Supporting Spatial Learning in Virtual Environments

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Author's declaration

No portion of work contained in this thesis has been submitted in support of any application for any other degree or qualification of this or any other university or institute of learning.
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Supporting Spatial Learning in Virtual Environments

Abstract

This thesis explores the acquisition of spatial knowledge as a means to support wayfinding in virtual environments. Specifically, the thesis presents an investigation into the potential benefits one might gain through the application of a variety of tools, each of which has been designed to support one of the three stages of cognitive map development—landmark-based representation, route-based representation, and survey-based representation (Siegel & White, 1975). Each tool has been evaluated with respect to improvements in wayfinding, and also in their support for environmental learning. Measures were taken of each tool used in isolation, and also when used together as a complete toolset.

The between-subjects evaluation process involved 101 participants, randomly assigned to one of five conditions. Each participant was asked to navigate a virtual environment to locate three specific items. To evaluate wayfinding, participants were asked to perform the same task on six occasions within the same session. After discovering all items, a measure indicating route efficiency was recorded. On completing all six trials participants were asked to produce a map of the virtual environment. It was hypothesised that the presence of tools would improve the acquisition of spatial knowledge, and thus route efficiency and map production.

Comparing the ‘no-tool’ and the ‘all tool’ conditions, a 2x6 repeated measures ANOVA found that when providing the tools concurrently there was a statistically significant improvement in the efficiency of route taken (F(1,38)=4.63, p<0.05). However, when evaluating the tools in isolation, no significant improvement in route efficiency was found. Also, no significant difference between conditions was identified when comparing the quality of maps produced by participants across conditions. The thesis concludes by arguing that the application of the complete toolset benefits wayfinding, although it is noted that the evidence does not support the hypothesis that this is caused by improved spatial learning.
Introduction

1.1 Research Context
An increase in the number of three-dimensional online environments, and the rise in popularity of video-game worlds, makes the navigation of virtual spaces a common task for digital natives. However, the navigation of virtual environments is also an undertaking that many find demanding, frequently resulting in user disorientation and frustration (Li & Ting, 2000). This thesis attempts to engage with the problem of user disorientation by developing tools to support knowledge acquisition in virtual environments. The domains of knowledge that are of interest here are those which we use to represent features of an environment – knowledge of objects within the environment, knowledge of pathways through the environment, and knowledge of how those objects and pathways are spatially configured. It is argued that having a better cognitive representation of a virtual environment will be beneficial when navigating it.

In developing tools to support the acquisition of spatial knowledge when negotiating 'virtual' environments, much has been taken from the rich body of literature concerning navigation in 'real' environments. Although there are clear differences between real and virtual spaces (there is no proprioceptive feedback within virtual environments, a poorer field of view and fidelity in virtual environments, and so forth), there are many studies which show that spatial knowledge gained within virtual worlds can transfer when navigating real worlds (Bliss, Tidwell, & Guest, 1997; Darken & Banker, 1998; Darken & Goerger, 1999; Goerger, Darken, Boyd, Gagnon, Liles, Sullivan, & Lawson, 1998; Johnson, 1994; Johnston, 1995; Regian & Yadrick, 1994; Rossano, West, Robertson, Wayne, & Chase, 1999; Waller, Hunt, & Knapp, 1998; Witmer, Bailey, & Knerr, 1995). This suggests that the same mechanisms, strategies and processes employed when navigating the real world are likely to be implemented when performing similar tasks in

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1 Prensky (2001) introduces the term digital natives to refer to people born during the digital age, distinguishing them from those who have to adapt to the digital world.
virtual worlds. If this is the case, then much of the knowledge on how to support real-world navigation would also be applicable to navigation in virtual worlds.

From Siegel and White's (1975) theoretical work regarding how we develop spatial models in the real world, tools were developed to support the development of spatial models in virtual worlds. To support the encoding of landmarks, a tool was developed with the intention of increasing the saliency of landmark items; to support the development of a procedural representation, a breadcrumb tool was developed; and to support the development of a survey representation, a map was provided. In order to evaluate the effectiveness of each tool separately and also the benefit of presenting the tools together, participants were asked to navigate a virtual space across six trials. A participant's knowledge of the environment was determined based upon their navigation performance, their ability to identify items and routes within the environment, and their ability to reproduce a map of the virtual environment. Statistical analysis of navigation performance suggests that the presence of the tools together did aid navigation of the virtual environment. However, analysis of the maps produced by the participants did not support the hypothesis that improvements in navigation were the outcome of enhanced spatial awareness of the environment.

1.2 Research Questions

The research presented in this thesis addresses the following questions:

1. Can a tool be designed that will demonstrate statistically significant enhancement of navigation in virtual environments?
2. Can a tool be designed that will demonstrate statistically significant enhancement of the navigator's cognitive representation of virtual space?
3. Do the tools support possible differences in how males and females might encode the environment?
The research questions were examined through the following programme of work:

- A review of the literature concerning navigation in virtual environments has been produced, where it was found that learning in virtual spaces can transfer to real world spaces.
- A review of the psychology literature concerning cognitive representations of spatial properties has been produced.
- A review of the literature concerned with navigation in real and virtual world spaces has been produced.
- Taking into account the findings of the reviewed literature, a set of tools were developed to support the encoding of the spatial configuration of virtual environments.
- To evaluate the tools a between-conditions approach was taken. A virtual environment was built, and 101 participants were randomly assigned to one of five possible conditions (No Tools / Tool #1 / Tool #2 / Tool#3 / All Tools). Each condition involved participants navigating the virtual environment across six trials. Between trials participants were asked questions regarding the properties of the virtual environment, and after the final trial they were asked to produce a map of the environment. Statistical analysis was carried out to determine whether differences across conditions were significant.

The thesis makes its primary contribution to the field of human-computer interaction (HCI). Specific contributions include the finding that the toolset significantly improved navigation when presented holistically; the ‘scatter map’ approach developed here to investigate a participant’s cognitive representation of their environment eliminates many of the concerns surrounding previous sketch-map studies; and the approach taken to provide a visualisation of cognitive map data facilitates easy cross-comparison of different data sets.
1.3 Thesis Structure

Chapter 2 provides a review of Virtual Reality technology, and shows how such machinery is particularly suited to applications of a spatial nature – such as data visualisation and spatial skill acquisition. However, user disorientation is a commonly reported side affect when navigating spatial structures. This chapter discusses methodologies for supporting wayfinding in virtual spaces and suggests the development of a tool to support spatial learning in virtual environments, which it is argued, would be suited to users who frequent the same virtual places.

To develop a tool to support spatial learning in virtual environments, it was considered necessary to review the psychological literature concerning peoples’ encoding of virtual spaces. With only limited literature particular to the cognition of virtual environments, chapter three considers the literature covering the cognition of real environments instead. In defence of this approach, a variety of studies are referred to where VR has been successfully used as a training tool for wayfinding in real worlds. It is argued that the transfer of navigational knowledge across domains suggests the likely involvement of the same cognitive processes.

Particular emphasis is placed upon the “Sequential and Hierarchical” model proposed by Siegel and White (1975), which identifies three categories of mental representation: landmark-based, route-based and survey-based. Taking this model as a basis, the Spatial Learning Tool (SLT) was proposed. The SLT has three components:

1. The Landmark Saliency Component (LSC) was designed to enhance landmark knowledge acquisition by increasing the saliency of specific items in the environment. The component allows the instructor to identify items in the environment which might increase the quality of the learner’s mental map.

2. The Breadcrumb Component, which shows the learner the routes they have travelled.
3. The Map Component provides the learner with a configuration of the environment, on which they can add further environmental knowledge gained during exploration.

