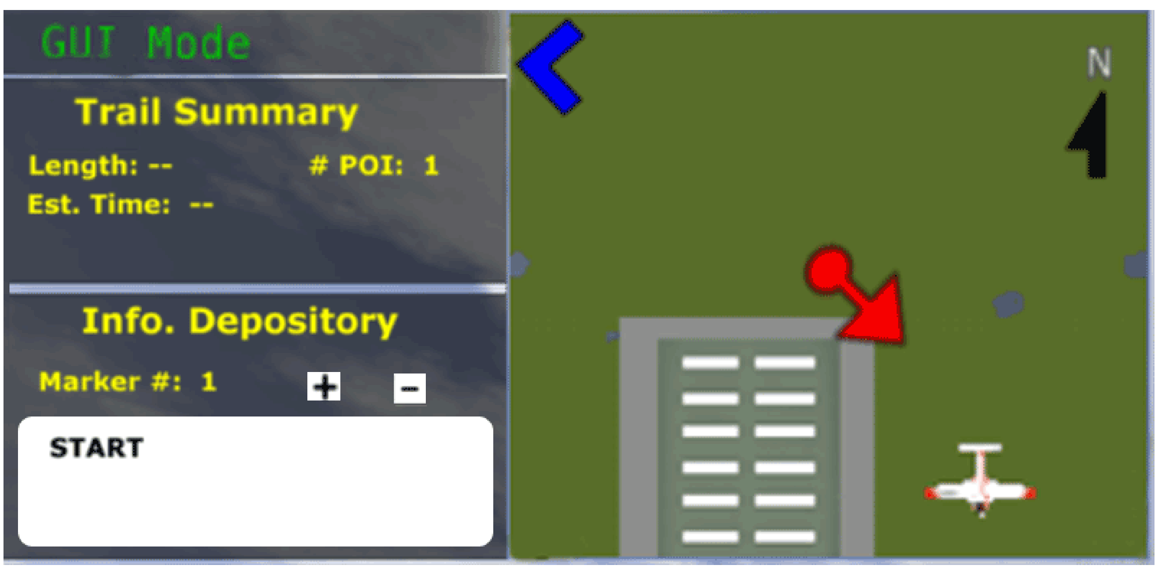

Figure 16: Enlarged view of modified VTrail Trailblazing interface based on results from TB1

6.2 Trailblazing Experiment Two

6.2.1 Objective

In Trailblazing Experiment One (TB1) participants were constrained to using a map and compass or the VTrail interface. While the results of TB1 suggested that providing additional features in the VTrail interface did not significantly hinder trailblazing performance, the experiment did not determine if the set of features included in VTrail interface was the ideal set. The next step was to determine if providing users with the ability to create a custom interface would result in more effective trailblazing compared to the VTrail interface, as well as user selection of a different set of interface features. Trailblazing Experiment Two (TB2) compared trailblazing performance between the default interface, modified to incorporate feedback from TB1, and the custom interface created by the participant.

An important consideration was that if the customization condition resulted in an improved trailblazing experience it would be difficult to determine the final design of the default interface due to possible variability in interface design between participants. However, reviewing the frequency and nature of the modifications should result in additional insight for changes to the design of the default VTrail interface.

Taking into account the variability within the customization condition the following results are expected:

Hypothesis TB2.1: As inexperienced trailblazers, participants are expected to include more features as part of the customized interface compared to the features available in the default interface.

Rational: Given that all of the participants are inexperienced with trailblazing in a virtual environment, it is reasonable to assume that they may select at least one additional interface component to assist them with the task.

Hypothesis TB2.2: Customizable interfaces will result in improved performance on the trailblazing task.

Rational: The purpose of providing users with the ability to customize an interface is to allow users to achieve performance gains by adapting the interface to fit personal preferences. Since customization is expected to occur due to differences in spatial ability there should be a measurable difference in performance given a range of spatial abilities.

Hypothesis TB2.3: The custom interface will be preferred over the default interface.

Rational: It is expected that a user would prefer using an interface created by himself as compared to an interface created by someone else.

6.2.2 Material and Setup

Material

The same computer and software platform as TB1, as described in Chapter 6.1.2, was used in this study. However, in place of the 81" Immersadesk, a 17" LCD display with 1024 by 768 resolution at a 70Hz refresh rate was used. Changing to this size of desktop display ensured that the entirety of the proposed interface were within the users field of view.

Taking into consideration feedback from TB1, participants were provided with the directional marker and an additional marker. The second marker, shown in Figure 17, was referred to as a Point of Interest (POI) marker since the design resembled a pin that could be used, to indicate landmarks. Although the effectiveness in terms of a user's ability to visually detect the POI marker in the environment was not previously tested, the sole purpose of the marker was to draw the attention of the trail follower and not convey any additional information.

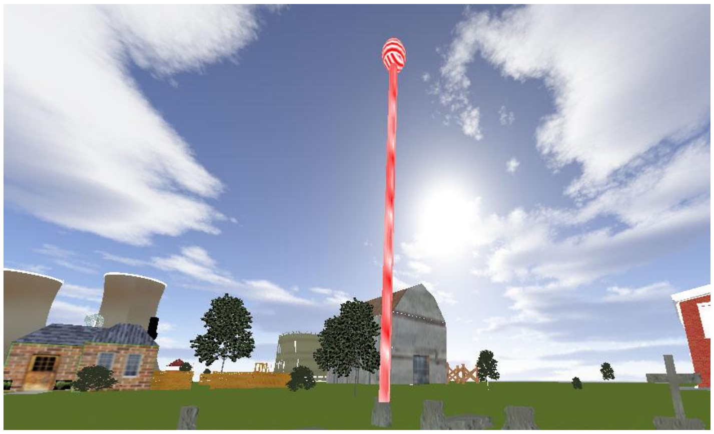

Figure 17: Point of Interest (POI) Marker available in TB2.

The experimental environments are constructed in the same manner as in TB1, but consisted of different buildings. The environments were created from a set of 27 unique tiles and no building was used twice to avoid the possibility that residual recall of a previously explored environment may influence performance on the spatial knowledge test.

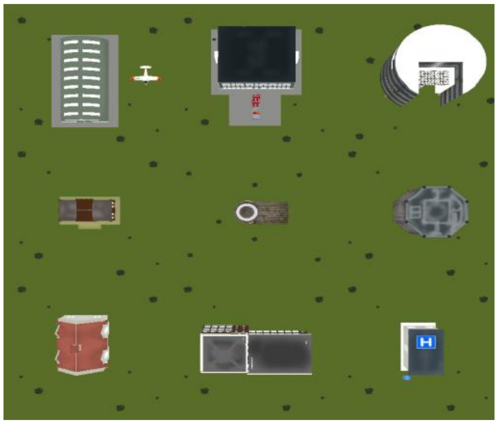

Figure 18: Exocentric view of one of the study environments used in TB2.

Table 7 provides a list of the three sets of delivery items and corresponding delivery locations used in the study.

Table 7: Sets of delivery items for TB2, provided to participants and expected target locations, not provided to participants.

Set Number	Item	Target Location
1	Telescope	Observatory
	Football	Stadium
	Headstone	Church
	Uranium Rod	Nuclear Power Plant
	Horseshoes	Stables
2	Egyptian Statue	Museum
	Handcuffs	Police Station
	Satellite	Space center
	Prayer mats	Mosque
	Carnival Tickets	Carnival Swing
3	Cross	Church
	Propeller	Airport
	Syringe	Hospital
	Fire Hose	Fire Station
	Foghorn	Lighthouse

Measures

The common experimental structure and measures, as described in Chapter 6.1.2 were used. In addition, the observer used the Interface Customization Checklist, see Appendix H, to track which features the user included in the custom interface. Any modifications to the default properties of a feature, for example changing size or location, were recorded.

6.2.3 Participants

The sixteen participants (8 male, 8 female) recruited for this study were acquaintances of the researcher living in the Greater Toronto Region. All participants had normal (20/20) or corrected to normal vision with no visual impairments like colour blindness, and all but one participant were right handed. Participants that ranked computer gaming experience lower than 3 on a 5-point Likert scale were thanked for their time and dismissed from the study. Participants were monetarily compensated ($10/hour) for their time.

6.2.4 Procedure

The common experimental procedure, as described in Chapter 6.1.4, was followed.

For the customizable interface condition the participant was presented with no interface and informed that he had the opportunity to create his own VTrail interface using the provided customization screens. The experimental trails began once the participant closed the customization menu and started to move. During the customized interface trial, the user could access the customization menu at anytime to make modifications.

6.2.5 Results

The results of the pre-task mental rotation test were analyzed to determine if there were any differences in spatial ability due to gender; and the result was not significant.

Performance Results

A 2 x 2 mixed design ANCOVA was used to analyze the time spent and distance traveled with the between-factor of Gender (male, female) and the within-factor of Interface (Custom, Default). Spatial score, based on the mental rotation test, was the covariate.

For the time data analysis, spatial ability was a significant predictor of time spent trailblazing $F(1,13) = 19.1$, $p < .005$. A participant's spatial ability was negatively correlated to time spent trailblazing, $r(32) = -.752$, $p < .001$.

Spatial ability was also a significant predictor of distance traveled when trailblazing, $F(1,13) = 19.3$, $p < .005$. Participants with a higher spatial ability score traveled less than participants with a lower spatial score, $r(16) = -.756$, $p < .001$.

Trail Quality Results

Trail quality was assessed in a manner consistent with TB1. The inter-rater reliability was found to be Cronbach's = 0.73, $p <0.01$. Summary of the trail quality scores based on gender and interface is shown in Table 8.

Spatial ability, $F(1,13) = 7.43$, $p <.05$, was a significant predictor of trail quality. A higher spatial score resulted in trails assessed as being of higher quality, $r(32) = .420$, $p < .05$. Gender was approaching significance, $F(1,13) = 3.72$, $p = .10$. There were no significant interaction or main effect found relating to interface design.

Table 8: Means (Standard Deviations) of Trail Quality (TQ) results from TB2.

	Interface	
Gender	Custom	Default
Male	33.4 (4.5)	34.3 (6.9)
Female	37.5 (6.0)	34.8 (4.5)

Usability Results

To determine if there were any preferential differences between the two interface designs, the usability questionnaire data was analyzed using Friedman's Test. Participants ranked the default interface ($M = 3.38$, $SD = 0.62$) as easier to learn, $\chi^2 (1, N= 16) = 10$, $p < .005$, compared to the custom interface (M = 2.50, SD = 0.73). Similarly, in terms of ease of use, χ^2 (1, N = 16) = 4.5, $p < .05$, the default interface is preferred (M = 3.19, SD = 0.54) over the custom interface (M = 2.69, SD = 0.60). For overall opinion on interface design, the default interface had a mean score of 3.25 (SD = 0.68) compared to the mean score of 2.81 (SD = .66) for the custom interface, with a statistical result close to significance, χ^2 (1, N= 16) = 3.77, p = .052.

The usability questions pertaining to the individual features were analyzed with a Chi-Square Test. Prior to analysis, the ratings from 1 to 2 were collapsed into a single value, "0", representing "Exclude from interface". Ratings from 3 to 5 were collapsed into a single value, "1", representing "Include feature with interface". Table 9 presents the result of all the Chi-Square tests. The difference in the ranges ensures that interface components, not currently considered essential to the interface but potentially beneficial, are not removed without first re-evaluating the component design.

Table 9: Summary of the Chi-Square results for the individual features for each interface condition. Where * indicates significant results.

Condition	Feature	χ^2	p
Custom	User Position	4.0	.05*
	User Orientation	2.25	.13
	Mini-map	2.25	.13
	Trail Summary	2.25	.13
	Marker Positions	6.25	.01*
	Marker Orientation	6.25	.01*
	Data Repository	.25	.62
Default	Mini-map	1.5	.22
	Trail Summary	10.67	.001*
	Data Repository	.51	.48

Spatial Knowledge Results

A 2 x 2 mixed design ANCOVA was used in the analysis of the TIS, TLS, and TOS SKAT data with the between factor of Gender (male, female) and the within factor of Interface (custom, default). Spatial ability was included as a covariate. For a discussion of how spatial knowledge acquisition was measured and the reliability of the SKAT see Chapter 8. Summary of the TIS, TLS, and TOS results is shown in Table 10.

Based on TIS data, spatial ability was a significant predictor performance, $F(1, 13) = 24.165$, $p < .001$, with a positive correlation, $r(32) = .639$, $p < .01$. Interface and gender were not significant.

Table 10: Means (Standard Deviations) of TIS, TLS and TOS data for TB2

		Interface	
SKAT Measure	Gender	Custom	Default
TIS	Male	7.75 (1.63)	5.37 (3.35)
	Female	4.44 (4.14)	4.25 (2.78)
TLS	Male	4.94 (2.64)	2.00 (3.14)
	Female	2.38 (3.72)	1.69 (2.42)
TOS	Male	0.94 (2.23)	-0.75 (2.27)
	Female	0.25 (2.75)	-0.50 (2.15)

Based on the TLS data, spatial ability predicted TLS performance $F(1, 13) = 15.2$, $p < .005$. There was a positive relationship between spatial ability and TLS, $r(32) = .566$, $p < .005$. No other factors were significant.

Participants' score on tile orientation was significantly affected by spatial ability, $F(1, 13) = 13.035$, $p < .005$. A higher spatial score was positively correlated to the TOS, $r(32) = .588$, $p < .005$.

Customization Results

Customization data, collected by the Interface Customization checklist, was analyzed using a one-sample Wilcoxon sign ranked test. Figure 19 shows the frequency count for the number of components used in the customized interface, and Figure 20 represents the frequency of each component used in an interface. There was no significant difference, $Z(16) = -.424$, $p = .67$, in the number of features used in the customized interface compared to the number of features included in the default interface (i.e. 3).

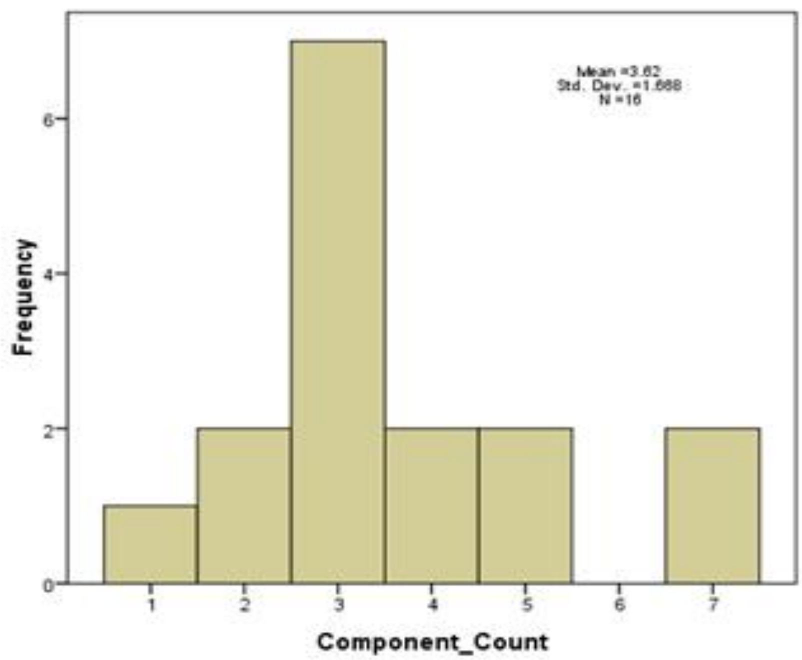

Figure 19: Histogram representing the frequency that the featured set selected for the customized differed from the proposed default VTrail interface

The number of modifications to the default properties of the components used was significantly more than 0, $Z = -3.22$, $p < .005$. Figure 21 shows the frequency in the different number of modifications performed by participants.