Chapter Four discusses the methodology employed in the evaluation of the Spatial Learning Tool. Participants were given a pre-test environment to navigate, and based upon their performance (and also their sex and their scores on a spatial IQ test) they were assigned to one of five conditions. The control condition offered no support for spatial learning. The control condition allowed comparison with the evaluation of the Spatial Learning Tool, and three further conditions where each component of the SLT was evaluated in isolation. Each condition required participants to navigate a virtual library and locate books on six separate trials. Between trials, and at the end of the wayfinding task, tests were administered to identify the fidelity of a participant’s cognitive representation of the environment and their wayfinding ability.

The result of the SLT evaluation, which are presented in Chapter 5, show that the SLT significantly aided wayfinding within the test environment but did not appear to support the development of the participant’s cognitive representation of the library. To determine whether specific components were either detrimental or beneficial to the task, each component was evaluated in isolation from the other SLT components. Chapter 6 details the results of each evaluation, and finds that males and females were affected by the SLT components differently. Females performed significantly better than males on the wayfinding task, and produced better representations of the environment when the LSC was evaluated in isolation. The results were reversed when the Map Component was evaluated in isolation, where it was found that males performed better than females on the wayfinding task, and produced significantly better maps of the environment than did females.

Despite the differences between males and females, there is no evidence that the SLT significantly improved the quality of a participant’s representation of the environment. However, as concluded in Chapter 7, this may well be because of the timing of the
Cognitive Map Task. The components appeared to have a greater effect on participant performance on the wayfinding task during the first two trials. From trial three onwards, there was little difference between conditions. It is argued that by the end of the evaluation participants had learned the configuration of the environment regardless of the condition.

In trying to alleviate the pressures and frustrations which often occur when navigating virtual spaces, the aim of this body of research has been to develop and evaluate a toolset which would enhance the spatial cognition of virtual environments, and thus support the navigation of such spaces. The toolset was developed after a thorough review of the HCI and psychological literatures concerning navigation in real and electronic spaces. The tools were then evaluated by 101 participants as they navigated through a virtual library. Statistical analysis indicates that the toolset significantly supports a participant’s navigation of virtual space, although there is no conclusive evidence to support the hypothesis that this was the direct result of an enhanced spatial representation.

However, there are a number of issues that must be taken into account when reviewing the evaluation results. Firstly, the tools have only been used within one environment, and it not clear whether the effects found will generalise to other virtual environments. There are many reasons to believe that effects will vary across environments. Firstly the evaluation was carried out within a 2 ½ dimensional environment, where the navigator remains on a single plane and cannot fly to higher/lower levels. Secondly, the tool is based upon the concept of enhancing one’s spatial representation of the environment. However, the navigation of some environments would not necessarily benefit from the possession of a better cognitive map. Where the environment is quite regular, simple, or configured to a set of rules (i.e., in alphabetical order), navigation using one’s cognitive map might not be the preferred, or even the best strategy.

Although not the focus of the thesis, it is noted that tools designed to support spatial learning in virtual environments might also benefit navigation in the ‘real’ world. This could be achieved through the introduction of support tools in the real world, or as a

Introduction
result of prior training within a virtual representation of a specific place. Professionals such as soldiers and fire-fighters, whose lives are at risk when they enter unknown environments, would clearly benefit from knowing the layout of an environment before entering. However, the use of such tools in the real-world is clearly left for further investigation.
This chapter introduces the mechanics involved in the use of Virtual Reality and reviews the most common applications of such technology. It is shown that Virtual Reality is particularly suited to the visualisation of spatial information, frequently involving the navigation of 3-dimensional structures. The chapter makes the case for tools to aid navigation of virtual worlds, providing many examples where wayfinding through complex 3D structures often results in disorientation, as the user becomes lost in virtual space.

2.1 Virtual Reality: a definition

The following section provides a definition of what is meant by the term Virtual Reality and also covers associated terminology used throughout the thesis. The technology is defined within its historical context, including a review of a range of virtual reality paraphernalia, including the historically significant Sensorama, head-mounted display units, projection systems such as the CAVE™, and less immersive displays systems such as the Visual Display Unit.

2.1.1 What is Virtual Reality?

Virtual Reality (VR) is the simulation of environments using computer technology (Rheingold, 1991). Virtual Environments (VE) are computer generated spaces that can give users access to physical spaces that are not normally visible – such as visualising the structure of molecules (Byrne, 1996); or they might offer a re-creation of geographical spaces - to show how a new building might look in the context of its surroundings; they could be based on places that no longer exist – such as archaeological visualisations of pre-historic sites; or they might be places that exist only in the author’s imagination - such as computer and video games worlds. Where VR differs from other simulations is in
the user experience. Typically, the aim of VR is to simulate sensual information in order to fool the body into accepting the artificial as genuine; to immerse consciousness within another dimension (Pimentel & Teixeira, 1993).

The term commonly used to describe the psychological perception of existing within the virtual world is 'presence' (Heeter, 1992; Sheridan, 1992; Steuer, 1992; Witmer & Singer, 1998). To increase the level of presence experienced in virtual environments modern technology can be exploited to fool the human perceptual system. As discussed later in this chapter, presence can be increased by the addition of hardware to simulate the world - such as head-mounted displays (Slater & Usoh, 1993), head tracking (Hendrix & Barfield, 1996), stereoscopic display systems (Hendrix & Barfield, 1996), and through software by increasing the realism of the image presented (Welch, Blackmon, Liu, Mellers & Stark, 1996; Wilson, Nichols & Haldane, 1997; Witmer & Singer, 1994).

### 2.1.2 Overview of VR Technology

VR professionals use a variety of display systems to present information to the human eye, offering the user many ways to experience a virtual environment. Hardware solutions are a consequence of the trade-off between cost, usability, fidelity and the level of presence provided. Typical hardware includes the traditional visual display unit (VDU), screen projection, and the head-mounted display (HMD). The following section reviews each piece of hardware in turn, beginning with one of the earliest examples of VR technology, the sensorama.

**The Sensorama**

Given the earlier definition of VR, the Sensorama is not a true example of VR technology. Rather than presenting a computer generated image, the user watches a short film clip. However, the Sensorama does share one central goal with VR technology – to immerse consciousness within another dimension. The Sensorama also attempts to reach the goal in much the same manner as current VR endeavours – through the deception of the human senses. Heilig, the inventor of the Sensorama, found a solution that could fool
four of the five senses (sight, sound, touch and smell), arguing that they were the main sensory channels that needed stimulation to create the illusion of presence (Rheingold, 1991; Pimentel & Teixeira, 1993). His machine (see Figure 2.1) would present stereoscopic visual stimuli, giving the user a 3D cinematic experience; it would produce stereophonic soundscape; the seat would vibrate in response to changes in the visual field; a fan was used to blow air at the user; and it also incorporated technology that would create a range of different scents. The machine was originally designed to offer a superior cinematic experience. However, owing to the cost of production and the limit of only one user per session, the Sensorama failed to make an impact in the market place.

![Sensorama machine](image from Pimental & Teixeira, 1993)

**Figure 2.1**  
*Heilig’s Sensorama machine*

The Visual Display Unit

Most people experience their first virtual environment using a visual display unit. The VDU is the primary display system used in VR, mostly because of its ubiquity in
modern-day homes and offices, but also because of its versatility – it is small, relatively portable, and does not require specific lighting conditions for viewing. Further benefits include the price of VDUs, as the monitor is cheaper than alternative technologies, and the display can be viewed by multiple users simultaneously.

The VDU can offer higher resolution than many alternative display systems, and thus provide higher quality graphics. Increased realism in graphical output has been positively correlated with increase in reported levels of presence (Wilson, Nichols, & Haldane, 1997). However, the typical VDU fails to offer motion tracking, and does not encapsulate the field of view, both of which play a large role in increasing user perception of presence (Slater & Usoh, 1993). It is however possible to increase the level of presence when using a monitor by providing a binocular image (Hendrix & Barfield, 1996). Shutter glasses can create the illusion of a 3-dimensional binocular image on a 2-dimensional screen. The computer alternates the presentation of a right and left eye view of the virtual world, and shutter glasses work in tandem by obscuring the scene in one eye, and then when the display changes viewpoint, it switches to obscure the alternate eye. When presented in very quick succession this method of display can fool the human visual system into perceiving a three dimensional image coming out from the screen.