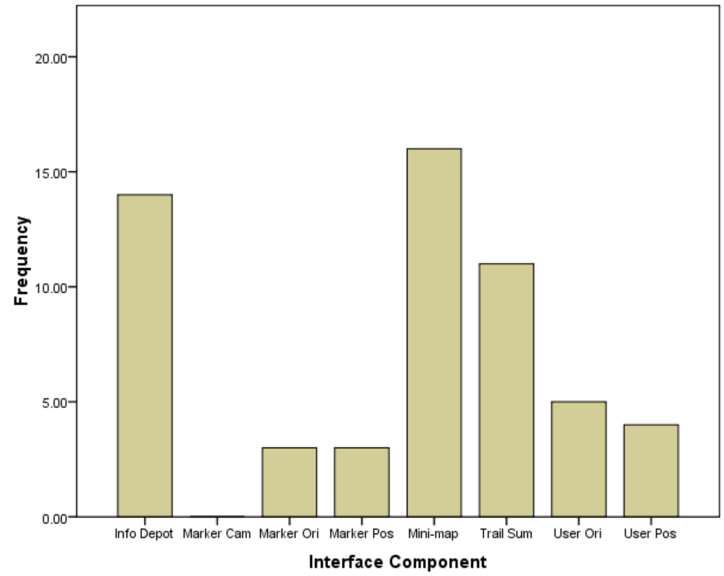

Figure 20: Histogram representing the frequency of usage for each interface component

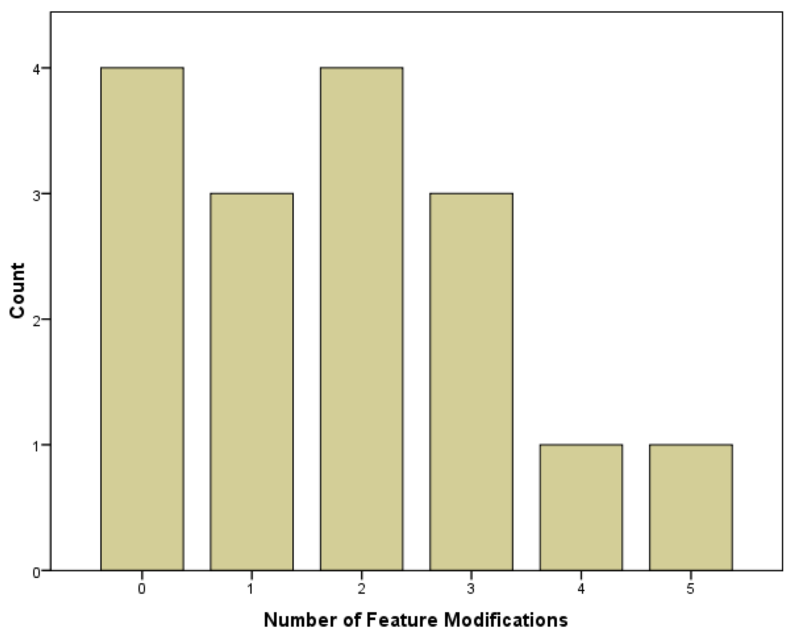

Figure 21: Histogram of number of modifications to the default characteristics of the components provided to the participants

The number of interface components used in the custom interface was analyzed using a one-way ANCOVA analysis of gender with spatial ability as the covariate. Spatial ability was significantly correlated to the number of components with, $F(1, 13) = 5.07$, $p < .05$. The resulting Person number was calculated to be $r(16) = -0.57$, $p < .05$.

A one-way ANCOVA analysis of the number of modifications found no significant effect due to gender or spatial ability.

6.2.6 Discussion

Customization is an opportunity for users to modify a system to fit personal preferences and may lead to improved task performance. Trailblazing Experiment Two was carried out to determine if the set of tools a user picks to perform a trailblazing task differ from the toolset provided as part of the proposed default VTrail trailblazing interface and if customization resulted in improved trailblazing performance.

The customization analysis indicates that participants generally utilized the same number of interface components as the default interface. Furthermore, while the median number of modifications is greater than zero, most participants did not make more than a couple (2-3) modifications to the default settings of the components. These results replicate previous findings in the literature (Page et al, 1996) that users, novice users in particular, tend not to modify default properties of software.

It is important to note that due to the counterbalance design of the study, half the participants had used the default interface in the initial trial. A participant in this group may have decided that the effort to redesign the interface was not worthwhile since he had already completed the task without difficulties. These results emphasize the necessity of a well-defined and tested default for the VTrail interface when considering novice users.

A comparison of the custom interface to the default interface on a trailblazing task found no performance difference in terms of time spent trailblazing, distance traveled, or quality of trails produced. The results suggest that providing the ability to create custom interfaces did not result in any significant improvements or significant degrading in performance for novice trailblazers. Thus, there is no clear user performance advantage or disadvantage for including interface customization options.

From the usability questionnaire it is clear that learning and using the custom interface is difficult. Since the components used in the default and custom interfaces are similar, the source of the difficulty exists with the act of customizing the interface. To make modifications to the interface the user must push the “tab” button to enter GUI mode, where clicking another button called up the customization screens. Although there was a mode display in the corner of the screen, users had difficulty remembering to changes modes. Unfortunately the need to make mode changes to be able to interact with the GUI elements is a limitation of the VNCEP platform.

The fact that spatial ability shows a significant negative correlation to the number of interface components selected by the users suggests that VTrail interface can be simplified further for individuals with a higher spatial ability. However, the current amount of support provided by the default interface is easy to use regardless of spatial ability.

Other results from the analysis of the customization data found that participants did not think that the user position, marker details (marker position, marker orientation), and marker camera features are needed in the design of the interface. These results reinforce the results from TB1.

While TB2 indicates that further refinement to the design of the customization system is needed, the current proposed trailblazing interface for the VTrail System is an appropriate starting point for design for effective trailblazing.

Chapter 7
Validation of Trail Following Interface Design

During the design of the default interface it was realized that the system would need to support both trailblazing and trail following. The design of the trail following interface adopted similar design guidelines as the design of the trailblazing interface. An additional design guideline unique to trail following states that since trail following is usually a secondary task, the design must not interfere with performance of whatever is the primary task (e.g. focusing attention on the detection of enemy units). A validation study, consisting of two experiments, was conducted to ensure that the proposed default VTrail trail following interface adhered to the design guidelines.

The first experiment compared performance on a trail following task using the default VTrail interface compared to an interface with basic wayfinding components (map and compass). Using the results from the first experiment, the design of the default interface was modified.

The second experiment compared trail following performance between the modified default interface and performance when users have the ability to create a custom interface.

The results from these two experiments were used to set the final design of the default VTrail trail following interface.

7.1 Trail Following Experiment One

7.1.1 Objective

The primary objective of TF1 was to address design concerns, such as: are there features currently included in the standard interface that increase the complexity of the design without any improvement to trail following; are there features that need to be added to improve trailblazing performance?

This study compared performance on a delivery task using a trail to guide a user to multiple targets in the environment. Participants were provided with either an interface with a basic feature set(map and compass) or the proposed default trail following interface.

Hypothesis TF1.1: Participants will perform the delivery task in a shorter period of time and distance when using the default interface compared to the minimum interface.

Rational: Information embedded in the markers and displayed via the default interface will eliminate the need for the participant to spend time deciding if a building is a valid target for delivery.

Hypothesis TF2.2: Participants will prefer using the default interface compared to the minimum interface.

Rational: The default interface provides additional information right at the user's disposal whereas the minimum interface requires the user to alternate between the map view and first person view to determine current location.

7.1.2 Material and Setup

Measures

The experiment was setup in a manner similar to TB1, see Section 6.1.2.

There were two types of measures used in the assessment and comparison of the interfaces: performance measures, and usability measures. For this study the dependent task measures were time, (Delivery Time, DT, Return Time, RT, Total Time, TT), distance traveled, (Delivery Distance, DD, Return Distance, RD, Total Distance, TD), and delivery task accuracy (Task Score, TS).

Material

The common experimental setup was used, see Chapter 6.2.2. However, the same materials (environments and delivery items) as experiment TB1 were used.

Participants were provided with two different trails, one per experimental environment, to aid in the delivery task. The trails provided to the participants were selected from trails that were created by participants in TB1. The selected trails were identified as the best trail, as measured by the TQQ, for each interface condition (i.e. minimum and default). Both trails were generated by the same participant, and constructed in a similar fashion.

7.1.3 Participants

Twelve participants (5 male, 5 female) were recruited from the University of Waterloo population (undergraduate, graduate, staff), and two participants (1 male, 1 female) were acquaintances of the researcher. All participants had normal (20/20) or corrected to normal vision with no visual impairments, and all participants were right handed. Participants that ranked computer gaming experience lower than 3 on a 5-point Likert scale were thanked for their time and dismissed from the study. Participants were monetarily compensated ($10/hour) for their time.

7.1.4 Procedure

The common experimental procedure, as described in Chapter 6.1.2 was followed.

Upon completing the familiarization task, participants began the experimental trials. The participant completed three (minimum/default/control interfaces) trials. For each trial the participant was asked to deliver five packages to appropriate locations, with only one package per location. The participant was informed that a trail was provided to assist with the task. The participant was not informed about the quality of the trail. At the beginning of each trial the trail follower was provided with a list of delivery items that the participant needed to memorize, and which corresponded to the experimental condition. After 30 seconds, the participant returned the list to the experimenter and started the corresponding trial. The experimental trial began once the user started to move through the environment. The experimental trial was considered to be complete when the participant returned to the starting location after delivering the five items.

7.1.5 Results

A t-test was performed and determined that there were no differences in the spatial ability between genders. Since data from two participants was collected in a slightly different research environment, the data from those two participants was compared to the data from all the other participants. Since the data for the two different participants fell within the confidence intervals for the remainder of the participants, it was deemed that the two participants could be included in the analysis. As a check, the analysis reported below was performed without the two additional participants (ie. 10 instead of 12 participants) without major changes in overall results. It was decide to keep all 12 participants to increase power in the experiment for the purposes of analysis.

Performance Results

Analysis of the Task Score (TS), Delivery Time (DT), Return Time (RT) and Total Time (TT) data, and Delivery Distance (DD), Return Distance (RD) and Total Distance (TD) data was performed using a 2 (default, minimum) x 2 (male, female) Mixed ANCOVA design with spatial ability as the covariate.

There were no significant effects for the TS.

From the DT data there was a significant interaction between interface and gender, $F(1,9) = 5.33$, $p < .05$, shown in Figure 22. Females using the default interface ($M = 196.2$s, $SD = 73.0$) were faster when they used the minimum interface ($M = 281.5$s, $SD = 131.9$); in contrast DT for males was slightly faster with the minimum interface ($M = 226.1$s, $SD = 64.6$) than when they used the default interface ($M = 270.1$s, $SD = 49.2$).

Analysis of the RT and TT data found no significant effects.

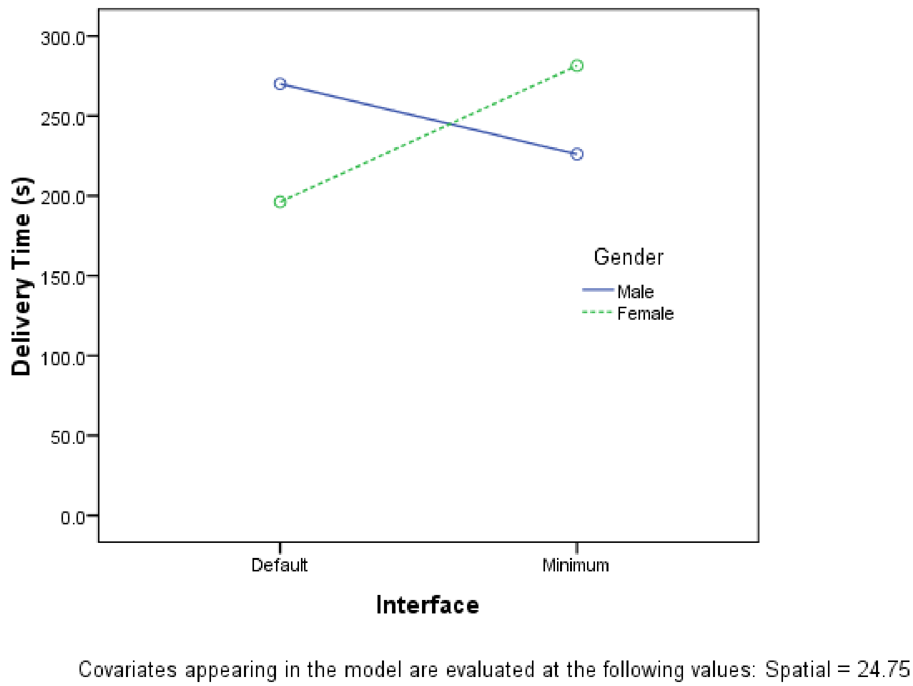

Figure 22: Profile plot of interaction between Gender and Interface for Delivery Time.

The DD data revealed a significant interaction between interface and gender, $F(1,9) = 5.48$, $p < .05$, in shown in Figure 23. In keeping with the DT results, females traveled further when using the minimum interface (M = 1745.1m, SD = 644.5) than when using the default interface (M = 1293.0m, SD = 443.8); and males traveled further using the default (M = 1924.3m, SD = 243.4) than when they used minimum interface (M = 1553.1m, SD = 773.7). No other factors were significant.

The RD and TD data found no significant results.

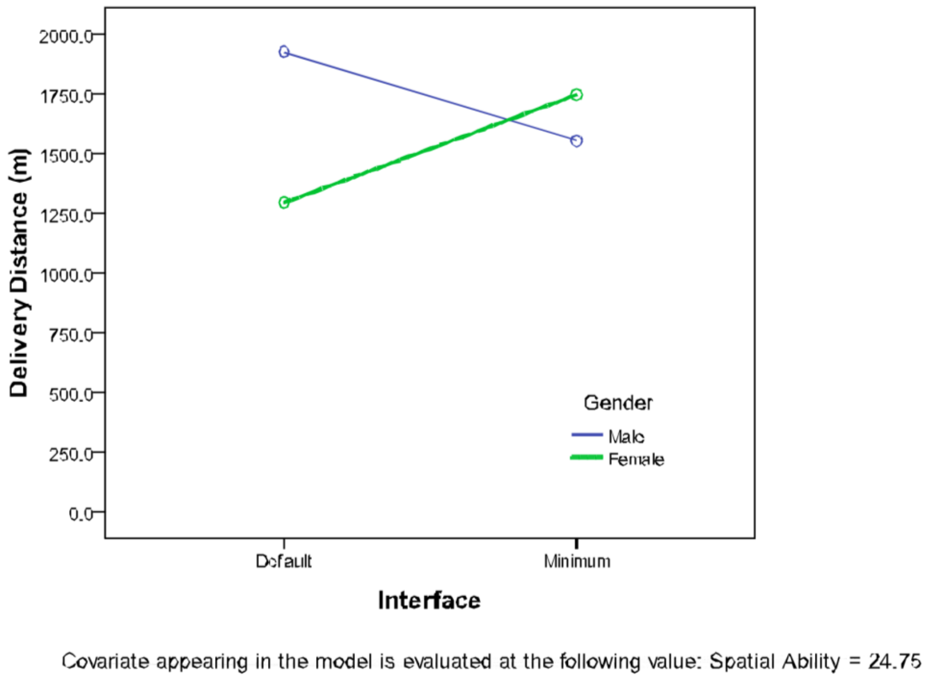

Figure 23: Profile plot of Delivery Distance interaction between Gender and Interface.

Usability Results

To determine if there were any preferential differences between the two interface designs the usability questionnaire data were analyzed using Friedman's Test. Task Difficulty was close to being significantly different for the two interfaces, χ^2 (1, N= 12) = 3.57, p = .06. However there were no differences in terms of ease of learning, or ease of use. Overall there was no significant preference for one interface compared to the other.

The usability questions pertaining to the individual features were analyzed with a Chi-Square Test. Ratings from 1 to 2 were collapsed into a single value, "0", representing while ratings from 3 to 5, were collapsed into a single value, "1", representing "Include feature with interface".

Based on the results of the analysis, there were no features that users identified as being an essential feature to include in the interface design. However, the negative reaction to the marker camera, χ^2(1, N= 12) = 5.0, $p < .05$ and information repository, χ^2(1, N= 12) = 5.0, $p < .05$, suggests that these features that should not be included in the interface.

Spatial Knowledge Results

Analysis of all the SKAT data was conducted using a 2x2 Mixed ANCOVA design. Summary of the results can be found in Table 11.

For the TIS data the spatial ability covariate was significant, $F(1,9) = 15.7$, $p < .01$. Pearson analysis found a significant correlation, $r(24) = 0.63$, $p < .01$.

For the TLS data the interaction of spatial ability and interface, $F(1,9) = 11.1$, $p < .01$, achieved significance. A significant relationship between the covariate and factors in an ANCOVA signifies a violation of the homogeneity of regression slopes, and this is evident in Figure 24. However, Hamilton (1977) found that the power of ANCOVA was not severely altered by heterogeneous regression slopes as long as the group sizes were equal. The main within factor of interface was also significant, $F(1,9) = 11.439$, $p < .01$, with the default interface (M = 1.91, SD = 1.87) resulting in a higher TLS score on average when compared to the minimum interface (M =1.583, SD = 2.32). Spatial ability reached significance, $F(1,9) = 9.01$, $p < .05$. Spatial ability was positively correlated with the TIS score, $r(24) = 0.64$, $p < .01$.

The TOS measure found a significant effect due to gender, $F(1,9) = 21.02$, $p <.001$. Males scored a higher TOS (M = .148, SD = 2.32) compared to females (M = -1.94, SD = 2.14). Spatial ability was significant, $F(1,9) = 27.08$, $p < .001$ and was positively correlated, $r(24) = 0.55$, $p <.01$.

Table 11: Means (Standard Deviations) of TIS, TLS and TOS data for TF1

SKAT Measure	Gender	Interface	
		Minimum	Default
TIS	Male	6.83 (1.63)	7.58 (1.46)
	Female	5.42 (4.14)	6.75 (2.47)
TLS	Male	2.58 (1.59)	1.92 (3.49)
	Female	1.25 (2.02)	1.25 (2.21)
TOS	Male	0.83 (1.99)	0.50 (2.79)
	Female	-1.92 (1.93)	-2.25 (2.75)

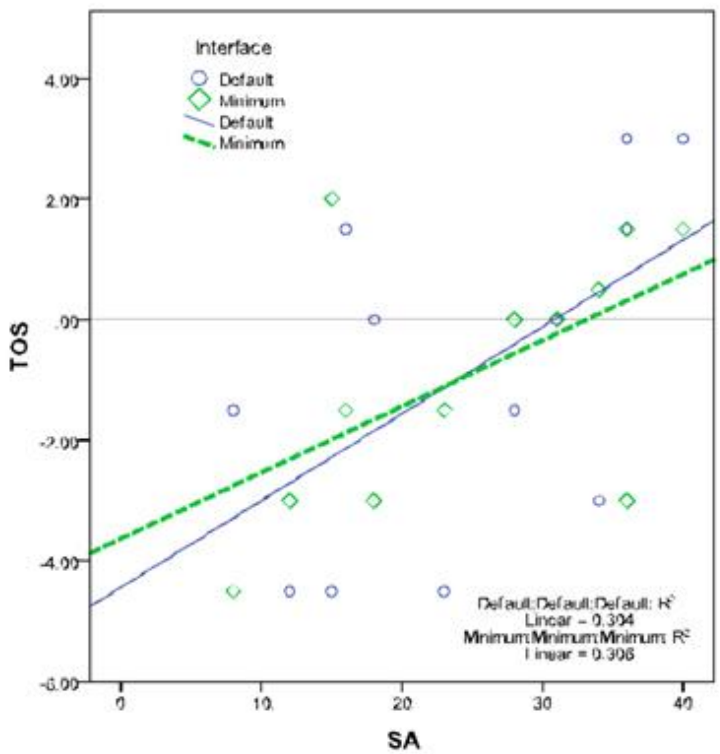

Figure 24: Scatter plot demonstrating the interaction between interface and spatial ability on the TLS score.

7.1.6 Discussion

The objective of TF1 was the validation of the design of the default VTrail interface for trail following according to the design guideline of simplicity set at the start of the research project. TF1 investigated the effect of providing additional information, the default VTrail interface, on trail following performance compared to using only a map and compass. To ensure a universal design, individual factors, such as gender and spatial ability were included in the analysis.

Since wayfinding is a secondary task while in a VE, a key design requirement was that the VTrail interface must not interfere with primary task performance. The lack of a significant difference in the accuracy on the delivery task suggests that the VTrail interface did not significantly hinder primary task performance.

The gender and interface interaction is surprising since the literature suggests that females performed navigation tasks better with a wider unobstructed field of view. However, the results suggest that the amount of information provided on the default interface (which would decrease usable field of view) improved female performance compared to the minimum interface. Conversely, the presence of additional information on the interface appears to be a distraction for males, resulting in slower delivery task performance. The results from this experiment are not sufficient to conclude that there is a definite need for a version of the VTrail interface that is gender specific. The second trail following experiment that focuses on user customization of the trail following interface will help determine if there is a distinct gender difference in the preference in the amount of information on the interface.

The interaction between gender and interface in DD performance is not surprising given that the corresponding time measure is significant. Since movement speed is fixed, the results for DD would only vary from DT if participants spent more time standing around trying to decide what to do next, or traveled at a faster speed by running around the environment.

The lack of preference between the interfaces or interface components can be explained by the nature of the trail following task. Following a visibly marked trail is not a cognitively demanding task provided that the directional signage is clear. The addition of the memory task increases the cognitive demands, but not sufficiently to result in a noticeable difference. Increased cognitive demands, by increasing the number of items to memorize, or adding a time constraint may lead to possible differences in interfaces. However, the objective of TF1 is to gain insight into the tools and information necessary to improve the design and not to stress test the effect of cognitive load on trail following performance.

The majority of the participants traveled off the provided trail at some point, either intentionally or by missing a directional marker. By venturing from the provided trail, participants provided an opportunity to observe how well the interfaces supported returning to the trail. The limitation of route-based knowledge is that straying off the route can lead to getting lost, and to difficulty in returning to the route due to insufficient global knowledge. During this study, participants were able to visually detect the trail markers to get back on the trail, but they could not tell where along the route they were located. In one case a participant, having completed the delivery of the items, picked up the trail near the starting location, and proceeded to follow the trail around the entire environment. So, the trail following interface requires modifications to the design.

Modifications to Default Interface

From this study it was clear that participants had little difficulty in following a trail to deliver the items, however, based on feedback from users and observations there were several modifications to be included in the next experiment.

This study demonstrated that users do not need detailed information, such as the location of the markers or the user's current position, to perform the task. Instead the user may benefit from more general information and the ability to access the detailed information when needed. The marker position and orientation information, the user's position and orientation and the marker camera will no longer be included in the default interface, although users can turn them on through the customization menus.

Two new components were added to the interface design, trail summary, and trail progress. The trail summary provides an overview on the structure of the trail such as the number of marked points of interest, the length of the trail, and the estimated time to traverse. The trail progression component informs the participant of the current trail segment (the route between two points of interest), and the progression along the entirety of the trail.

One component that will remain in the default interface is the mini-map. Although participants were able to visually relocate the trail when they wanted to return, the mini-map provides a constant exocentric view of the surrounding which is beneficial to the spatial knowledge acquisition. Similar to TB1, the mini-map will be relocated so that it is more easily accessible to the user.

The trail repository will also be included in the redefined interface. Although the presence of the embedded information did not significantly decrease time spent in delivering the items, several participants commented that the information was useful, while other participants indicated that they had not noticed the information located at the bottom centre of the display. Therefore the information repository will be reposition to make it more noticeable to users.

The redefined default trail follower interface used for Trail Following Experiment Two (TF2) is shown in Figure 25.

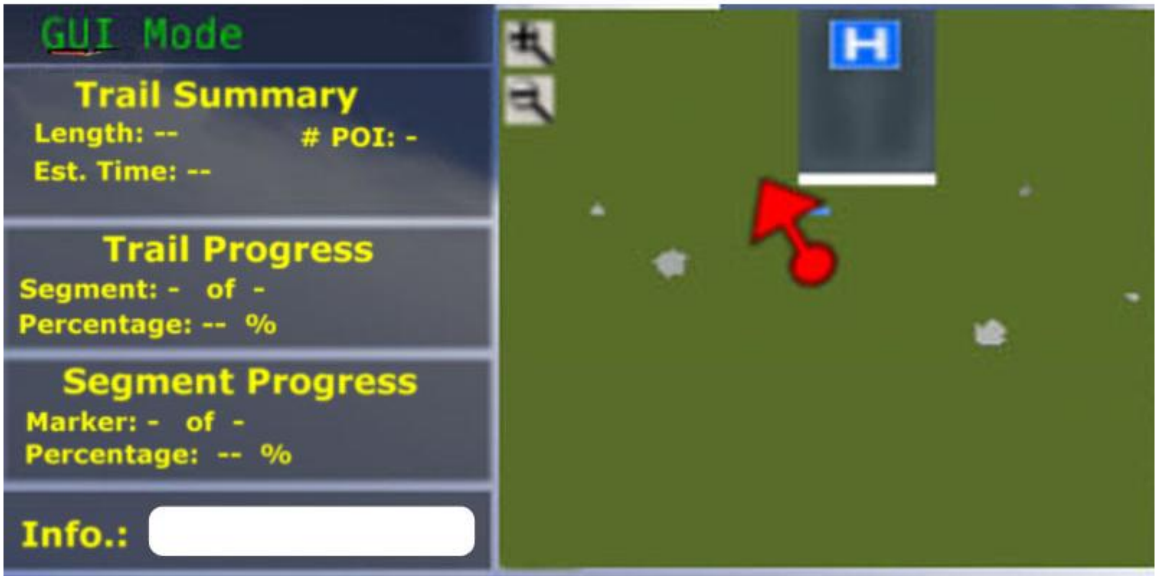

Figure 25: Enlarged view of the interface components as they appear on the redesigned default trail follower interface.

7.2 Trail Following Study Two

7.2.1 Objective

In Trail Following Experiment One (TF1) participants were constrained to using a map and compass or the VTrail interface. While TF1 determined that providing additional features in the VTrail interface did not hinder trail following performance, the experiment did not determine if the VTrail was the optimal design or if the possibility of a more effective interface exists between the VTrail interface and the minimum interface. The next step was to determine if providing users with the ability to create a custom interface would result in more effective trail following. Trail Following Experiment Two (TF2) compared trail following performance between the default interface, modified to incorporate feedback from TF1, to a custom interface created by the participant.

Hypothesis TF2.1: As inexperienced virtual trail followers, participants are expected to include more features as part of the customized interface compared to the features available in the default interface.

Rational: Given that all of the participants are inexperienced with trailblazing in a virtual environment, it is reasonable to assume that they may select at least one additional interface component to assist them with the task.

Hypothesis TF2.2: Customizable interfaces will result in improved trail following performance.

Rational: The purpose of providing users the ability to customize an interface is to allow users to achieve performance gains by adapting the interface to fit personal preferences.

Hypothesis TF2.3: Participants will prefer using the customizable interface compared to the default interface.

Rational: Participants have the opportunity to create an interface to suit personal preferences so the resulting custom interface should score higher on usability metrics.

An important factor to take into consideration is that if the customization condition results in an improved trail following performance it is difficult to determine the final design of the default interface due to possible variability between customized interfaces. However, by reviewing the modifications users make to the interface it may be possible to gain additional insight for modifications to the default design. TF2 also gathered feedback from participants for additional means of providing customization to the user to enhance the interface functionality.

7.2.2 Material and Setup

Measures

The common experimental materials, as described in Chapter 6.2.2, and experimental measures as described in Chapter 7.2.1 were used.

7.2.3 Participants

Sixteen participants (8 male, 8 female) were recruited from the University of Waterloo population (undergraduate, graduate). All participants had normal (20/20) or corrected to normal vision with no visual impairments and all participants were right handed. Participants that ranked computer gaming experience lower than 3 on a 5-point Likert scale were thanked for their time and dismissed from the study. Participants were monetarily compensated ($10/hour) for their time.

7.2.4 Procedure

The common experimental procedure used in Chapter 6.2.4 was followed.

7.2.5 Results

A t-test was performed and determined that there were no differences in the spatial ability score between genders.

Performance Results

All delivery task accuracy data (TS), time data (DT, RT, TT) and distance data (DD, RD, TD) was analyzed using a 2x2 Mixed ANCOVA design with spatial ability as a covariate.

There were no significant effects for the TS data.

Analysis of the DT data found that the spatial ability covariate was significant, $F(1,9) = 19.15$, $p < .005$, but no other factors were significant. From the RT data only spatial ability, $F(1,9) = 5.26$, $p < .05$, reached significance. For TT performance spatial ability, $F(1,9) = 14.78$, $p < .005$, was significant. No other factors were significant. Summary of a correlation analysis between spatial ability and time data is shown in Table 12.

Table 12: Summary of correlation analysis between Spatial Ability Score and Time measures (DT, RT, TT) in TF2. ** Correlation significant at the .01 level.

Measure	N	R
DT	32	-0.74**
RT	32	-0.51**
TT	32	-0.70**

Spatial ability covariate reached significance for DD, $F(1,9) = 13.72$, $p < .005$, RD, $F(1,9) = 5.22$, $p < .05$, and TD, $F(1,9) = 12.2$, $p < .005$. No other effects were significant. Table 13 shows the correlation results between spatial ability and the task distance measures.

Table 13: Summary of correlation analysis between Spatial Ability Score and Distance measures (DT, RT, TT) in TF2. ** Correlation significant at the .01 level.