Screen Projection

By attaching the computer output to a projector, it is possible to cast the virtual world onto a cinema screen. The image can be large enough to encapsulate the user's field of view, which is beneficial for increasing user perception of presence (Hendrix & Barfield, 1993). Some systems, such as the CAVE™ and the VR-CUBE, have the user surrounded by an array of projection screens, which allow the user to turn their head and still maintain their level of presence (as shown in Figure 2.2). The VR-CUBE also employs the use of shutter glasses to provide a binocular image on each wall, increasing depth perception.
The Head-Mounted Display

The head-mounted display (HMD) is a visual display unit supported by user's head, with small screens that hang several inches in front of the eyes. The benefit of such a device is that the most, if not all, of the user's field of view of the physical world is taken by the simulation. Most HMDs used in VR will support head tracking, and will support a one-to-one spatial mapping between the user's head movement and the view of the computer generated image. The computer system continually updates the display with respect to head position, and helps create the illusion that the user is inside the Virtual World. This method of computer input is particularly suited to humans as it also directly maps onto the method we use to interact with the physical world.

Motion Tracking

A variety of devices have been produced to track the user's body movements. Head tracking systems, such as the iTrax2 (Intersense, 2003) can be attached to the HMD to identify spatial movement such as the pitch, yaw and roll of the head. This allows the

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user to look up/down, left/right, and tilt their head in the virtual environment. Other devices allow the user to spatially interact with the virtual world by tracking hand movements. The Phantom desktop (manufactured by SensAble technologies) detects the user’s manipulation of a pen-shaped device. The Phantom desktop provides haptic feedback, which means that the user can feel the shape and texture of the virtual world as the device is moved through space. This is particularly useful for training surgeons on new techniques and procedures, where the pen simulates the cutting motion of a scalpel (Buttolo, 1996). The cyber glove goes beyond the functionality of the Phantom desktop and allows the user to use their whole hand to interact with the virtual world (Virtual Technologies, 1998). As well as detecting hand movement in space, the glove contains sensors positioned above each joint of the finger, to detect inflexion. This allows the user to pick up items in the simulated world by making the same manoeuvre necessary in the physical world.
2.2 Virtual Reality Applications

Much of what we do as human beings is mediated by space. It influences our thinking, how we communicate with others, and how we navigate our lives (Anders, 1999). Our fundamental concepts appear to be organised in terms of spatial metaphors, evident by how our speech is littered with spatial references (Lakoff & Johnson, 1981). People talk of needing their own space, of distancing themselves from others when they disagree with their viewpoint, and of building bridges when they are looking for reconciliation.

We also use spatial relations as a tool for thought. Graphs – histograms, scatter plots, pie charts, and so forth - are all methods for communicating and analysing information spatially. Diagrams are used to both develop and to communicate new scientific models of physical systems. Einstein’s general and special theories of relativity, for example, were the consequence of thought experiments with reference to travelling on a beam of light (Anders, 1999). Norman (1988) regards space as an important factor when producing usable interactions with the systems around us. He argues that good spatial mapping can instantly indicate how the user should use a system. The importance of our spatial world is central to the popular windows-based operating systems pioneered by Apple and subsequently adopted by Microsoft. This direct manipulation desktop metaphor, which replaced the command line prompt, allows users to interact with their machine spatially, instead of having to remember and type obscure commands with awkward syntax.

Space is clearly central to our cognition and our communication. This makes VR a valuable tool as it affords spatial interaction. VR is fundamentally concerned with information and imposing and/or maintaining a spatial structure. It is either used to visualise information in novel ways, to provide spatial interaction with information, or it is used to simulate spatial structures. Therefore applications where VR is proving most valuable are typically involved with the visualisation and representation of data, the navigation of 3D spatial structures, and in training humans to interact with simulated systems (Weiss & Jessel, 1998).
2.2.1 Applications Involving the Visualisation and Representation of Information

As a tool for visualisation VR can present data and make it understandable to the layman. A 3-dimensional visualisation of architectural plans will allow clients to wander in and out of rooms, understand the spatial perspective, and see the building in the context of the surrounding landscape. It is the ability to make data ‘come alive’ that also makes the technology relevant to the entertainment industry. Video games merely support player interaction with domain data – it is the visualisation and representation of that data that makes games so appealing. This section will show how different industries use VR as a tool for visualisation and representation.

VR and Entertainment

From the simple 2D representation of Space Invaders (Nishikado, 1978) to the complex 3D space battles of Home World 2 (Relic Entertainment, 2003), digital games have always been situated in virtual environments. Some games have a simple graphic engine which allows gamers to interact with a complex simulation of the world, as in Sim City (Wright, 1989) – whereas others have concentrated on the visual aspects of the simulation and recreated immersive 3D representations of the world, as in the game Unreal (Epic, 1998). Games such as Unreal possess graphic engines so technologically advanced that they compete with high-end specialised graphical workstations (Lewis & Jacobson, 2002). Owing to the public demand for photo-realistic graphics, and the high competition between developers for the multi-million pound game market, contemporary gaming environments are exceeding the technical limitations of both military applications and academic VR solutions. The superiority of graphic engines developed by the entertainment industry and other VR based industries can clearly be seen by comparing a modern game engine (Figure 2.3) with a modern military application (Figure 2.4).
Owing to the quality of the VR products produced by the gaming industry, the academic community has recently been investigating the possibility of utilising game technology for their research. Game engines can be so powerful and so cheap compared to traditional VR applications that they are now becoming the tool of choice for many researchers (Lewis & Jacobson, 2002; Jakobson & Hwang, 2002; Kaminka et al., 2002; Piekarski & Thomas, 2002). Many of the games come with their own editors which allow users to create their own worlds (see Doom, Max Payne, Never Winter Nights, Quake, Unreal). Often the editor will support the importation of 3D meshes, 2D textures to clothe the polygons, novel sounds – both direct and ambient, and complex scripting to influence the running of the game engine. This empowers researchers as they can change the look and feel of their own projects, and also adapt the software to work alongside other VR gaming peripherals, such as the HMD.

Games generally rely upon the quality of the graphic engine to increase player presence within the game world. However, companies have experimented with using various peripherals to alter the level of immersion experienced by gamers. In 1995, the Japanese hardware manufacturer Nintendo, released the ‘Virtual Boy’. The Virtual Boy was a portable HMD-based console (see Figure 2.5). Rather than attaching the head set to a machine, the HMD had the games console built inside. Although the system did not provide motion tracking, it did provide a monochrome stereoscopic display to increase
immersion. However, owing to concerns about children’s health when using HMDs (Mon-Williams, Wann, & Rushton, 1993), the machine failed to find an audience of significant numbers.

Toy company Mattell tried to increase player immersion in games with the release of a data glove for Nintendo’s SNES (Super Nintendo Entertainment System) (see Figure 2.6). The glove measured finger inflexion, and ultrasonic transmitters on the back of the glove could track position and roll by emitting pulses which were then received by microphones (Hollands, 1996). The glove was so advanced for its time that VR academics have adapted the glove to work with a PC based system in order to build low-cost solutions for research projects (Bryant, Eberhart, Fredrick, Gawel, & Turner, 1993; Schaefer & Wassermann, 1995).

VR technology has also made a large impact on the film industry. Virtual world development tools, such as 3D-Studio, Maya and SoftImage are now commonly used to create special effects for movies. The Last Starfighter (Castle, 1984) was one of the first films to use CGI (computer generated imagery) to realise the imagination of author Jonathan Betuel. Up until that movie, space craft had been modelled out of physical materials, but in The Last Starfighter the models were entirely virtual. The benefit of CGI
is that it allows directors to realise their imagination on the screen – even if it is physically impossible to create in the physical world. It can also offer savings in time and money. Producing one virtual model will take time, but once one has been created it is possible to copy as many as the scene requires at no extra cost, allowing vast armadas for the same price as one ship. In comparison, building ‘actual’ models has costs attached for each realisation, making the cost of producing an armada significantly more than in CGI.

Recently, rather than just using CGI for special effects, the technology has been used to develop a whole movie. Toy Story, the first entirely ‘virtual’ feature length film was developed by the graphics company Pixar (Lasseter, 1995). The CGI was used to animate children’s toys – something both difficult and expensive to produce using traditional modelling techniques.

Currently there is much discussion about the use of virtual actors (computer generated characters) replacing real actors in films. The Lara Croft character from the Tomb Raider games, has recently been used in an advertising campaign for Lucasade; Yuki Terai is a ‘virtual star’ who has been cast in 6 short films (Kutsugi, 2002); Anna Nova is a virtual news reader; and E-Cyas is the first male virtual pop star (BBCi, 2000). The benefit of virtual stars over ‘real’ stars is that they never age, they follow direction, and they do not demand large salaries.

**VR in Manufacturing and Design**

The ubiquity of VR technology within the gaming arena is slowly being replicated in other industries. With respect to manufacturing and design, VR is of most benefit when providing a visualisation during the design stage. Designers often work in a medium that is unsuitable for non-experts. Many people find it hard to visualise what the finished product might look like, from a set of design plans. VR allows non-experts to view a design in a less ambiguous way (Weiss & Adam, 1998). Viewing a design with a HMD can allow clients to see the product to scale, move around it, interact with it, and also observe how the product will appear in a typical context.
Bringing the design to a non-expert audience can open up opportunities for product design as VR can help both with the design and the evaluation of a product. Participatory design is a technique where the user contributes to the design of a product (Wilson, 1997; Shewchuck, Chung, & Williges, 2002). Having the intended audience take a role in the design of a product can be helpful to ensure product usability. Designers are rarely domain experts in the product domains for which they work. Potential users are therefore valuable members of a design team, as they can flag possible design flaws at conceptual stage – rather than further down the process, where fixing an inappropriate design can incur significant costs. Designers themselves can also benefit from the visualisation techniques. For example, a fully immersive wheelchair VR system allows architects to explore their designs and identify potential issues for the disabled (Murphy, 1993).

VR can also support rapid prototyping, a product development process where a mock-ups of a product are quickly generated at various stages of development. This technique can cut development time down by as much as 50 percent (Morrison, 1999). VR is very useful for rapid prototyping, not just because it aides visualisation, but also because user feedback can quickly be incorporated in new designs. Using VR to support rapid prototyping has proved to be particularly cost effective in the automotive industry where usability studies have been carried out on the interior layout of new vehicles – see figure 2.6 where the dashboard of a car is being evaluated (Beier, 1994).
2.2.2 VR in Training and Education

Training differs from education in a number of significant ways. Training is concerned with work-related skill acquisition (Kurtus, 1999), whereas education is concerned with the acquisition of higher-order, abstract, transferable knowledge (Moshell & Hughes, 2002). The following section describes how VR technology can be used to support both types of learning.

VR and Education

The benefit of VR technology in the classroom is a topic regularly explored by academics. This is because VR allows students to visualise abstract concepts, and to interact with artefacts that would be impossible in real life, owing to issues surrounding safety, distance, time, scale or money (Fällman, Backman, & Holmlund, 1999). There are two main approaches to education, which can be supported through the use of VR technology: situated learning, and constructivism. Each will be discussed in turn.

Much like role-playing, situated learning is based on the concept that learning occurs in story-based, human-centred situations (Moshell & Hughes, 2002). Using VR it is possible to replicate an authentic setting and thus provide a suitable context for learning –
something essential for situated learning (Brown, Collins, & Duguid, 1989). This has been accomplished using Ghost Writer (Robertson & Oberlander, 2002), a multiplayer game involving students and teachers who each take on the role of selected characters for a role-playing session. Pairs of children engage in computer-mediated role-play, with each child taking on the role of a character in the story. A teacher plays some of the story’s different characters, and in role, encourages the children to become emotionally involved in the story and collaborate with each other on difficult decisions. After the role-play session the children write stories based on their experiences within the virtual world. Results have shown that the VR experience had a positive effect on descriptive writing ability when children were asked to write stories afterwards (Robertson, 2001).

The constructivist theory of education argues that students are active in their own learning, and that they build their own internal models of the world, rather than passively accepting incoming data (Dick, 1992; von Glaserfels, 1995). In constructing a model of the world, the student builds ‘structures of experiences’ (Cunningham, 1992). This means that knowledge is not transferred by simply filling the learner’s memory from the instructor’s ‘vial’, but is instead constructed using previous models of the world. Learning in this context comes from exploration and discovery, something easily supported through the use of VR technology.

Many projects have implemented a constructivist approach to learning in virtual environments (Dede, Salzman, Loftin, & Ash, 1997; Johnson, Moher, Ohlsson, & Gillingham, 1999; Mikropoulos, 1995; Osberg, 1997). A particularly interesting example is Dede et al.’s (1997) ‘Science Space’ project, which aims to teach students some of the main concepts behind modern science. Science Space is a collection of three virtual worlds: Newton World – which examines the concepts behind Newtonian physics, Maxwell World – where users can manipulate representations of force and energy, and the Pauling World – where the user explores the atomic construction of different molecules. Evaluation of the learning outcomes showed a positive benefit of using VR technology. When using Maxwell World, for example, students’ understanding of an electric field’s 3-dimensional aspects improved significantly, and was found to be
significantly superior to the control group who used traditional 2D software teaching aids.

**VR and Training**

While VR can be applied to education, the technology is perhaps better suited to training. As discussed above, training is more concerned with learning a particular item of knowledge or skill – such as learning how to ski. Skill acquisition is perhaps best supported by the concept of learning-by-doing. This is something VR can assist by simulating various aspects of the activity. This is particularly important where the activity is too dangerous to allow the student to learn-by-doing in the physical world, or where there is a possibility of the student causing damage to expensive equipment, or to other people.

There are many academic projects and publicly available software packages that support training in virtual environments (Loftin & Kenney, 1994; Rise & Billinghurst, 1995; Seymour, Gallagher, Roman, O'Brian, Bansal, Anderson, & Satava, 2002; Stiles, McCarthy, Munro, Pizzini, Johnson, & Rickel, 1996). Most software packages support practising a new skill in a virtual context. This better prepares the user for when they try the activity out for real. For example, fire and arson investigators can purchase InterFireVR (InterFire, 2003), which provides different scenarios where the user must investigate the fire scene to identify the cause of the fire. The VR solution provides many benefits over on-the-job training. Firstly, the scene of a fire may turn out to be a crime scene, and inappropriate for trainee interference. Secondly, the VR application allows the investigator to take their time over the analysis of the scene, a luxury not always available in the physical world. Thirdly, the trainee can access the simulated fire-scene at their own convenience. The ability to learn throughout both the day and the night is particularly suited to training, where many of the students will have other responsibilities during regular hours.

The benefit of training in Virtual Environments has been recognised in the maritime industries, where the financial costs of ‘real’ world training are almost prohibitively
expensive. The DISCOVER project (Turner & Turner, 2000) looked at team-based training of mariners and oil-rig workers, and Hays, Vincenzi, Seamon, and Bradley (1998) have looked at using VR to train submarine pilots. Virtual Environment for submarines (VESUB) is an immersive system which places the student submarine officer on the deck of a virtual submarine. The officer’s task is to give the appropriate commands to crew members and pilot the submarine through the harbour, avoiding all obstacles. The results of the VESUB project show significant learning on eleven of the fifteen variables – including a 57% improvement in contact management.
2.3 Lost in Virtual Space

As emphasised above, VR technology is particularly suited to spatial applications, supporting users in the adoption of a spatial metaphor to navigate and manipulate data. Despite the benefits gained from such interactions, a negative consequence of spatial navigation is the sensation of disorientation often experienced when users lose their way. Evidence suggests that wayfinding within electronic spaces is much more difficult than the navigation of 'real' spaces, which can lead to fear and potential nausea (Cruz-Neira, Sandin, & DeFanti, 1993). Reports suggest that users are likely to lose their way when navigating both 2D hyperspace (Theng, Jones, & Thimblby, 1998), as well as 3D virtual space (Chittara & Ranon, 2002; Ruddle, Payne, & Jones, 1997; Satalich, 1993; Stankiewicz, McCabe, Kelly, & Legge, 2003), which is the primary focus of this thesis.