Measure	N	R
DD	32	-0.66**
RD	32	-0.50**
TD	32	-.66**

Spatial Knowledge Results

All SKAT data (TIS, TLS, and TOS) were analyzed using a 2x2 Mixed ANCOVA design. Summary of the results are shown in Table 14.

In the TIS data the spatial ability covariate was significant, $F(1,9) = 41.45$, $p < .001$; and for the TLS data the spatial ability covariate was also significant, $F(1,9) = 68.0$, $p < .001$. From the TOS data the covariate, spatial ability approached significance, $F(1,9) = 3.59$, $p = .08$.

Table 14: Means (Standard Deviations) of TIS, TLS and TOS data for TF1

SKAT Measure	Gender	Interface	
		Custom	Default
TIS	Male	6.63 (1.58)	6.37 (2.37)
	Female	6.50 (1.46)	6.31 (1.62)
TLS	Male	2.31 (2.55)	2.63 (2.95)
	Female	2.38 (2.13)	1.88 (2.49)
TOS	Male	-0.56 (1.99)	-1.50 (1.07)
	Female	-1.38 (1.62)	-1.06 (1.76)

Usability Results

The Friedman's Tests found that there were no significant differences in Task Difficulty or Ease of Use between the two interfaces. However, participants ranked the default interface [M =1.75] easier to learn, χ^2 (1, N= 16) = 6.40, p < .01, compared to the custom interface [M= 1.25]. The overall preference for the default interface compared to the minimum interface approached significance, χ^2 (1, N= 16) = 3.00, p = .08.

The usability questions pertaining to the individual features were analyzed with a Chi-Square Test. The ratings from 0 to 2, were collapsed into a single value, "0", representing "Exclude from interface". A rating from 3 to 5, were collapsed to a single value, "1", representing "Include feature with interface". Table 15 presented the result of all the Chi-Square tests.

Based on the results of the Chi-Square analysis for the custom interface, participants indicated that there is no need to include user position, marker position, marker orientation, and marker camera features in the design of the interface. The mini-map feature was identified as necessary to include in the interface design. For the default interface, the trail progress component was identified as necessary.

Table 15: Summary of the Chi-Square results for the individual features for each interface condition. Where * indicates significant results.

Condition	Feature	χ^2	p
Custom	User Position	2.25	.13
	User Orientation	.25	.67
	Mini-map	6.26	.01*
	Trail Details	.25	.67
	Trail Progress	2.25	.13
	Marker Positions	6.25	.01*
	Marker Orientation	6.25	.01*
	Data Repository	2.25	.13
	Marker cameras	16.0	.00*
Default	Mini-map	.510	.48
	Trail Details	1.50	.22
	Trail Progress	7.59	.01*
	Data Repository	.094	.76

Customization Results

Customization data, collected by the Interface Customization checklist, was analyzed using a one-sample Wilcoxon signed rank test. Figure 26 shows the frequency count for the number of components used in the customized interface, and Figure 27 represents the frequency of each component used in an interface. There was no significant difference, $Z(16) = -1.38$, $p = .17$, in the number of features used in the customized interface compared to the number of features included in the default interface (i.e. 4).

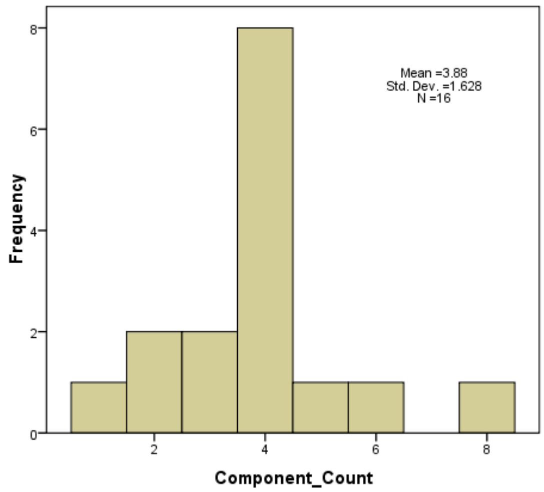

Figure 26 Histogram representing the frequency of the feature set size for each custom interface resulting from TF2

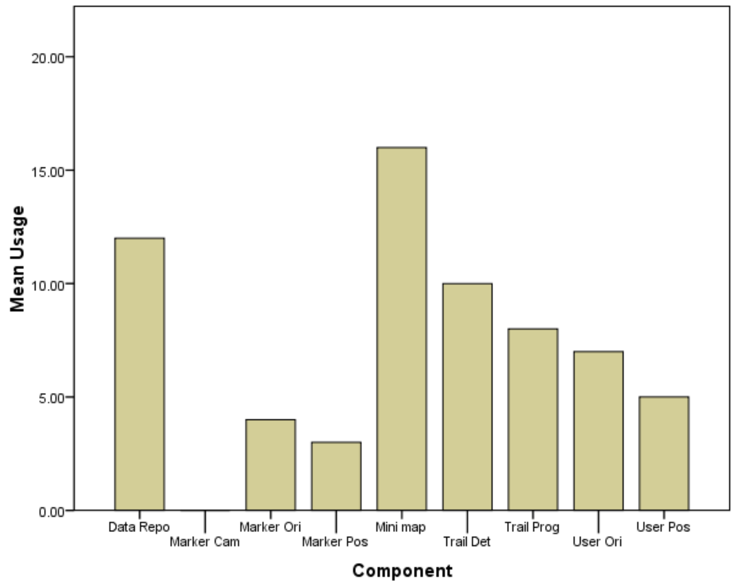

Figure 27 Histogram representing the frequency of usage for each component provided to the participant in TF2

The number of modifications to the default properties of the components used was significantly more than 0, Z = -3.08, $p < .005$. Figure 28 shows the frequency in the different number of modifications performed by participants.

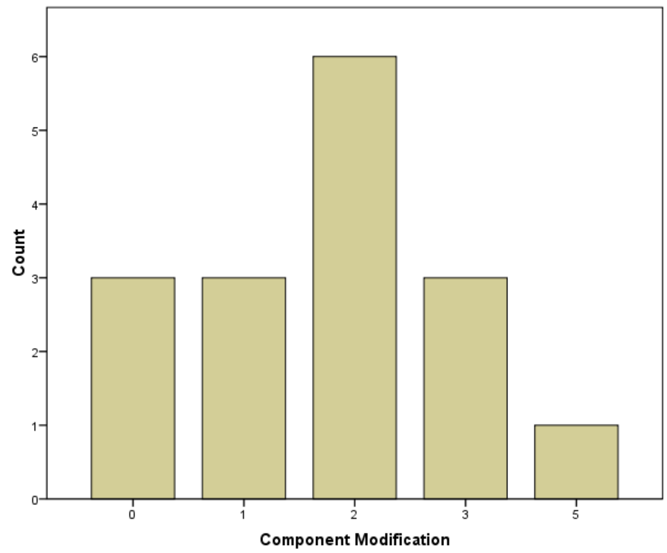

Figure 28 Histogram of number of modifications to the default characteristics of the components provided to the participants

A one-way ANCOVA of the customization data (number of features, number of modifications) based on gender with spatial ability as a covariate found no significant results.

7.2.6 Discussion

Customization is an opportunity for users to modify a system to fit personal preferences and improve task performance. Trail Following Experiment Two was carried out to determine if the set of tools a user picks to follow a trail differ from the toolset provided as part of the proposed default VTrail trail following interface and if customization would result in improved performance.

Contrary to expectations, participants did not use any additional interface components to aid wayfinding performance. Overall, participants did make modifications to the default properties of the components, but no more than a couple of changes (e.g. repositioning, resizing, turning an interface component on or off), which is similar to the customization behavior observed in TB2.

Participants did not have a significant preference for the default interface or the customized interface. The difference in the ease of learning between the default and customizable interface may be due to the usability questionnaire not distinguishing between ease of learning the interface and ease of learning the customization screens, but participants found it easier to use the default interface. Difficulty in using the customization screens and the sluggish system response to the user's efforts to customize may have hindered participant's ability to create exactly the intended "right" interface configuration.

There were no significant performance results in terms of task accuracy, task time or distance traveled. The lack of significant results suggests that users did not achieve any meaningful performance benefits from customization. Since trail following is not a cognitively demanding task even with the demands of a memory task, there is likely to be no performance difference between novice and experience trail followers. Providing the ability to customize the trail following interface appears to be unnecessary from a performance perspective. However, the customization function should continue to be available on the VTrail system as it could be useful to researchers interested in manipulating the interface design in future studies.

Modifications to proposed interface

Based on the results from TF2, participants did not make a sufficient number of changes to the default interface to warrant a redesign in terms of the features. However, based on user feedback there are some changes that need to be made to the design of some features, as well as to the system behaviour.

It was observed that some participants failed to detect information embedded in the markers. Failure to notice the information may be due to the fact that once a building was identified with a POI marker, the participant was able to easily decide the appropriate item to delivery. Larger sets of delivery items would make a memorization task more challenging and may increase the reliance on the embedded information. There was no information embedded in the directional markers used to mark the trail so it is not possible to determine if any information provided in that context would be noticed. To facilitate the detection of embedded information one solution is to overlay the information over the marker as the user approaches or make the trail markers more dynamic so as to provide a visual signal to indicate the presence of information

Participants provided suggestions for changes to the VTrail System behaviour. The first recommendation was to change the system so that the interface is not persistent. Although the screen real estate devoted to the VTrail interface is small, participants mentioned the possibility of having the information hidden and easily triggered to appear. Another recommendation to consider is providing the trail follower with the ability to mark departures from the trail to facilitate returning. However, providing the trail follower with the ability to add information into the environment raises the issue of supporting transitions between the role of trailblazer to the role of trail follower and vice versa, particularly since each role, for now, has a different interface.

Chapter 8
Contributions to Research Tools and Theory

This research project was primarily an exploratory exercise into the design issues associated with creating an interface to support trailblazing in VEs However, in the process of achieving the main objective there were unexpected outcomes including: the development of a novel approach to measuring spatial knowledge, an investigation into the effect of individual differences, and a new method to evaluate virtual trail quality from a user's perspective.

8.1 Spatial Knowledge Acquisition Test

The common approach to assessing spatial knowledge acquisition is to make use of tests that require the participants to either draw the environment or provide verbal answers to questions about structure of the environment (i.e. the bakery is North of the gas station). These tests are dependent on the participant's ability to draw, or verbalize spatial knowledge. This study proposes a novel method of assessing spatial knowledge acquisition called the Spatial Knowledge Acquisition Test (SKAT).

The SKAT is a puzzle where each puzzle piece represents a portion of the environment that the user has just explored. The puzzle pieces are square and uniform in size and lack information that might suggest any relationship to an adjacent tile. Each piece contains an image of a building depicted as they appear from an angle 10° from a birds-eye view. An off-angle representation provides information about the height and appearance of the front of the building. Additional puzzle pieces representing features not in the environment are included as a distracter set. After exploring an environment the participant is asked to place the pieces in the correct location and with the correct orientation on a test scorecard, see Appendix E, provided to them. To discourage guessing participants are penalized for incorrect responses, and a time limit is added to ensure uniform time between participants. While eliminating the time restriction may improve performance on the SKAT, it may obscure differences between different levels of ability. Before the SKAT can be widely and reliably used it must be validated through further studies.

8.1.1 Objectives

The purpose of this study was to determine if the proposed SKAT can be used as a means of assessing spatial knowledge acquired through VE experience.

The study used a between participant design with gender (male, female) and number of distractors (6, 9), and Previous Experience (Trailblazer, Trail Follower) with spatial ability as a covariate. Since some participants completed the SKAT having previous experience only as a trailblazer and others had experience only as a trail follower, the previous experience factor is included in the model. Spatial ability, as measured by the cube comparison test from the ETS (Elkstrom et al., 1976), is included as a covariate in the analysis. The dependent variables used to assess performance on the SKAT were:

- Target Identification Score (TIS): score based on the number of correct puzzle pieces identified.
- Target Location Score (TLS): score based on the number of puzzle pieces placed in the correct location.
- Target Orientation Score (TOS): score based on the number of puzzle pieces placed in the correct orientation, based on the participants perceived starting location.

The data used for the analysis of the SKAT was from the control conditions of the trailblazing (TB1, TB2) and trail following (TF1, TF2) studies since the participant is performing the delivery task without the benefit of an interface.

Hypothesis 1.1: There will be a significant positive correlation between spatial ability and TIS, TLS and TOS.

Rationale: Spatially ability is consistently linked with the ability to learn the structure of an environment. The SKAT is a measure of the participant’s ability to recreate an explored environment.

Hypothesis 1.2: Males will score higher than females for the TOS SKAT measure.

Rationale: Since the cube comparison test and SKAT are similar, the gender difference predicted by the cube comparison test will exist in the SKAT.

Hypothesis 1.3: There will be a significant difference in the scores for all three SKAT results (TIS, TLS, TOS) due to the size of the distractor set.

Rationale: The increase in the distractor set will influence SKAT performance due the decreased probability of successfully guessing a tile.

8.1.2 Material

For the purpose of this study, the environments used in the assessment of the SKAT were constructed in the form of a 3x3 matrix, consisting of nine square puzzle pieces each 100m x 100m. The environment represented a rural setting with no road network to provide information about adjacent tiles. Each puzzle piece contained a large feature (e.g. a building), a smaller feature (e.g. windmill), and assorted vegetation (e.g. trees and bushes). The purpose of the small feature was to aid with determining the correct orientation of the puzzle piece. Each tile was laminated to avoid showing signs of usage, and a number was printed on the back to facilitate recording of the participants’ response on the SKAT Scorecard, see Appendix E.

8.1.3 Participants

The 56 participants (28 male, 28 female) in this study were the same sample that participated in the trailblazing and trail following studies described in Chapters 6 and 7. From this group, 24 participants were in Group One (G1) with only 6 distractors and 32 participants were in Group Two (G2) with 9 distractors. Participants received monetary compensation as part of participating in the VTrail interface validation studies.

8.1.4 Procedure

Data Collection

The data used in the analysis of the SKAT was collected as part of the studies on the validation of the VTrail interfaces. Participants had already completed one familiarization trial and two experimental trials using the VTrail interfaces. Participants were provided instructions on how to complete the SKAT at the end of the familiarization trial and had opportunities to perform the SKAT after the first and second experimental trials in the interface validation studies. Only the data from the control trial (no interface assistance), which was the third experimental trial for all participants, was used in the analysis of the SKAT.

The third trial was always the control condition and was similar between groups performing the trailblazing studies or the trail following studies. The control condition required the participant to complete a delivery task, in which five items were dropped off at the appropriate locations in the environment as quickly as possible. Once the items were delivered, the participant returned to the starting location to end the trial. The amount of time spent in the environment by the participant was limited to 10 minutes to discourage participants from exploring the environment solely for the purpose of improving performance on the SKAT.

At the end of the trial the participant was provided with the SKAT template and the puzzle pieces, including the distracter set, necessary to recreate the environment. The participant was given 5 minutes to complete the SKAT. Once the time was up, the participant was asked to mark his perceived starting position on the map.

Test Scoring

Participants were not provided with any means of determining their orientation in the world, so it was expected that participants would assume that they started at the bottom (south) end of the world and generate the world map based on a North Up orientation, despite the fact that the starting position was sometimes on the East, West or North sides of the world. Consequently, the evaluator of the SKAT rotated the participant-generated map such that the user's perceived starting position matched the same side as the actual starting position.