There are a variety of reasons why users might find it difficult to orient themselves in virtual environments. In comparison to real environments, virtual environments fail to deliver a complete sensory experience. The display is often presented at a low resolution, with a low field of view, making it hard to distinguish distant items when orientating oneself, and it can is common for the screen refresh rate to appear out of step with one's movements. Also none of the current VR solutions are able to fool the user's proprioception. Although the visual display might show the user travelling uphill, if the floor remains flat, a mismatch occurs between the user's vestibular and visual input.

Many of the navigation aids we use in the physical world are also being used to support wayfinding in virtual spaces. Darken and Sibert (1993) identify a variety of such tools (flying, spatial audio, breadcrumb markers, coordinate feedback, districting, landmarks, grid navigation and mapview) and provide an informal evaluation for each. Their findings are interesting in that they show how each tool affects wayfinding behaviour. When landmarks were present, for example, they were used by participants as orientation devices, but would also help users to separate different areas within the environment – making it easier to split the space into manageable chunks. Such tools support wayfinding, but do not necessarily help the user learn the configuration of the space in
which they travel. All navigation aids involve both cognitive and temporal costs in their usage, but such overheads may well be unnecessary if we could instead support spatial learning.

2.3.1 Why support spatial learning?

Where the navigator’s experience of a virtual environment is limited to a single occasion, there is probably little benefit to be gained from developing a cognitive representation of the space. Under such circumstances, many of the tools described above would be sufficient to support wayfinding. However, there are many occasions where the user receives repeated exposure to the same virtual space. ‘Star Wars Galaxies’, for example, is one of many Massive Multiplayer Online Role Playing Games (MMORPG) where the player enters the same virtual space over many months. A player using peripheral navigation aids under such circumstance incurs increased cognitive load, and takes much longer to find one’s way compared to a player with complete navigational knowledge of the environment. Clearly there is navigational benefit to be had from a tool which supports rapid cognitive map development - especially if such a tool could also support wayfinding as part of the learning process. The development of such a tool is the goal of the research reported here.

There are typically two ways in which people learn the configuration of a novel environment. They can either encode the environment through direct exposure (i.e., whilst travelling through the environment), or they can develop a cognitive representation based upon secondary information sources, such as maps, sketches, verbal directions, etc. (Golledge, 1999). However, the approach taken when learning the configuration of an environment can have potentially negative consequences on the resulting cognitive representation. Although knowledge gained through secondary sources is often much quicker to attain than through direct exposure to the environment (Thorndyke & Hayes-Roth, 1982), the quality of the cognitive representation is typically poorer than knowledge provided by direct experience with the environment.
Studies have shown that the alignment of landmarks on sketch maps, and participant’s estimations of distances are typically poorer if the participant has learned the environment via a secondary source, rather than a primary source (Wickens, 1992). Also, having learned the layout from a secondary source, navigators are exposed to potential difficulty when applying their understanding to wayfinding (Rossano, West, Robertson, Wayne & Chase, 1999). Iconic representations, such as maps, can prove difficult when learning spatial relations, as the map reader has to interpret the icons and then map them onto their physical world environment. This requires specific cognitive strengths, making it a non-trivial task for many participants in an earlier study (Thorndyke & Hayes-Roth, 1982). It has also been shown that learning the configuration of an environment from a top-down representation requires further cognitive effort as the navigator must perform spatial transfigurations of the map view to interpret the eye-level representation. Again, mental rotation is a task at which some individuals are particularly poor, making maps a learning tool unsuitable for all users (Kimura, 1992). Also, learning from a map will usually result in orientation-specific learning of an environment, whereas leaning from walking around the environment does not (Presson & Hazelrigg, 1984; Rossano et al., 1999).

Although a tour of the environment offers the user direct exposure to the configuration of the space, as a method for spatial learning it is also a particularly poor way to learn the layout of a place (Evans, Skorpanich, Garling, Bryant, & Bresolin, 1984; Goldin & Thorndyke, 1982). Evans et al. (1984) had subjects watch a filmed tour around a city. The film was shot from the driver’s perspective, which meant that the audience could see where they were going. Findings indicated that participant learning of orientation cues was very poor. This was very similar to the findings of Goldin and Thorndyke (1982) who instead took their participants onto the bus for a physical tour of the city.

Tours and flyovers are poor tools for learning spatial structure because of the passive nature of the experience. Cheesman and Perkins (2002, p375) argue that interactivity is better than passive participation because the navigator “encodes information in more automatic, elaborated form, with multi-modal components that include conceptual,
visual, sensory and motor components”. When we explore our environment we interact with it, making predictions about where pathways lead. When those predictions are proved true, then we assimilate the new information and add the new route to our internal database, and when the prediction is found to be false, we have to restructure our internal model to accommodate this new information. The difference between active and passive learners has been explored by Peruch, Vercher, and Gauthier (1995). They compared the spatial learning of compartments within a wall-limited space across three conditions. The first group were active learners, and could freely explore the environment’s structure. The second and third groups were passive, and could only view a tour of the environment, or static scenes at key points within the environment. As predicted, active learners performed significantly better when finding their specified target. Both groups of passive learners were equally poor at finding a direct route to the goal.

Conclusions

VR technology provides us with the possibility of interacting spatially with digital environments. Human interaction with the world around us is also spatially mediated, and so our experience of using VR technology to interact with computer systems often feels natural. However, the introduction of the spatial metaphor also introduces the likelihood of losing one’s way in the virtual world, and there is therefore a need to support navigation in electronic space. Where the user receives a single exposure to a virtual environment, many of the traditional navigation aids are suitable. However, where the user is exposed to repeated navigation of a virtual environment, tools which support spatial learning might be of greater benefit – especially if they also support wayfinding. Finding appropriate tools to support spatial learning is not as simple as providing a map of the space, or a tour of the facility - such methods produce poor cognitive representations. Instead it was decided to consider the psychological literature on cognitive representations of virtual space as a basis for developing such a tool.
This chapter considers how we navigate and encode space (physical space, virtual space, and conceptual space). It is divided into three sections. The first concerns both the nature and development of cognitive spatial representations. The second is a discussion on navigation in real-world spaces. The third and final section discusses wayfinding tools which might also support spatial learning in virtual environments.

3.1 Cognitive representations of space

"Make me no maps, sir, my head is a map, a map of the whole world"

[Henry Fielding, Rape upon Rape, act 2, scene 5]

3.1.1 Differences in encoding physical and virtual spaces

In developing a spatial learning tool, the intention was to determine the processes involved during the cognition of virtual spaces. Unfortunately, there is little published work specific to the cognitive mapping of virtual space, and such work that does tackle the subject typically refers to theories based on the cognition of the physical space. The likelihood that the cognition of virtual and physical space involves the same cognitive processes is increased by the finding that spatial configurations learned in virtual spaces transfer well to physical world situations (Bliss, Tidwell, & Guest, 1997; Darken & Banker, 1998; Darken & Goerger, 1999; Goerger, Darken, Boyd, Gagnon, Liles, Sullivan, & Lawson, 1998; Johnson, 1994; Johnston, 1995; Regian & Yadrick, 1994; Rossano, West, Robertson, Wayne, & Chase 1999; Waller, Hunt, & Knapp, 1998; Witmer, Bailey, & Knerr, 1995). Johnson (1994) found that soldiers who had been given navigation training in virtual environments were able to transfer their knowledge to the actual environment being modelled. Witmer et al. (1995) were concerned with training
Supporting Spatial Learning in Virtual Environments

Special Operation forces to successfully combat hostage situations by familiarizing soldiers with room configurations within buildings. They found that VR training also transfers to the built environment. Such work suggests that many of the cognitive skills associated with representing space are the same, regardless of the modality.

There are some studies which suggest that cognitive representations of virtual spaces are not as rich as those attained in physical environments. Although many studies demonstrate users can develop a representation of virtual environments based on pathways and routes, the evidence for the development of a spatial representation is not conclusive (Goerger et al., 1998; Rossano et al., 1999). However, even in the physical world people can travel somewhere and not acquire a survey representation within a year of exposure (Moeser, 1988), as it appears that the development of a survey representation requires some motivation on the part of the navigator (Lindberg & Garling, 1983). On this basis this thesis is based upon the assumption that the cognition of virtual spaces and physical space is much the same.

3.1.2 The cognitive map
The term ‘cognitive map’ was coined by Tolman (1948) and refers to the mental representation of spatial information. In this context, the term ‘map’ is a functional description of the representation, rather than a structural description. The cognitive map does not possess the same formation as a cartographic map, but instead offers similar functionality to the cartographic map, in that it provides necessary information for route planning and wayfinding. Downs and Stea (1973) argue that the cognitive map stores information about the ‘relative locations’ and also the ‘attributes of phenomena’ in our everyday spatial environment. They argue that the cognitive map is much more than a representation of spatial structure, but also stores other attributes of place, such as accessibility (which roads are busy at rush hour), sensory experience (sights and sounds), emotional connotations (location of first kiss) and evaluation perceptions (rough neighbourhood). The distance and directional information is considered to be a subset of
the locational information, and the descriptive and evaluative attributes are subcomponents of the attributes of place (as shown in figure 3.1).

<table>
<thead>
<tr>
<th>Spatial Phenomenon</th>
<th>(Blind Poet Pub)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Locational Information</strong></td>
<td>(where is it?)</td>
</tr>
<tr>
<td>Distance - 2 miles</td>
<td>Direction - due south</td>
</tr>
<tr>
<td>- 30 mins by bus</td>
<td>- downtown</td>
</tr>
<tr>
<td>- beside the uni</td>
<td>- expensive taxi ride</td>
</tr>
</tbody>
</table>

**Figure 3.1**
Classes of information used in cognitive maps (based on Shum, 1990)

Siegel and White's (1975) 'Sequential and Hierarchical' model argues for three stages of cognitive map development:

1. **Landmark-based representation**
   Salient aspects of the environment, which maintain a consistent location can be used as a reference point during navigation, and are commonly referred to as landmarks. Landmarks facilitate encoding by allowing us to segment the environment into smaller, more manageable components. This is exemplified by experiments which show that memory for items increases when we imposing an organised structure upon them (Anderson, 1980; Thorndyke & Stasz, 1980). By using landmarks as the centroid for segmenting the environment, we ease the task of spatial encoding. Allen (1982) and Allen and
Kirasic (1985) argue that we chunk the environment into segments, and then determine whether a landmark will be found within or outside of a given segment. For example, we might remember the rose bush being near the blossom tree. Chunking is a strategy we employ to enhance learning. Rather than encoding a large amount of information, we ‘chunk’ the information into smaller packets, that are easier to remember. Telephone numbers, for example, are often presented in a series of chunks (0131 337 3307), rather than a continual data stream (01313373307).

When we write a letter we identify the house name, the street, the city, and finally the country. There is evidence to suggest that our chunking of the environment is encoded within a hierarchical structure (Wilton & Pidcock, 1982; Tversky, 1991). To image the whole planet at the granularity we might recall a single room would be a fantastic cognitive feat. Luckily it appears that we have developed a solution where such cognitive dexterity is unnecessary. Instead, the nesting of chunks (as shown in Figure 3.2), allows us to mentally zoom in and out of our representation as and when we require different levels of detail (Wilton, 1979). Infield (1991) argues that the zooming between levels of complexity requires the recognition of a common element in each.

Because we compartmentalise the environment in this way, it can be difficult to think across conceptual boundaries. This has been demonstrated by Stevens and Coupe (1978) who found that when a sample of Americans were asked to judge which of two cities was most Westerly – Reno or San Diego, most would incorrectly state San Diego. They could visualise California, and they could visualise Nevada, but they had great difficulty visualising the lower ordinate structures simultaneously. Instead they relied upon their higher order structure of the US in their thinking. From their knowledge of the US states they were able to determine that California is more Westerly than Nevada and drew the incorrect conclusion that San Diego must therefore be west of Reno. A similar finding was replicated in the UK. When participants had to state
which town was further north, their response time was much quicker if the towns were in different countries (Wilton, 1979).

Landmarks are used to pilot the environment because they stand out from the environment and are immediately noticeable. Factors that influence the saliency of objects vary between people. Items such as a particular headstone in the graveyard, or the family home might be salient to one person, but not to another, whereas landmarks such as London’s Big Ben are salient to the majority. In studies investigating landmark saliency, personally significant items account for approximately half of the landmarks identified by participants (Golledge & Spector, 1978). It is therefore clear that each of us will possess significantly different mental structures to represent the same environment, as we each have different landmarks - the foundation stones of our cognitive map. To distinguish them from popular landmarks, the term ‘anchor point’ will from this point be used to refer to landmarks of a personal nature.

Despite individual differences in our choice of landmarks, Vinson (1999) proposes a single set of guidelines for adding landmarks to virtual environments. As shown in Table 3.1, Vinson argues that landmarks are places or structures that stand out because of some unique quality. This quality is usually thought of as being purely visual, however, objects in the environment might be salient because they are associated with a particular sound, scent or even activity (Golledge, 1999). For example, the Houses of Parliament stand out - not just because of their grand design - but because the political decisions taken there are significant to the population of the United Kingdom. The same can be said about the area around Wall Street, which is world famous for being the financial district of New York. There are many more locations around the world that are salient because of the activity they are associated with such as Piccadilly Circus, Saville Row, Fleet Street, Times Square.
Figure 3.2 An example of the cognitive map's hierarchical structure
2. Route-based / procedural representation

Representing the environment as a series of landmarks is limiting when it comes to navigation. Although the navigator might recognise a landmark along their journey, such a model would not detail how they could arrive at their destination. The procedural representation is a more complex cognitive structure which represents the environment as a network of pathways between landmarks (Siegel & White, 1975; Golledge, 1999). Having identified the salient features of the environment it is possible for the navigator to begin the process of route formation. This is where the navigator learns simple procedural rules that can be used to form routes from one landmark to the next. Using this approach, each landmark is used to prime the direction of the next. Piloting between landmarks allows the navigator to reach their goal. For example, when the navigator recalls that turning right at the statue will lead them to the lecture theatre, they will have defined a route. Slowly, with increased exposure to the environment, the number of known routes increases. As the known routes overlap and intersect one another, the complexity of the cognitive map increases. Different routes begin to take on varying levels of importance depending upon the frequency of travel and directness of route. Eventually the mental representation becomes analogous to a large road network consisting of motorways, A-roads and B-roads.

3. Survey-based representation

Evidence of a further representation is offered by Appleyard (1970). He found that the greater the exposure a person has to a particular environment, the more likely it was that they would possess a configurational (also known as survey) representation of their surroundings. Unlike the egocentric, sequence-based nature of procedural knowledge, the distinguishing factor of configuration-based knowledge is that it is spatially structured. However, rather than representing absolute relations, sketch-map studies suggest that the configurational model contains a normalised view of the environment.
(Appleyard, 1969, 1970; Lynch, 1960; Evans, 1980). For example, the navigator is likely to remember routes being straighter than they actually are. Junctions are remembered more as right angles. And relative relationships are remembered rather than specific locations, which results in items being thought of as closer to landmarks.