To determine the building identification score, the SKAT evaluator counted the number of correct buildings identified, regardless of location and orientation, and subtracted half a point for every incorrect building identified. Blank spots were not penalized to discourage guessing. For G1 there were nine possible correct tiles and six possible incorrect tiles resulting in the worst possible score being zero (3 correct - 6 incorrect x 0.5 = 0). Due to the increase in the number of distracter tiles for G2, it is possible to achieve a negative score (0 correct – 9 incorrect x 0.5 = -4.5).

The building location score and building orientation score were calculated in a manner similar to the building identification score. However, penalties were only based on the number of correctly identified buildings in the incorrect location to avoid a double penalty by having incorrectly identified a building. For example, if a participant correctly identified eight buildings but only six were in the correct locations the participants Tile Location Score (TLS) would be five (6 correct – 2 incorrect x 0.5 = 5). For the building location score only buildings in the correct location regardless of orientation, after taking into account the possible global rotation are assigned a point, and incorrect buildings are a half point deduction, and no deductions for blanks. For the building orientation score only buildings with the correct orientation, regardless of location, after taking into account the possible global rotation are assigned a point, and incorrect buildings are a half point deduction, and no deductions for blanks.

8.1.5 Results

A 2x2x2 (Gender, Previous Experience, Group Number) ANOVA was performed on the spatial ability data to determine if there were any differences between the participant groups. Based on the outcome there were no significant differences in spatial ability.

The TIS, TLS and TOS data was analyzed using a 2x2x2 Analysis of Covariance (ANCOVA) with spatial ability as a covariate.

For the TIS data the main effect Group Number, $F(1,47) = 25.56$, $p < .001$, was significant. G1 scored higher on average ($M = 7.27$, $SE = 0.27$) compared to G2 ($M = 5.49$, $SE = 0.23$). Spatial ability was a significant factor, $F(1, 47) = 30.58$, $p < .001$. The main effect of Gender was nearly significant, $F(1, 47) = 3.86$, $p < .055$. Correlation analysis of TIS and Spatial ability was significant, $r(56) = .588$, $p < 0.01$.

The TLS found only the covariate of spatial ability was a significant predictor, $F(1, 47) = 26.37$, $p < .001$. Spatial ability is positively correlated to TLS, $r(56) = .544$, $p < 0.01$. There were no other significant results.

For the TOS data spatial ability reached significance, $F(1, 47) = 13.84$, $p < .005$. Spatial ability was positively related to TOS, $r(56) = .436$, $p < 0.01$. There were no other significant effects.

8.1.6 Discussion

The objective of this study was to explore the potential of a novel tool, SKAT, as a means of assessing spatial knowledge acquired while performing a task in a virtual environment. The SKAT collected three pieces of information, TIS, TLS and TOS, which was used to assess the participant's knowledge of building identification, building location and building orientation respectively.

As hypothesized, spatial ability was significantly correlated to TIS, TLS and TOS. This suggests that the SKAT could be considered a valid measure of spatial ability, which is linked to spatial knowledge acquisition. Overall, spatial ability moderately correlated to performance on the SKAT. A minimum correlation of at least .70, with an ideal Pearson value around .9- .95, is desired to claim the SKAT as a successful measure of spatial knowledge acquisition. However the current results show that the SKAT has promise as a measurement tool.

The difference in TIS between G1 and G2 was expected due to the increase in the number of distractor tiles. Participants in G1 had a higher probability (4 correct non-target tiles, 6 distractor tiles) of guessing the correct non-target building tile, compared to G2 (4 correct non-target tiles, 9 distractor tiles). A similar effect was expected for all three SKT measures (TIS, TLI, TOS), but since the score of the TLS and TOS was calculated based on the TIS, the total number of distractor tiles does not affect the TLS, TOS.

To achieve the desired level additional modifications to the SKAT test are necessary. For example the SKAT should be broken into a set of 3 independent sub-tests, where a participant is given a fixed period of time for each sub-test. In the first test the participant is asked to identify the buildings in the environment. In the second round participants places the buildings in the desired locations. In the third round participants orientates the buildings to the desired orientations. These three steps ensure the results are independent of each other.

Another means of increasing potential uses of the SKAT is to compare the actual starting location to the participant's perceived starting location as a measure of the starting location error.

Future steps for the development of the SKAT should be directed towards investigating the reliability of the measure, by recruiting a group of participants to perform the SKAT at least two times with a period of time between each instance of taking the test. Finally, the SKAT would benefit from digitalization, which will reduce time required to analyze the results.

8.2 Role of Individual Differences

Dillon and Watson (1996) suggest that there is a great need to understand how individual differences impact the design of human computer interaction. Two key individual differences that affect wayfinding performance, spatial ability and gender, were included to determine the impact on interface design.

8.2.1 Spatial Ability

Spatial ability had been linked to wayfinding performance in the real world (Malinowski & Gillespie, 2001), and improved spatial knowledge acquisition in VE (Bailey, 1994; Darken & Sibert, 1996). However, the literature discussing the impact of spatial ability on interface design for spatial wayfinding is limited (Chen, Czerwinsk & Macredie, 2000).

To determine if there was a relationship between spatial ability and interface features a correlation analysis of the usability results was performed. The spatial ability of the participant did not influence the ranking of the interface features. While the inclusion of additional interface components is not beneficial to individuals with high spatial scores, providing additional support is not a hindrance. Therefore, providing an alternative design of the VTrail interface to accommodate individuals with a high spatial score does not appear to be necessary.

However, the results reaffirm the relationship between spatial ability and performance on wayfinding tasks in VE. In all trailblazing and trail following experiments a higher spatial ability score resulted in shorter time and less distance traveled to accomplish the delivery task. Higher spatial scores were also positively correlated with improved spatial knowledge acquisition as measured by the SKAT.

Another interesting result was the lack of a significant difference between the genders in terms of the spatial ability score. The pre-trial spatial ability measure predicted (Elkstrom et al., 1976) that males would score higher than females on the mental rotation task. Participants were recruited from engineering, math, science and arts faculties with no gender predominantly from a single faculty. This result may be an anomaly due to the population sample or may be indicative of a decrease in spatial ability differences between the genders.

8.2.2 Gender

An issue common to all research in human wayfinding is gender differences. Although suggesting the need for different interface designs for each gender is controversial, previous studies (Tan et al., 2006) found that accommodating gender differences results in equitable performance in VE.

For TB1 and TF1 there were significant and near significant interactions between gender and interface. In both experiments females performed the delivery task better with the default interface compared to the minimum interface, and vice versa for males. The performance gain for females from the inclusion of the additional information on the default is larger than the performance decrement to males. In selecting the final design for the VTrail interface the decision is use a a design that is equally usable by both genders. Although an argument can be made for having a male and female version of the VTrail default interface, spatial ability is the stronger predictor of wayfinding performance and there appears to be no difference in spatial ability between genders where these experiments were concerned.

Performance differences between genders can be explained by differences in computer gaming preferences. Although the factor of computer gaming experience was included to filter out inexperienced computer users from the study, the questionnaire does not differentiate the type of computer games played. Cassell and Jenkins (1998) found that playing computer games contributes to skill development and competitive advantages. Lucas and Sherry (2004) found that females are less likely to play competitive computer games and games that involve 3D orientation. The difference in computer game preference by gender may contribute to the development of different skills and different levels of experience with the controls for interacting with the VE, which replicated typical first person games. Future studies will need to take into consideration the nature of the computer games regularly played by participants to help manage gender difference results.

Another result to highlight is from TB2, where there is a near significant effect of gender on trail quality. Since the time and distance measures based on gender were not significant, this result suggests that females generated slightly better trails, without engaging in any activities that had additional costs not associated with moving around the environment and placing markers. Female participants dropped more markers (M = 19.2, SD = 18.7) compared to males (M = 16.3, SD = 11.5). The variation of a couple markers can be the difference between finding the way around and getting lost. Dropping additional markers may also be a result of low confidence in wayfinding abilities. A previous study (Lawton, 1994) found that females had a lower self-rated level of self-confidence in wayfinding. To compensate for a perceived weakness in wayfinding ability the user adds additional information into the environment. While it is difficult to clearly explain this behaviour the near significant result demonstrates that a gender factor should continue to be considered in future studies investigating wayfinding.

8.3 Trail Quality Questionnaire

A key measure for assessing the performance of the interfaces was the metric of trail quality. Although trails can be evaluated using quantitative measures similar to the TSP, this research project set out to evaluate the trails based on qualitative measures from the perspective of the trail user. Approaches to evaluating trails in the real world include physical factors that are not applicable in a VE. By modifying the guidelines used by Parks Canada (1978) a set of criteria for evaluating virtual trail quality, in the form of the Trail Quality Questionnaire (TQQ), were proposed.

Analysis of the TQQ data found no significant difference between the trails generated by different interfaces within each experiment. However, a t-test comparison of trail quality generated by the default interface in TB1 and TB2 found a significant difference, $t(26) = 4.52$, $p < .05$. Default trails from TB2 had a mean score of 35.9 (SD = 4.72) compared to a mean of 30.8 (SD = 7.59) for default trail in TB1. Since there was no difference in the spatial abilities between the two sample groups, the difference is due to improved support for trailblazing by the modified default interface. This result, combined with the detected gender difference in trail quality in TB2, demonstrates that the TQQ is capable of distinguishing between trails of different levels of quality. The TQQ was an attempt to qualitatively evaluate trail quality and these results indicate that the measure shows promise, but additional refinement is necessary.

One limitation of these studies is that only the top rated trail was used for the trail following experiments. Future use of the TQQ should make use of the top and lowest rated trails to determine if there is a noticeable effect on trail following performance. Despite using the highest rated trails for TF1 and TF2, participants strayed from the trail. Not remaining on the trail indicates that participants may not have considered the trail to be "very good", which contradicts the results from the TQQ, or that participants did not trust the trail.

The lack of trust between the trailblazer and trail follower is a concern. When navigating around an airport or large building people follow the provided guidance because there is an assumed level of trust in the authority of the people that placed the signage. During the trail following studies, participants were informed that a previous participant created the trail to aid in completing the task. It is possible that the trail follower presumed that the trailblazer lacked the authority or ability to create a reliable trail. The issue of trust in content created by strangers is interesting given the growth of social media on the Internet and other applications. The current effort to commercialize the VTrail depends on the acceptability and trust of social media. A variation of the trail following studies could determine if claiming the researcher created the trail would result in a higher number of participants trusting the trail. Alternatively, having the two participants meet prior to the study may result in improved trail quality, or trust in the trails since either party will now know each other resulting increased sense of responsibility.

Chapter 9
Conclusion

The slow adoption of 3D technology can be attributed, in part, to the lack of useful tools for interacting with VEs. The current approach of developing a single tool for all types of navigation is unworkable because not all navigational tasks are the same. Navigation is a complex skill that is comprised of both physical and cognitive components, and each component can be further broken down. To achieve success with the acceptability of 3D interactions, there is a need for more specificity in the design of interaction tools.

This research project continues the development of a VE tool designed to support the wayfinding behaviour known as virtual trailblazing. The role of the trailblazer is to explore unfamiliar environments and provide guidance to others that follow by marking a trail. While trailblazing may be a disappearing skill in a world filled with digital navigation aids, trailblazing can be beneficial in VE. The VTrail System was created to support effective trailblazing and guidance for training in a VE.

The primary objective of this research project was to design and validate a default VTrail interface that adheres to the guidelines of simplicity, universality, and non-interference with primary task performance. The VTrail interface started off as a concept and after preliminary research took form as a paper prototype. Following a scenario-based task analysis, the VTrail interface evolved into the prototype implemented on the QUAKE gaming platform and subsequently the VNCEP platform. Following two design iterations where participants used the VTrail to perform either a trailblazing or trail following task, the design of the default VTrail interface is complete and the result is two interfaces, one for trailblazing and one for trail following.

The original design of trailblazing interface maintained simplicity in the design and number of features provided to the user. To avoid complexity in learning how to use the interface, components, like the compass, map and position coordinates, were provided as individual features rather than integrating all the devices into a single more complex feature. The goal was to ensure participants would make use of previous knowledge of how the individual components behave to aid in trailblazing. However, it became clear that most users were novices due to the novelty of trailblazing and unsure how to use traditional wayfinding devices. For example, one participant, having delivered the final package, determined the location of the starting marker from the information display, but could not figure out how to use the positional information to find the way back to the starting location. Although participants expressed a preference for the default interface there were no significant performance benefits compared to the minimum interface.

The solution was to reduce the number of features to minimize visual clutter and maintain the overall simplicity of the overall interface, at the cost of increased complexity of the features by integrating related information. For example, the compass was integrated into the mini-map and participants now need to infer heading based on the direction of the arrow on the north-up map. The participants in the first study created the trail as they explored the environment and generally did not review or modify the trail once the delivery task had been completed and the participant was back at the starting location. The trail overview information is provided in case the user modifies the trail and wants to see how the change affects the time and distance to follow the trail. Based on the results of the second trailblazing study, there is little need for any additional modifications to the proposed trailblazing interface. However, participant feedback did indicate frustration with the customization screens.

Unlike trailblazing, trail following is not a cognitively demanding task, and users do not require much more information to follow the trail other than the directional markers in the environment. However, when the user strays from the path the system must provide additional support. In the initial prototype the user was able to lookup the location of the nearest trail marker and make use of the co-ordinates to find the way back onto the trail. Since users did not make use of the marker information, the feature was removed from the design for the second experiment. Post-trial discussion indicated that the participants did not trust the provided trail and believed that they could do a better job. Lack of trust may be due to the fact that the user was not provided with any information on the structure of the trail.

The second implementation of the trail following interface included additional information about the structure of the trail in the attempt to increase the level of trust in the trail follower. However, since participants in the second study continued to venture off the trail, it appears that the trail information, though useful, did not ensure participants remained on the trail. Therefore, the design of the interface needs to provide guidance back to the path when the user strays. Finally, providing increased interface customization may not be useful for trail following, the simplicity of trail following ensures that there is likely little room for improvement gain from experience other than through improved controls.

While the primary objective of this research project was the design of a default interface to be used with the VTrail System, there were secondary benefits from the research such as the Trail Quality Questionnaire, SKAT and individual differences results.

Trails generated during the trailblazing study were evaluated using the proposed TQQ, a qualitative approach to evaluating a trail. The TQQ is based on a modified set of guidelines used by Parks Canada and takes into consideration the structure of the trail, the use of directional information and overall trail following experience. The TQQ was created to help evaluate a trail from the users' perspective rather than a traditional approach based on graph theory.

The research project also resulted in the design and use of a novel form of measuring spatial knowledge acquired during the use of a VE. By asking participants to recreate the environment using uniformly shaped pieces of a puzzle the SKAT eliminates the dependency on artistic ability prevalent in pencil and paper based measures. The SKAT measured the participant's ability to identify, position and orientate the buildings to recreate the environment. The measure also captures the participant's perception of starting location, which can be used to calculate an error measure. Further refinement of the SKAT is necessary to continue to improve the tool.

The expectation that gender would influence the interface design was validated by the user studies. The results suggest that females performed the trailblazing and trail following task better when using the default VTrail interface compared to a map and compass. The novelty of the trailblazing task reduced the experience gap that exists between the genders, but the interaction between the interface and gender on the trail following task is indicative of possible gender differences. Although male performance was not as good with the default interface as compared to the minimum interface, the decision to use the default interface is a compromise solution to support users of both genders. Additional research on identifying differences between the genders in wayfinding could lead to improved interface designs.

The gender difference is unrelated to spatial ability since there were no noticeable differences between the spatial ability of males and females in these experiments. The cube comparison task used to measure spatial ability predicted a gender difference. However, the measure is based on results from studies conducted in the 1970's and may not reflect the changes in gender abilities.

Although gender may not have been a reliable predictor of task performance, spatial ability was consistently linked to task performance. Individuals with a higher spatial ability performed the trailblazing task faster, traveled less, and remembered more about the environment than individuals with a lower spatial aptitude. There is no indication that individuals with higher spatial scores require or prefer a different set of tools or interface design.

The VTrail now has a user friendly interface and can be integrated into the training simulations. The potential for the VTrail extends beyond just virtual training simulators. Possible applications range from use in military operations to providing an enhanced tourism experience. However, more research is required to move the VTrail to the next step in its evolution. It is time to start creating the tools so that the next generation of trailblazers can open up new frontiers for everyone.

9.1 Future Work

In the immediate future there is a need to adapt the current proposed VTrail interface for a different platform. Currently there is an effort to commercialize the VTrail on smart phones, which are capable of providing real-time location based services to users. However, there are two challenges to adapting the VTrail for a mobile platform. First, the directional markers are not currently feasible for a mobile phone platform, so the system will be redesigned to provide a new means of indicating changes in path direction. Second, the mobile screen is much smaller so the sizing and placement of the interface components will need to be reconsidered. However, the experience and understanding of user needs for trailblazing and trail following gained through this research will facilitate that design process.

The next step forward is to address design and human performance issues when the VTrail System is implemented on an AR platform. The redesign of the interface will need to be examined given the varied nature in the controls between interacting with a VE and an AR. However, the successful implementation on an AR platform increases the range of possible applications of the VTrail to any situation where embedding information in the real world is needed. For example, after natural disasters, wayfinding can be difficult due to the loss of landmarks and changes in the landscape. However, virtual landmarks are unaffected by changes in the surrounding environment.

The SKAT is a novel approach to measuring the acquisition of spatial knowledge and has shown great potential. However, additional research focused on ensuring the validity and reliability of the SKAT is necessary. Future studies can also look at manipulating other factors in the SKAT setup, such as the complexity of the puzzle, the number of distracters, and the time limit for completing the test. Furthermore, processing the data gathered from the SKAT is time consuming, so digitalizing the test will facilitate the evaluation of the data.

Another measure from the study that could use some additional refinement is the TTQ. To determine if the measure has sufficient resolution to differentiate between low quality and high quality trails requires a comparative study. Further research can also explore the possibility of introducing a quantitative measure into evaluating trail quality.

There is a need for an improved understanding of the factors that lead someone to trust or distrust the reliability of a trail. There is no point in differentiating between high and low quality trails if users do not make use of the trail. Future research might investigate questions like: what factors can lead to distrust of a trail, particularly trails that do not provide any social navigation cues; and what effect does environmental complexity, knowledge of trailblazer expertise play in the level of trust in the trail?

Finally, all the participants in this research project were novice trailblazers and completed a single trailblazing sessions consisting of two trials. Future studies should explore the effect of experience on trail quality. From a design perspective, it would be helpful to know whether multiple trailblazing sessions result in improved trail quality (for the trailblazer) and improved navigation performance and improved trail quality (for the trail follower); and whether or not increased familiarity with trail tasks would change the user perceptions of which interface components are of most value to aid overall performance.

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Glossary

ANCOVA	Analysis of Covariance
AR	Augmented Reality
DD	Delivery Distance
DDM	Degrees Decimal Minutes
DT	Delivery Time
DMS	Degrees/Minutes/Seconds
DRDC	Defense Research and Development Canada
FIND	Future Infantry Navigation Device
GIS	Geographical Information Systems
GPS	Global Positioning Systems
GUI	Graphical User Interface
HMD	Head Mounted Display
RD	Return Distance
RT	Return Time
SKAT	Spatial Knowledge Acquisition Test
TD	Total Distance
TB1	Trailblazing Experiment One
TB2	Trailblazing Experiment Two
TF1	Trail Following Experiment One
TF1	Trail Following Experiment Two
TIS	Target Identification Score
TLS	Target Location Score
TOS	Target Orientation Score
TS	Task Score
TT	Total Time
TSP	Traveling Salesman Problem
TTQ	Trail Quality Questionnaire
UTM	Universal Transverse Mercator
VE	Virtual Environment
VNCEP	Virtual Navigation and Collaborative Environment Platform

Appendix A
Completed Office of Research Ethics Documents

A. GENERAL INFORMATION

1. Title of Project: Design and Validation of Virtual Trailblazing and Guidance Interfaces for the VTrail System

2. Principal and Co- Investigator (List Principal Investigator FIRST)

Faculty [ ] Post-doctoral [ ] Administration [ ] Research Associate [ ]

Name Department Ext: e-mail:

Co-Investigator(s)

Faculty [ ] Post-doctoral [ ] Administration [ ] Research Associate [ ]

Name Department Ext: e-mail:

3. Collaborator(s)

Name Department Ext. e-mail:

4. Faculty Supervisor(s) Carolyn MacGregor Department Systems Design

Eng Ext: e-mail:

5. Student Investigator(s) Daniel Iaboni Department Systems Ext: 35607 e-mail:

diaboni@engmail.uwaterloo.ca Local Telephone Number: 597-3270

6. Level of Project: Faculty Research [ ] Post-doctoral Research [ ]

Thesis Research:

Ph.D. [X] M.A. [ ] M.Acc. [ ] M.E.S. [ ] M.A.Sc. []

M.Math. [ ] M.Phil. [ ] M.Sc. [ ] Honours [ ]

Non-thesis Course Projects: Undergraduate [ ] Graduate [ ]

Specify course and number: Administration [ ] Other, specify

Research Project/Course Status:

New Project/Course [ ] Renewal [ ] of ORE # Pilot Research [X]

7. Funding Status:

Is this project currently funded? Yes [X] No [ ]

If Yes, provide: Name of Sponsor CRESTech

Period of Funding: 2004-2008

If No, is funding being sought? Yes [ ] No [ ]

Name of Sponsor (s)

Period of Funding:

8. Is this research a multi-centre study? Yes [ ] No [x]

If Yes, what other institutions are involved?

9. Has this proposal been submitted to any other Research Ethics Board/Institutional Review Board? Yes [ ] No [x]

If Yes, provide the name of the REB/IRB, date of ethics review, and decision.

10. For Undergraduate and Graduate Thesis Research:

Has this proposal received approval of a Department Thesis Committee?

Yes [ ] No, approval pending [ ] No, not a departmental requirement [x]

If Yes or Approval pending, provide approval date

11. a. Indicate the anticipated commencement date for this project: 05/1/08

b. Indicate the anticipated completion date for this project: 12/31/08

B. SUMMARY OF PROPOSED RESEARCH

1. Purpose and Rationale for Proposed Research

a. Briefly describe the purpose (objectives) and rationale of the proposed project and include any hypothesis(es)/research questions to be investigated. Where available, include a copy of the research proposal.

Although there is great potential for the use of virtual environments, there are limitations that still need to be addressed. One of the key concerns is the tendency for users to become disoriented and lost in large-scale environments. Addressing this issue requires the development of specialized navigational tools to assist the users.

To help counter the effects of navigator disorientation in virtual environments and 3D simulations, Prof MacGregor and her students working in the Use-IT Lab are developing a software-based navigational aid called the Virtual Trailblazing (VTrail) System. The VTrail System allows users to place markers at locations of their choosing that can be used as future reference points or way points for other users. However, before the design of the virtual trailblazing techniques can be completed, experimental work must be conducted to determine the most effective configuration and features of the virtual markers so they are distinguishable from the environment in which they are placed and so they are effective at communicating direction in both sparse and dense environments.

In an initial study (ORE # - 11441) it was determined that an implicit directional marker (e.g. the shape of an object suggests direction) can be recognized at a greater distance than an explicit marker (e.g. an arrow or word) for navigation in a 3D virtual world. Another study (ORE # 12122) explored the effect of marker design on trail following performance. The objective of the currently proposed study is to investigate the design of the interface to determine the configuration and layout that is easy to learn, easy to use and results in improved performance on a trailblazing task.

A study consisting of two experiments will be conducted to determine if different interface designs can improve participant performance when trailblazing or trail following in virtual environments. In the first study the participants are told to create a path for the delivery of a small number of parcels. A sample of trails identified as poor and good quality will then be used in the second study where participants will be asked to fallow the trail to delivery a small number of parcels before returning to the starting location. Participants in both studies will complete a spatial knowledge test to ascertain the role of interface design on spatial learning. In addition, participants will also be asked to complete questionnaires concerning the perceived usability of the interfaces. The results of this research project will help determine design parameters for the VTrail interface.

b. In LAY LANGUAGE, provide a one paragraph (approximately 100 words) summary of the project including purpose, the anticipated potential benefits, and basic procedures used.

One of the key limitations of virtual environments is the tendency for users to become disoriented and lost in large-scale environments. Prof MacGregor and her students are developing a software-based navigational aid called the Virtual Trailblazing (VTrail) System. Experimental work must be conducted to determine the most effective configuration of the interface.

Two experiments will be conducted to determine the effect of interface design on performance of trailblazing and trail following tasks. For the trailblazing task participants are asked to create a trail that will be used by others and provide feedback on the usability of the interface. Participants in the trail following task will follow a path an provide feedback on the design of the interface. The results of this research project will help determine design parameters for the VTrail System interface.

C. DETAILS OF THE STUDY

1. Methodology/Procedures

a. Which of the following procedures will be used? Provide a copy of all materials to be used in this study.

( ) Survey(s) or questionnaire(s) (mail-back) Are they standardized?

All ( ) Some ( ) No ( )

(x) Survey(s) or questionnaire(s) (in person) Are they standardized?

All ( ) Some (x) None ( )

(x) Computer-administered task(s) or survey(s) Are they standardized?

All ( ) Some ( ) None (x)

( ) Interview(s) (in person)

( ) Interview(s) (by telephone)

( ) Focus group(s) ( ) Audiotaping

( ) Videotaping

( ) Invasive physiological measurement

( ) Venipuncture

( ) Catheter insertions

( ) Muscle biopsies

( ) Other tissue samples Specify

( ) Non-invasive physiological measurement

( ) Exercise

( ) Muscle stimulation

( ) Electromyography

( ) Heart rate

( ) Blood pressure

( ) Analysis of secondary data set (no involvement with human participants)

(x) Unobtrusive observations

Other Specify

b. Provide a brief, sequential description of the procedures to be used in this study. For studies involving multiple procedures or sessions, use of a flow chart is recommended.

Different participants will be recruited for each of the two studies in the research project (24-40) participants per study). Each study will consist of 2 experiments, described below.

Experiment One

1. The study Information/Consent Letter (1-2 mins) - provided to the participant to read and sign.
2. Background Questionnaire (2-3 mins)– collects basic information on demographics and self-report experience with virtual environments, 3D video games, navigational experience.
3. Cube Comparison Test – pencil and paper survey to measure individual spatial ability. (5 mins)

4. Familiarization with equipment setup (1-3 mins)

5. Experimental Trials –3 trials in total with each trial consisting of the following steps.

a. Trailblazing task (15 mins) – generate a trail to facilitate the delivery of 5 parcels to their appropriate locations.

b. Usability Questionnaire on Interface Design (2-3 mins)

c. Spatial knowledge survey (5 mins) – assesses the amount and accuracy of spatial knowledge of the virtual environment acquired during the experimental trial.

6. Feedback Letter and Thank you (cookies and beverage, an opportunity to play Wii on large screen, dispensation of study compensation)

Experiment Two

1. The study Information/Consent Letter (1-2 mins) - Appendix B - provided to the participant to read and sign.

2. Background Questionnaire (2-3 mins) – See Appendix D– collects basic information on demographics and self-report experience with virtual environments, 3D video games, navigational experience.

3. Cube Comparison Test – pencil and paper survey to measure individual spatial ability. (5 mins)

4. Familiarization with equipment setup (1-3 mins)

5. Experimental Trials –3 trials in total with each trial consisting of the following steps.

a. Trailblazing task (15 mins) – generate a trail to facilitate the delivery of 5 parcels to their appropriate locations.

b. Usability Questionnaire on Interface Design (2-3 mins)

c. Spatial knowledge survey (5 mins) – assesses the amount and accuracy of spatial knowledge of the virtual environment acquired during the experimental trial.

6. Feedback Letter and Thank you (cookies and beverage, an opportunity to play Wii on large screen, dispensation of study compensation)

c. Will this study involve the administration of any drugs? Yes () No(x)

If Yes, specify drugs, dose and administration route.

2. Participants Involved in the Study

a. Indicate who will be recruited as potential participants in this study.

UW Participants:

(x) Undergraduate students

(x) Graduate students

( ) Faculty and/or staff

Non-UW Participants:

( ) Children

( ) Adolescents

( ) Adults

( ) Seniors

( )Persons in Institutional Settings (e.g. Nursing Homes, Correctional Facilities)

Other (specify)

b. Describe the potential participants in this study including group a gender, age range and any other special characteristics. If only one gender is to be recruited, provide a justification or this.

University of Waterloo undergraduate or graduate students, equal number of female and male are required. Experiences with virtual worlds or 3D video games are required. Participants require normal or corrected to normal vision, and can not be colour blind as it may interfere with detection of the trail markers.

c. How many participants are expected to be involved in this study?

16-20 participants are required per study (50% male and 50% female preferred).

Gender issues are not the focus of the study; however there gender is a significant factor in wayfinding performance.

3. Recruitment Process and Study Location

a. From what source(s) will the potential participants be recruited?

(X) UW undergraduate and/or graduate classes

(X) UW Psychology Research Experiences Group

( ) Other UW sources (specify) ( ) Local School Boards (ORE Form 102 must be completed)

( ) Kitchener-Waterloo Community

( ) Agencies

( ) Businesses, Industries, Professions

( ) Health care settings, nursing homes, correctional facilities, etc.

( ) Other, specify (e.g. mailing lists)

b. Identify who will recruit potential participants and describe the recruitment process. Provide a copy of any materials to be used for recruitment (e.g. posters(s), flyers, advertisement(s), letter(s), telephone and other verbal scripts).

Daniel Iaboni will be responsible for recruiting participants through flyers and in class presentations. In addition, participant recruits will be recruited using Cogpool available through the UW Psychology Research Experiences Group.

c. Where will the study take place? If procedures involve direct contact with participants or occur in an o completed.

(x) On campus Location: E2-3367

4. Compensation of Participants

Will participants receive compensation (financial or otherwise) for participation?

Yes (X) No () If Yes, provide details: participants recruited either through the direct recruitment or through the Cogpool will be compensated in accordance with the Cogpool guidelines.

5. Feedback to Participants

Briefly describe the plans for provision of feedback and attach a copy of the feedback letter to be used. Wherever possible, written feedback should be provided to study participants including a statement of appreciation, details about the purpose and predictions of the study, contact information for the researchers, and the ethics review and clearance statement.