Table 3.1

Vinson’s guidelines for the use of landmarks in virtual environments

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>ONE</td>
<td>It is essential that the VE contain several landmarks</td>
</tr>
<tr>
<td>TWO</td>
<td>Include all five types of landmarks (paths, edges, districts, nodes, landmarks)</td>
</tr>
<tr>
<td>THREE</td>
<td>Make your landmarks distinctive</td>
</tr>
<tr>
<td>FOUR</td>
<td>Use concrete objects not abstract ones</td>
</tr>
<tr>
<td>FIVE</td>
<td>Landmarks should be visible at all navigable scales</td>
</tr>
<tr>
<td>SIX</td>
<td>A landmark must be easy to distinguish from nearby objects and other landmarks</td>
</tr>
<tr>
<td>SEVEN</td>
<td>The sides of a landmark must differ from each other</td>
</tr>
<tr>
<td>EIGHT</td>
<td>Landmark distinctiveness can be increased by placing other objects nearby</td>
</tr>
<tr>
<td>NINE</td>
<td>Landmarks must carry a common element to distinguish them, as a group, from data objects</td>
</tr>
<tr>
<td>TEN</td>
<td>Place landmarks on major paths and at path junctions</td>
</tr>
<tr>
<td>ELEVEN</td>
<td>Arrange paths and edges to form a grid</td>
</tr>
<tr>
<td>TWELVE</td>
<td>Align the landmarks main axes with the path/edge grid’s main axes</td>
</tr>
<tr>
<td>THIRTEEN</td>
<td>Align each landmark’s main axes with those of other landmarks</td>
</tr>
</tbody>
</table>

Navigation
Supporting Spatial Learning in Virtual Environments

Figure 3.3
The development of the cognitive map – a visual illustration using the London underground railway system as an example

(a) A Landmark Representation of London Tube Stations
The landmark representation is characterised by the lack of linking pathways or spatial distance between landmarks

(b) A Procedural Representation of London Tube Stations
(image adapted from Garland, 1994)
A procedural representation of the London underground system would show pathways between landmarks, but would be limited by poor spatial knowledge.

(c) A Survey Representation of London Tube Stations
(image adapted from Garland, 1994)
A survey representation of the London underground railway would contain the spatial configuration of landmarks and pathways.
Demonstrating how a person’s sketch map of an environment might develop from a landmark-based representation, to a configurational representation, Figure 3.3 uses the London Underground Map as an example. Figure 3.3 (a) shows the city of London represented by a series of landmarks - from Leicester Square to Tottenham Court Rd. As experience of London increases, so does the complexity of the representation. Routes are recognised until one by one an intricate network of pathways are uncovered (see Figure 3.2(b)). Eventually, after many years of exposure to an environment, a configurational representation matures from the route based structure to a survey representation of London (see Figure 3.3(c))

Although three different mental representations have been presented (landmark / procedural / configurational), each with increasing complexity, it is important that they are not perceived as necessary or sequential stages of development. Studies have shown that the three representations develop in parallel to each other (Ruddle, Payne, & Jones, 1997; Ruddle, Payne, & Jones, 1999), and that it is very easy to jump to a configurational representation of an environment by learning a route from a map rather than through first hand experience (Clayton & Woodyard, 1981). Using maps to gain instant configurational knowledge can prove advantageous as many people never move from a procedural to a configurational perspective. This was found to be the case in Appleyard’s study (1970), where 66% of long-term residents still had a mainly procedural representation of their city. It is also apparent from the same study that the type of representation may be linked to intelligence. Appleyard found that people who could be thought of as having a higher intelligence (in this case business executives) had a more spatial representation of their surroundings than those of a lower intelligence (skilled workers). The effect of individual differences will be discussed in greater detail later in the next section.

3.1.3 Individual Differences
In designing tools to enhance spatial learning in virtual environments, it may be necessary to cater for individual differences with respect to spatial cognition. The study of individual differences is concerned with performance variation between sub-groups of
Supporting Spatial Learning in Virtual Environments

a population. Once identified, individual differences may be accommodated through various support mechanisms such as training, better design of the task, or the adoption of user support tools. Messick (1976) identified three strategies to compensate for individual differences:

- the challenge match, a sink or swim method where a deliberate mismatch between task and skill-set are enforced to push the individual into adapting to the challenge of the task.
- the capitalisation match, where the task is adapted to match the skills of the individual.
- the compensatory match, where the individual’s difficulties on a task are tackled through training, or support tools.

It is the aim of this study to offer a compensatory match, by providing software tools to support wayfinding difficulties experienced by navigators.

To identify the appropriate strategy to support individuals in performing a task that requires complex skills, such as wayfinding, Egan & Gomez (1985) recommend that you must first:

1. isolate the individual differences which significantly influence the task
2. identify the components of the task that account for the variation in performance
3. and then modify or remove those components that account for variation in performance

There are a multitude of individual differences which may influence wayfinding, ranging from spatial intelligence to social class.

Differences in Spatial Intelligence

Performance measures in spatial cognition show tremendous variation with respect to individual differences. For example, in a study by Fine and Kobrick (1983) 16 people were asked to judge a set of long distances (600m – 1600m) in a field, and their
estimations ranged from 27% to 217% of the true distance. In the light of such a finding it is reasonable to expect that differences in spatial cognition affect wayfinding ability.

Most research has concentrated on just two of the most dominant dimensions of spatial intelligence: Spatial Orientation and Visualisation (McGee, 1979). Spatial orientation (SO) is concerned with the ability to adopt and/or appreciate different visual perspectives. This is considered to be important for the learning of a new environment because the landmarks which help to deconstruct the environment may be experienced from a multitude of angles and perspectives. In order for a landmark to be useful in learning and navigation it is important that it is recognised, regardless of the direction of travel. Also, if the navigator is able to determine the perspective from which they are seeing a landmark item, they are also able to orient themselves with respect to the landmark and identify their location. It is also likely that SO will be relevant to the adoption of a configurational representation, where the navigator moves from a ground-level view to a survey view of the environment (Waller, 1999).

Whereas tests of SO involve the participant imagining different perspectives around a stationary image (i.e., ego referenced), spatial visualisation (Vz) is concerned with the mental manipulation of the image itself and not the viewer (i.e., object referenced). Tests used to determine Vz include tasks such as paper folding (Ekstrom, French, Harman, & Dermen, 1976) and mental rotation (Cooper, 1975; Shepard & Metzler, 1971), both of which require the participant to complete complex mental transitions such as folding, rotation and reflection. The difference between SO and Vz is merely a switch of reference point. Although the difference between SO and Vz may at first seem subtle, the difficulty of adopting a different reference scheme is soon noticed when designing software for presenting virtual environments. In the ‘real’ world the scene remains static and the navigator does the moving. In computer simulated worlds, the navigator actually remains still and the programmer has to determine how to make the world move around them.
It is expected that spatial ability correlates positively with wayfinding ability. However, Waller’s review of the psychometric literature found the link to be ‘tenuous’ (Waller, 1999). Apart from a couple of notable exceptions (Walsch, Krauss, & Regnier, 1981; Rovine & Weisman, 1989), the correlation between tests of spatial ability (both SO and Vz) and wayfinding performance was found to be around 0.2 (Bryant, 1982; Goldin & Thorndyke, 1982; Pearson & Ialongo, 1986; Sholl, 1988; Allen, Kirasic, Dobson, Long, & Beck, 1996). This is perhaps not as surprising a finding as it might initially seem. In the light of previously discussed theory of environmental learning, it would be likely that an individual’s wayfinding ability would be heavily influenced by how they organise the spatial information received. As Chase and Chi (1981) observed, ‘a great deal of spatial knowledge, perhaps most, is inferred’. Therefore, although the lower level spatial abilities undoubtedly affect our ability to identify locations, it is likely that the strategy used when deconstructing and organising those locations in memory will be the factor that is most tested when wayfinding. This position is supported by the results of a study looking at how people acquire knowledge from maps, where it was found that those with better map reading skills use more active learning strategies (Thorndyke & Stasz, 1980). It appears that good map readers are better at focusing their attention on unlearned knowledge, and ignoring information that is already known.