A copy of the feedback letter is provided in Appendix F. Furthermore, if participants are interested in obtaining a summary of the results, they will be provided with an electronic copy of the results and conclusions upon completion of the study.

D. POTENTIAL BENEFITS FROM THE STUDY

1. Identify and describe any known or anticipated direct benefits to the participants from their involvement in the project.
Participants will have the opportunity to use high-tech visualization equipment and the chance to navigate through novel virtual environments.

2. Identify and describe any known or anticipated benefits to the scientific community/society from this study.
Due to the increasing popularity of using virtual environments (VEs) in a variety of applications from architectural design and remote surgery to pilot training there is increasing need for more e study will aid in the drafting of design guidelines on how to construct landmarks to assist navigation in virtual environments. Improvements in navigation will help alleviate the frustration and time wasted from getting lost or disoriented in VEs.

E. POTENTIAL RISKS TO PARTICIPANTS

1. For each procedure used in this study, provide a description of any known or anticipated risks/stressors to the participants. Consider physiological, psychological, emotional, social, economic, etc. risks/stressors. A study-specific medical screening form must be included when physiological assessments are used and the associated risk(s) to participants is minimal or greater.
( ) No known or anticipated risks. Explain why no risks are anticipated:
(x) Minimal risk. Description of risks:

The study requires the participants to navigate large-scale virtual environments, which may result in the participants feeling lost or disoriented. Furthermore, the study may induce cyber-sickness, with symptoms similar to motion sickness.

( ) Greater than minimal risk Description of risks:

2. Describe the procedures or safeguards in place to protect the physical and psychological health of the participants in light of the risks/stresses identified in D1.

To reduce the risk of cyber-sickness participants will be asked prior to signing the information/consent form, if they are susceptible to motion sickness or have ever had a seizure (asked as one question to protect the individual's medical history). Individuals that are prone to motion sickness or have experienced a seizure will be encouraged to withdraw from the study. During the study there will be two researchers present. One is responsible for running the computer equipment and the other will be acting as the test monitor to oversee the running of the trials and to monitor the participant. The contact information for contacting the hospital, and Prof. MacGregor are located next to the phone in the lab in the event of an emergency. Furthermore, participants can withdraw from the study at any time. At the end of the study participants will be encouraged to remain and play the Wii gaming system or relax until the effects dissipate. The Use-IT Lab has a couch upon which a participant who is not feeling well can lie down. There is an operable window above the couch to allow for fresh air into the Use-IT Lab. In addition, the lab has a sink to provide water if needed while the participant recovers.

F. INFORMED CONSENT PROCESS

1. What process will be used to inform the potential participants about the study details and to obtain their consent for participation?

(X) Information letter with written consent form; provide a copy

( ) Information letter with verbal consent; provide a copy

( ) Information/cover letter; provide a copy

Other (specify)

2. If written consent cannot be obtained from the potential participants, provide
a justification.

3. Does this study involve persons who cannot give their own consent (e.g. minors)? Yes( ) No (X)

If Yes, provide a copy of the Information Letter and Permission Form to be used to obtain permission from those with legal authority to give it.

G. ANONYMITY OF PARTICIPANTS AND CON- FIDENTIALITY OF DATA

1. Explain the procedures to be used to ensure anonymity of participants and confidentiality of data

both during the research and in the release of the findings.

Any data collected will be kept confidential and participant identities will remain anonymous. A numeric code will be the only identifier associated with participant data. Our reports will focus on the average of data across groups of participants. The only people who will have access to the original data are the researchers directly involved with this project. All data will be kept for a minimum of three years. Once we are finished with the data, all written and electronic records will be destroyed.

2. Describe the procedures for securing written records, questionnaires, video/audiotapes and electronic data, etc.

The experiment results will safely stored in Professor MacGregor's Use-IT lab in E2 3367, ext 35607. All paper records will be stored in a locked filing cabinet and all electronic records are stored on a computer that is password protected.

3. Indicate how long the data will be securely stored, the storage location, and the method to be used for final disposition of the data.

(x) Paper Records

(x) Confidential shredding after 3 years

( ) Data will be retained indefinitely in a secure location

( ) Audio/Video Recordings

( ) Erasing of audio/video tapes after years

( ) Data will be retained indefinitely in a secure location

(x) Electronic Data

(x) Erasing of electronic data after 3 years

( ) Data will be retained indefinitely in a secure location

( ) Other (Provide details on type, retention period and final disposition, if applicable)

Specify storage location: E2-3367

4. Are there conditions under which anonymity of participants or confidentiality of data cannot be guaranteed? Yes ( ) No (X)

If Yes, please provide details:

Appendix B
Trailblazing Study Information

Faculty Supervisor: Prof. Carolyn MacGregor
Student Researcher: Daniel Iaboni
Usability & Interactive Technology Lab
Dept of Systems Design Engineering
University of Waterloo
888-4567, Ext. 5607
useitlab@stargate.uwaterloo.ca

Title of Research: Design and Validation of Virtual Trailblazing and Guidance Interfaces for the VTrail System

Study Objectives

We are conducting a study to assess 3 different interfaces designed to aid performance on a trailblazing task in a virtual environment.

Tasks

You will be asked to fill out a participant background questionnaire that includes general demographic questions along with some questions on your familiarity with virtual environments and other types of 3D graphic experiences. This information will help us understand the general backgrounds and experiences of the people who participate in this study. You can decline to answer questions if you wish.

We will then ask you to complete a standard test designed to measure the level of your spatial ability. Spatial ability is a vital correlate to navigation performance and needs to be measured.

We will then help you become familiar with the virtual environment equipment (mouse and keyboard) we will be using for this study. For the main experiment you will asked to complete 3 experimental trials. Each trial consists of a trailblazing task where you are asked to generate a trail that connects 5 delivery destinations. Participants in another study will deliver the 5 parcels using the trails generated from this study. After each trial you will be asked to complete a spatial knowledge test to measure the amount of spatial knowledge acquired during the study. In addition you will be asked to complete a usability questionnaire on the interface you used during the trial. When you have completed the questionnaire you can take a brief 3-5 min break or continue immediately on to the next trial.

To thank you for volunteering your time to help us with our research project, you will be remunerated $10/hour.

Benefits Of Participating In This Study

This study will allow us to determine the design of the interface to be used in the VTrail System. Participants have the benefit of having the opportunity to experience traveling through a large-scale virtual environment using a large screen monitor.

Risks

Individuals that are sensitive to motion sickness may experience symptoms such as nausea and dizziness. As well, since trailblazing is a navigation task, users may become lost in the virtual world. If you experience any symptoms such as nausea, dizziness or become disoriented, notify the experimenter and they will end the study and provide a glass of water and the option to lie down on a couch in the lab until the symptoms dissipate.

Right to Withdraw

You have the right to withdraw from this study at any time. To withdraw from the study, simply tell the research assistant that you withdraw your consent. Any data collected will be excluded from the analysis and destroyed. You will receive remuneration prorated at $10/hour if you withdraw.

Time Commitment

The experimental session should take approximately 2.0 hours of your time.

Recorded Measures

During the study the computer will be measuring the time and distances traveled to complete the trailblazing tasks. This data will be used to determine if there are any performance differences resulting from different interface designs. In addition, an experimenter will be observing your reactions while using the various interfaces. Recorded observations are a means of assessing the interface being tested and not the individual using the interface.

Confidentiality

Any data collected will be kept confidential and your identity will remain anonymous. A numeric code will be the only identifier associated with your data. Our reports will focus on the average of data across groups of participants. The only people who will have access to the original data are the researchers directly involved with this project. All data will be kept for a minimum of three years. Once we are finished with the data, all written and electronic records will be destroyed.

Ethics Review

This research has been reviewed and received ethics clearance through the Office of Research Ethics. In the event you have any questions or concerns about your participation in this study, please contact Dr. Susan Sykes at 519-888-4567, Ext. 36005.

Trail Following Study Information

Faculty Supervisor: Prof. Carolyn MacGregor

Student Researcher: Daniel Iaboni

Usability & Interactive Technology Lab

Dept of Systems Design Engineering

University of Waterloo

888-4567, Ext. 5607

useitlab@stargate.uwaterloo.ca

Title of Research: Design and Validation of Virtual Trailblazing and Guidance Interfaces for the VTrail System

Study Objectives

We are conducting a study to assess 3 different interfaces designed to aid performance on a trail following task in a virtual environment.

Tasks

You will be asked to fill out a participant background questionnaire that includes general demographic questions along with some questions on your familiarity with virtual environments and other types of 3-D graphic experiences. This information will help us understand the general backgrounds and experiences of the people who participate in this study. You have the right to refuse to answer questions.

We will then ask you to complete a standard test designed to measure the level of your spatial ability. Spatial ability is a vital correlate to navigation performance and needs to be measures.

We will then help you become familiar with the virtual environment equipment (mouse and keyboard) we will be using for this study. For the main experiment you will asked to complete 3 experimental trials. Each trial consists of a trail following task where you are asked to follow a path that connects 5 delivery destinations. You are asked to deliver 5 parcels to the appropriate locations.

Upon completing the 5 deliveries you will need to return the starting location to end the trial. After each trial you will be asked to complete a spatial knowledge test to measure the amount of spatial knowledge acquired during the study. In addition you will be asked to complete a usability questionnaire on the interface you used during the trial. When you have completed the questionnaire you can take a brief 3-5 min break or continue immediately on to the next trial.

To thank you for volunteering your time to help us with our research project, you will be compensated $10/hour.

Benefits Of Participating In This Study

This study will allow us to determine the design of the interface to be used in the VTrail System. Participants have the benefit of having the opportunity to experience traveling through a large-scale virtual environment using a large screen monitor.

Risks

Individuals that are sensitive to motion sickness may experience symptoms such as nausea and dizziness. As well, since trailblazing is a navigation task, users may become lost in the virtual world. If you experience any symptoms such as nausea, dizziness or become disoriented, notify the experimenter and they will end the study and provide a glass of water and the option to lie down on the couch in the lab until the symptoms dissipate.

Right to Withdraw

You have the right to withdraw from this study at any time. To withdraw from the study, simply tell the research assistant that you withdraw your consent. Any data collected will be excluded from the analysis and destroyed. You will receive remuneration prorated at $10/hour if you withdraw.

Time Commitment

The experimental session should take approximately 1.0 hour of your time.

Recorded Measures

During the study the computer will be measuring the time and distances traveled to complete the trail following task. This data will be used to determine if there are any performance differences resulting from different interface designs. In addition, an experimenter will be observing your reactions while using the various interfaces. Recorded observations are a means of assessing the interface being tested and not the individual using the interface.

Confidentiality

Any data collected will be kept confidential and your identity will remain anonymous. A numeric code will be the only identifier associated with your data. Our reports will focus on the average of data across groups of participants. The only people who will have access to the original data are the researchers directly involved with this project. All data will be kept for a minimum of three years. Once we are finished with the data, all written and electronic records will be destroyed.

Ethics Review

This research has been reviewed and received ethics clearance through the Office of Research Ethics. In the event you have any questions or concerns about your participation in this study, please contact Dr. Susan Sykes at 519-888-4567

Appendix C
Consent Forms

Trailblazing Study

Participant # ______________.

I agree to participate in the study entitled "Design and Validation of Virtual Trailblazing and Guidance Interfaces for the VTrail System". I have read over the information letter and have had the opportunity to receive additional details about my participation in this study.

I was informed that full participation in this study involves a 2-hour session (approximately).

I was informed that I will be asked to answer a background questionnaire for demographic purposes and complete a spatial ability test. I understand that I will also be asked to perform a trailblazing task using a series of interfaces.

I was informed that after I have completed each experimental trial I will be asked to perform a spatial knowledge test to determine how much of the environment I learned as well as answer some questions concerning my opinions of the usability of the inteface designs.

I was informed that the purpose of the tasks is to test the usability of the proposed interface designs to be used with the VTrail System and not a test of my ability to trailblaze.

I was informed that during the experimental trials observations of my behaviour will be observed and recorded solely for the purpose of assessing the interface designs.

I was informed that there is the potential risk that I may experience symptoms similar to motion sickness.

I was informed that I have the right to withdraw my consent to participate in this experiment at any time, and that upon doing so any data collected relating to my performance or me will be immediately destroyed.

I was informed that all information obtained as a result of my participation in this experiment will be kept confidential, and that I will not be individually identified in any reports or presentations pertaining to this research.

Participant's Name: ________________________________

Participant's Signature: _______________________

Name of Witness: ____________________________

Signature of Witness: ______________________________

Date: ____

Trail Following Study

Participant # .   .

I agree to participate in the study entitled "Design and Validation of Virtual Trailblazing and Guidance Interfaces for the VTrail System". I have read over the information letter and have had the opportunity to receive additional details about my participation in this study.

I was informed that full participation in this study involves a 1-hour session (approximately).

I was informed that I will be asked to answer a background questionnaire for demographic purposes and complete a spatial ability test. I understand that I will also be asked to perform a trail following task using a series of interfaces.

I was informed that after I have completed each experimental trial I will be asked to perform a spatial knowledge test to determine how much of the environment I learned as well as answer some questions concerning my opinions of the usability of the interface designs.

I was informed that the purpose of the tasks is to test the usability of the proposed interface designs to be used with the VTrail System and not a test of my ability to follow trails.

I was informed that during the experimental trials observations of my behaviour will be observed and recorded solely for the purpose of assessing the interface designs.

I was informed that there is the potential risk that I may experience symptoms similar to motion sickness.

I was informed that I have the right to withdraw my consent to participate in this experiment at any time, and that upon doing so any data collected relating to my performance or me will be immediately destroyed.

I was informed that all information obtained as a result of my participation in this experiment will be kept confidential, and that I will not be individually identified in any reports or presentations pertaining to this research.

Participant's Name: ______________________________

Participant's Signature: ______________________

Name of Witness: __________________________

Signature of Witness: ____________________________

Date: ______________________

Appendix D

Trail Quality Questionnaire

Trial Number: ____________________ Evaluator:____________________.

Criteria	Description	Evaluation
Marker Positioning	Are the markers placed in locations that are easy to distinguish from the rest of the environment?	/10
Marker Orientation	Are the markers oriented to clearly show the appropriate direction of travel? i.e. following marker orientation leads directly to next marker.	/5
Marker Frequency	Are markers placed at appropriate intervals? i.e. not too infrequent that the markers are not useful nor too frequent that the environment is cluttered	/5
Marker Usage	Are markers used to highlight important landmarks/features/locations	/5
Path Length	Was the path longer then necessary for successful completion of the delivery task? i.e. takes path follower to unnecessary locations, aimless wandering	/5
Path completeness	Does the path provide enough information to quickly and accurately return back to the starting location?	/5
Path Reliability	Did the path lead the follower to the correct locations to successfully accomplish the delivery task?	/5

What is your overall impression of the quality of the path that was generated (Circle the appropriate answer)?

1 Poor	2	3	4	5	6	7	8	9	10 Excellent

Total Mark:

Additional Comments (i.e. any creative usage of markers or strategies with the trail)

____

____

____

Appendix E

Spatial Knowledge Acquisition Test Scorecard

Spatial Knowledge Puzzle Scorecard

Part Number: ____________

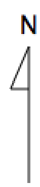
Trial Number: ____________

Environment ID: ____________

Start ID: ____________

List ID: ____________

Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______	Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______	Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______
Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______	Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______	Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______
Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______	Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______	Visted (Y/N)? ______ Participant Answer: ______ Actual Answer: ______



Appendix F
Background Questionnaire

Participant # ____________________.
To be collected once participant has signed consent letter

This information will be used for the purposes of creating general descriptions of the groups of participants involved in this study. The questions concern basic demographic information, familiarity with technology related to virtual environments and navigational experience. Your answers will help us to interpret our findings. There are no right or wrong answers, and you are free to skip questions that you are not comfortable answering.

Gender: MALE FEMALE **Age:** < 20, 20---24, 24--29, 30--34, 35--39, 40 +

Dominant Hand (used for writing): RIGHT LEFT

Do you have any visual impairment of which you are aware? NO YES
If yes, then please explain.

Do you typically have problems distinguishing between colours? NO YES
If yes, which colours do you have trouble telling apart?

<u>Virtual Technology Experience</u>

How familiar would you say you are with virtual environment technology?
Please circle the most appropriate number.

1 2 3 4 5
|————-|————-|————-|————-|
Not at all Familiar | Somewhat Familiar | Very Familiar

How familiar would you say you are with playing video games that use 3-D graphics? Please circle the most appropriate number

1 2 3 4 5

|————-|————-|————-|————-|

Not at all Somewhat Very

Familiar Familiar Familiar

Wayfinding Experience

How familiar are you with using a compass? Please circle the most appropriate number

1 2 3 4 5

|————-|————-|————-|————-|

Not at all Somewhat Very

Familiar Familiar Familiar

How familiar are you with using a map? Please circle the most appropriate number

1 2 3 4 5

|————-|————-|————-|————-|

Not at all Somewhat Very

Familiar Familiar Familiar

\

Have you ever participated in any wayfinding activity (e.g. orienteering,)? NO YES

Have you ever used a portable GPS unit to aid with navigation? NO YES

Appendix G
Usability Questionnaires

Part Number: _______________

Interface Number: __________________

Please fill the circle corresponding to the answer that best fits your response to the usability criteria

	Scale				
	Very Difficult	Difficult	Neither Easy or Difficult	Easy	Very Easy
Task difficulty with interface	○	○	○	○	○
Ease in learning interface	○	○	○	○	○
Ease in finding information	○	○	○	○	○

The following questions deal with the design of the VTrail interface. If this trial did not make use of this interface then skip ahead to the next question.

Rate the following VTrail Components on how useful they were in aiding in the performance of the trailblazing task use the following scale:

	Scale				
Component	Useless	Not Very Useful	Somewhat Useful	Useful	Necessary
Marker Location	○	○	○	○	○
Marker Orientation	○	○	○	○	○
Current Position	○	○	○	○	○
Current Orientation	○	○	○	○	○
Mini-map	○	○	○	○	○
Marker Cameras	○	○	○	○	○
Information Repository	○	○	○	○	○

What is your overall feeling towards the interface?

1	2	3	4	5
Very Strong Dislike	Dislike	Neither Like Nor Dislike	Like	Very Strong Like

Do you have any suggestions or comments on features, or information that could be included to improve the design?

____
____
____
____

What were the problems, if any, that you encountered when using the interface?

____
____
____
____

Are there any additional comments regarding your experience with the interface?

____
____
____
____

Usability Questionnaire: Minimal VTrail Interface

Part Number: _______________

Please fill the circle corresponding to the answer that best fits your response to the usability criteria

	Scale				
	Very Difficult	Difficult	Neither Easy or Difficult	Easy	Very Easy
Task difficulty with interface	O	O	O	O	O
Ease in learning interface	O	O	O	O	O
Ease in finding information	O	O	O	O	O

The following questions deal with the design of the VTrail interface. If this trial did not make use of this interface then skip ahead to the next question.
Rate the following VTrail Components on how useful they were in aiding in the performance of the trailblazing task use the following scale:

	Scale				
Component	Useless	Not Very Useful	Somewhat Useful	Useful	Necessary
Current Orientation	O	O	O	O	O
Mini-map	O	O	O	O	O

Do you have any suggestions or comments on features, or information that could be included to improve the design?

What were the problems, if any, that you encountered when using the interface?

Any additional comments regarding your experience with the interface?

Usability Questionnaire: Customizable VTrail Interface

Part Number: _______________

Please fill the circle corresponding to the answer that best fits your response

	Scale				
	Very Difficult	Difficult	Neither Easy or Difficult	Easy	Very Easy
Task difficulty with interface	○	○	○	○	○
Ease in learning interface	○	○	○	○	○
Ease in finding information	○	○	○	○	○

Rate the following VTrail Components on how useful they were in aiding in the performance of the trailblazing task use the following scale (Select "Not Applicable" if not included as part of the interface):

	Scale					
Component	Not Applicable	Useless	Not Very Useful	Somewhat Useful	Useful	Necessary
Marker Location	○	○	○	○	○	○
Marker Orientation	○	○	○	○	○	○
Current Position	○	○	○	○	○	○
Current Orientation	○	○	○	○	○	○
Mini-map	○	○	○	○	○	○
Marker Cameras	○	○	○	○	○	○
Trail Details	○	○	○	○	○	○
Trail Progression	○	○	○	○	○	○
Information Repository	○	○	○	○	○	○

Do you have any suggestions or comments on features, or information that could be included to improve the design?

____

____

____

____

What were the problems, if any, that you encountered when using the interface?

____

____

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____

Any additional comments regarding your experience with the interface?

____

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Usability Questionnaire: Customizable VTrail Interface

Part Number: _______________

Please fill the circle corresponding to the answer that best fits your response

	Scale				
	Very Difficult	Difficult	Neither Easy or Difficult	Easy	Very Easy
Task difficulty with interface	○	○	○	○	○
Ease in learning interface	○	○	○	○	○
Ease in finding information	○	○	○	○	○

Rate the following VTrail Components on how useful they were in aiding in the performance of the trailblazing task use the following scale (Select "Not Applicable" if not included as part of the interface):

Component	Scale				
	Useless	Not Very Useful	Somewhat Useful	Useful	Necessary
Mini-map	○	○	○	○	○
Trail Details	○	○	○	○	○
Trail Progression	○	○	○	○	○
Information Repository	○	○	○	○	○

Do you have any suggestions or comments on features, or information that could be included to improve the design?

____

____

____

____

What were the problems, if any, that you encountered when using the interface?

Any additional comments regarding your experience with the interface?

Appendix H

Interface Customization Checklist

Participant Number: _________________.

Feature	Present	Modified	Comments
User Position			
User Orientation			
Mini map			
Trail Details			
Trail Progression			
Marker Pos Info			
Marker Ori Info			
Data Repository			
Marker Camera			

Appendix I

Trailblazing Experiment One Results

Time Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	11.57**
Gender (G)	1	4.53
Error	9	(78266.61)
	Within – Subject Effects	
Interface (I)	1	0.05
G x I	1	0.39
S x I	1	4.40
Error	9	(41467.71)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Distance Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	15.14**
Gender (G)	1	4.60
Error	9	(5848969.25)
	Within – Subject Effects	
Interface (I)	1	1.54
G x I	1	6.20
S x I	1	2.29
Error	9	(3745472.97)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Trail Quality Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	1.79
Gender (G)	1	0.58
Error	9	(91.58)
	Within – Subject Effects	
Interface (I)	1	0.46
G x I	1	0.73
S x I	1	0.55
Error	9	(10.61)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Identification (TIS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	1.42
Gender (G)	1	0.03
Error	9	(3.73)
	Within – Subject Effects	
Interface (I)	1	0.44
G x I	1	3.4
S x I	1	0.73
Error	9	(1.2)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Location (TLS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	2.21
Gender (G)	1	0.34
Error	9	(36.55)
	Within – Subject Effects	
Interface (I)	1	0.15
G x I	1	0.01
S x I	1	0.18
Error	9	(6.10)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Orientation (TOS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	.065
Gender (G)	1	0.02
Error	9	(9.28)
	Within – Subject Effects	
Interface (I)	1	0.06
G x I	1	0.45
S x I	1	0.53
Error	9	(1.43)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

Appendix J

Trailblazing Experiment Two Results

Time Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	19.08**
Gender (G)	1	0.40
Error	13	(12373.00)
	Within – Subject Effects	
Interface (I)	1	0.02
G x I	1	0.07
S x I	1	0.01
Error	13	(994.32)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .01$.

Distance Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	19.33**
Gender (G)	1	0.30
Error	13	(532697.39)
	Within – Subject Effects	
Interface (I)	1	0.09
G x I	1	0.09
S x I	1	0.02
Error	13	()

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Trail Quality Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	7.43*
Gender (G)	1	3.72
Error	13	(29.84)
	Within – Subject Effects	
Interface (I)	1	0.03
G x I	1	1.42
S x I	1	0.13
Error	13	(19.97)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

SKAT Measure – Target Identification (TIS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	24.17**
Gender (G)	1	2.81
Error	13	(4.53)
	Within – Subject Effects	
Interface (I)	1	0.89
G x I	1	0.37
S x I	1	0.56
Error	13	(7.71)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

SKAT Measure – Target Location (TLS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	15.19**
Gender (G)	1	0.52
Error	13	(36.55)
	Within – Subject Effects	
Interface (I)	1	0.48
G x I	1	0.40
S x I	1	0.17
Error	13	(6.45)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

SKAT Measure – Target Orientation (TOS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	12.19**
Gender (G)	1	0.16
Error	13	(4.00)
	Within – Subject Effects	
Interface (I)	1	0.78
G x I	1	0.32
S x I	1	0.49
Error	13	(3.85)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Appendix K

Trail Following Experiment One Results

Time Measure – Delivery Time (DT)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	3.37
Gender (G)	1	0.06
Error	9	(8360.02)
	Within – Subject Effects	
Interface (I)	1	0.05
G x I	1	5.33*
S x I	1	0.31
Error	9	(4636.84)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .01$.

Time Measure – Return Time (RT)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	1.52
Gender (G)	1	0.01
Error	9	(9394.98)
	Within – Subject Effects	
Interface (I)	1	2.16
G x I	1	0.00
S x I	1	1.50
Error	9	(4030.91)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .01$.

Time Measure – Total Time (TT)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	3.87
Gender (G)	1	0.54
Error	9	(21361.56)
	Within – Subject Effects	
Interface (I)	1	1.30
G x I	1	2.82
S x I	1	1.47
Error	9	(9143.28)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .01$.

Distance Measure – Delivery Distance (DD)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	0.28
Gender (G)	1	0.56
Error	9	(507317.32)
	Within – Subject Effects	
Interface (I)	1	0.09
G x I	1	5.48*
S x I	1	0.00
Error	9	(182713.60)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Distance Measure – Return Distance (RD)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	19.33**
Gender (G)	1	0.30
Error	9	(336086.20)
	Within – Subject Effects	
Interface (I)	1	1.56
G x I	1	0.59
S x I	1	0.15
Error	9	(134939.32)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

Distance Measure – Total Distance (TD)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	0.21
Gender (G)	1	0.74
Error	9	(884095.14)
	Within – Subject Effects	
Interface (I)	1	0.17
G x I	1	1.72
S x I	1	0.14
Error	9	(431183.67)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

Task Accuracy Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	8.30*
Gender (G)	1	0.59
Error	9	0.53
	Within – Subject Effects	
Interface (I)	1	0.02
G x I	1	0.78
S x I	1	0.02
Error	9	0.20

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Identification (TIS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	15.73**
Gender (G)	1	2.17
Error	9	(1.96)
	Within – Subject Effects	
Interface (I)	1	0.62
G x I	1	0.54
S x I	1	0.23
Error	13	(2.17)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Location (TLS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	1.84
Gender (G)	1	9.01*
Error	13	(5.39)
	Within – Subject Effects	
Interface (I)	1	11.44**
G x I	1	0.26
S x I	1	11.10**
Error	13	(1.05)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Orientation (TOS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	27.08**
Gender (G)	1	21.02**
Error	13	(1.23)
	Within – Subject Effects	
Interface (I)	1	0.07
G x I	1	0.10
S x I	1	0.09
Error	13	(6.49)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

Appendix L

Trail Following Experiment Two Results

Time Measure – Delivery Time (DT)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	19.14**
Gender (G)	1	0.05
Error	13	(4561.63)
	Within – Subject Effects	
Interface (I)	1	0.00
G x I	1	0.56
S x I	1	0.02
Error	13	(932.79)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .01$.

Time Measure – Return Time (RT)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	5.26*
Gender (G)	1	0.34
Error	13	(5223.87)
	Within – Subject Effects	
Interface (I)	1	0.61
G x I	1	0.00
S x I	1	0.82
Error	13	(559.66)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .01$.

Time Measure – Total Time (TT)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	14.78.**
Gender (G)	1	0.05
Error	13	(14395.37)
	Within – Subject Effects	
Interface (I)	1	0.06
G x I	1	0.25
S x I	1	0.04
Error	13	(2309.25)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .01.

Distance Measure – Delivery Distance (DD)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	13.72**
Gender (G)	1	0.00
Error	13	(292279.77)
	Within – Subject Effects	
Interface (I)	1	0.77
G x I	1	0.33
S x I	1	0.75
Error	13	(93771.54)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

Distance Measure – Return Distance (RD)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	5.22**
Gender (G)	1	0.35
Error	13	(243662.57)
	Within – Subject Effects	
Interface (I)	1	0.70
G x I	1	0.00
S x I	1	0.42
Error	13	(25947.44)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Distance Measure – Total Distance (TD)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	12.22**
Gender (G)	1	0.13
Error	13	(801798.01)
	Within – Subject Effects	
Interface (I)	1	0.30
G x I	1	0.57
S x I	1	0.23
Error	13	(174164.63)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Task Accuracy Measure

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	2.82
Gender (G)	1	0.13
Error	13	(0.41)
	Within – Subject Effects	
Interface (I)	1	0.71
G x I	1	0.01
S x I	1	1.26
Error	13	(0.20)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Identification (TIS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	24.17**
Gender (G)	1	2.81
Error	13	(4.53)
	Within – Subject Effects	
Interface (I)	1	2.37
G x I	1	0.04
S x I	1	1.96
Error	13	(0.80)

Values enclosed in parentheses represent mean square errors. * p < .05. ** p < .0

SKAT Measure – Target Location (TLS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	15.19**
Gender (G)	1	0.52
Error	13	(36.55)
	Within – Subject Effects	
Interface (I)	1	0.07
G x I	1	0.69
S x I	1	0.05
Error	13	(1.84)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

SKAT Measure – Target Orientation (TOS)

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	12.19**
Gender (G)	1	0.16
Error	13	(4.00)
	Within – Subject Effects	
Interface (I)	1	0.78
G x I	1	1.53
S x I	1	.069
Error	13	(1.79)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$

Appendix M

SKAT Analysis Results

Factor	df	F
	Between Subject Effects	
Spatial (S)	1	30.58**
Gender (G)	1	3.86
Distractors (D)	1	25.56*
Experience (E)	1	0.17
G x D	1	0.50
G x E	1	.058
D x E	1	2.34
G x D x E	1	2.34
Error	47	(1.71)

Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .0$