**Differences between the Sexes**

Studies investigating sex differences with regard to route learning appear to indicate that females differ from males in the type of landmarks they adopt. Females are more likely to use objects in the environment as a focus for piloting, whereas males are equally able to use the configuration aspects of a scene (Bever, 1992; Couclelis 1996; Galea & Kimura, 1993; Holding & Holding, 1989; Lawton, 1994, 1996; Miller & Santoni, 1986; McGuiness & Sparks, 1983; Sandstrom, Kaufman, & Huettel, 1998; Schmitz, 1999). Males appear more accurate when judging directions after a route learning task (Holding & Holding, 1989), they are more likely than females to give directions using distance measures (Miller & Santoni, 1986, Ward, Newcombe, & Overton, 1986), and they appear to exploit *both* landmark and geometric information when navigating (Sandstrom et al,
Supporting Spatial Learning in Virtual Environments

1998). In comparison, females are more likely to give directions using landmarks (Miller & Santoni, 1986) and appear to rely predominantly upon landmark information when navigating (Sandstrom et al, 1998; Schmitz, 1999). It is likely that these findings are a reflection of spatial ability. Females have been found to be less confident of their spatial skills (Lawton, 1996), and are frequently out-perform by males on tests of visuo-spatial ability (Goodrich, Damin, Ascione, & Thompson, 1993; Kimura, 1992).

Although differences in wayfinding strategy between the sexes is heavily suggested by much contemporary research, it is interesting to note that in a natural environment there does not appear to be any significant difference in wayfinding performance between males and females. The difference between males’ and females’ wayfinding performance is only evident when the environment supports one wayfinding strategy over the other. For example, in studies by Sykes et al (1996) and Moffat et al (1998) it was found that when participants were presented with an environment without ‘landmark’ information, males were significantly better then females when searching for their goal. However, when landmarks were present, there was no significant difference between male and female performance. This finding has clear implications for the building of virtual environments and for the care needed in undertaking and catering for differences in spatial abilities and in preferred navigation strategies.

Differences between Cultures and Social-Class
Various studies have suggested that there might be differences in environmental cognition between cultures and social-class. Appleyard (1976) found that lower class people in Venezuela had a more detailed knowledge of their city than did those people of a higher social standing. This is in direct contrast to research that instead found that people of a higher social class possess greater knowledge of their environment in two cities within Italy, and in Los Angeles (Orleans, 1973; Francescato, & Mebane, 1972). It is interesting to note that in each case the authors argued that the effect was probably a product of environmental exposure. In Venezuela the higher class inhabitants generally live closer to the city, so they do not travel around their environment as much as the
lower class occupants, who have to travel through several suburbs to get to work (Appleyard, 1976). Orleans (1973) argued that the higher classes of Los Angeles have more knowledge of their environment because they were more likely to have friends outside of their immediate neighbourhood.

### 3.2 Navigation

The word ‘navigation’ was originally used to refer to a ship’s movement across water, although nowadays it has come to refer to the planned movement of any object within any environment (Darken & Sibert, 1993). We navigate many different spaces; spatial, social and semantic (Dourish & Chalmers, 1994). This section concentrates primarily on the spatial domain, although arguments have been made that navigation is remarkably similar across the different modalities (Benyon, 1998; Shum, 1990). Benyon (1998), for example, argues that navigation through semantic spaces (i.e. databases, the world wide web, etc) is similar to the act of navigating the physical world. This view is supported by the cognitive processes involved when grand masters play the game of chess (Chase & Simon, 1973a, 1973b). Unlike most artificial intelligence algorithms which perform a cost/benefit analysis on a series of possible outcomes to a given move, experts in chess appear to use a landmark/route type strategy. The problem space of chess can be represented by a number of set positions on the board (i.e., the spatial relationship between the pieces) and from these positions chess masters can recall the sequence of play to reach their goal – whether that is to take the opponent’s queen, or to take the game. The aim of their game is to try and realise a known configuration on the chess board (i.e., landmark position) so that they can then re-play the winning sequence of moves (i.e., retrace a known route to the goal). Research has demonstrated that the better the chess player, the more set positions / landmarks they appear to remember. A Master can typically recall approximately 50,000 different configurations, whereas a good club player can recall around 1,000 patterns.
Successful navigation, whichever mode, involves four distinct activities: route identification, orientation, course maintenance, and goal recognition (Downs & Stea, 1973). Each will be discussed in turn.

3.2.1 Route identification

*Route identification* is the process whereby the navigator determines the most suitable route from the start position to the destination. The suitability of a route is dependant upon the context of the activity, and although the chosen route is commonly the path that is the quickest to traverse, the navigator might instead choose the most scenic route, the route that requires the least effort (i.e. no hills, has a bridge to cross the river), the shortest route (which may be different from the quickest route depending on roads, time of day, etc), or the safest route (bypassing a quiet area, or staying where it is well lit). All such information can be accessed by the cognitive map (Clayton & Woodyard, 1981; Kuipers, 1983). It is not just the Euclidean dimensions of space, but also the qualitative (such as aesthetics/lighting/etc) and the temporal (such as places to avoid at particular times – on the grounds of safety/congestion/etc) information about the environment that are noted during one’s encounter with the world.

3.2.2 Orientation

*Orientation* refers to the activity we undertake to determine our location in space. Modern technology has made it easy to define our position with the introduction of instruments like the Global Positioning System (GPS), which relies on calculating the distance from four of the twenty-four satellites surrounding the earth. However, we can navigate quite comfortably without the aid of special devices, and instead use our cognitive maps to orientate ourselves. There are various methods available for calculating position without external navigation aids – such as dead reckoning, trilateration and triangulation (Golledge, 1992). When orientating using dead-reckoning, the navigator determines their location relative to a start point. This is done by estimating the speed of movement, the time taken to reach the current position and the direction of travel. The speed of travel and the time taken to reach the current location will give the distance...
travelled from the start point. Knowing the distance and the direction travelled one can then determine the current position relative to the start point. It is clear that using the dead-reckoning method, the poorer the estimation, the greater the degree of error. However, this is usually acceptable because for most journeys approximation is adequate.

Although trilateration and triangulation can be used without realising the maths involved, they are both orientation techniques that originate from trigonometry. Trilateration involves estimating the distance from known landmarks. As is shown in figure 3.4(a), if the distance to landmark ‘A’ is 6m, our position must lie somewhere along the circumference of the red circle – which is 6m in radius. If we also know that landmark ‘B’ is 4m away our location must be at one of the two points where the circles intersect. This is because only at those points will we be both 6m from landmark ‘A’ and 4m from landmark ‘B’. To ascertain an exact location on a 2D plane – which is typical of our natural terrain – only a third landmark is necessary. The navigator will aim to match visible objects with items on a map (cognitive or otherwise), in order to determine their location.

3.2.3 Course Maintenance
When making their way to the goal, it is important that the navigator continually ensures that they are following the appropriate path. There are various methods to ensure course maintenance. The navigator will certify that they are passing landmarks which are known to punctuate the route, they may refer to a map, they will even ask people local to the area of they are still going the correct way. Involving others to maintain our course is called social navigation (Dieberger, 1997). The people with whom the navigator interacts can be real, or in a VR context they might be artificial agents. The game Zelda: Ocarina of Time, for example, provides the player with a fairy which helps the player navigate two spaces: the geographical space and the game space. In helping the player navigate geographical space the fairy will suggest the player should head in a particular direction. Perhaps more interestingly, the fairy will also keep the player on-course with respect to the game space. If it appears that you are unsure what should be done next to advance the narrative, the fairy might suggest that you visit the local town to confront the Ogre, or remind you what
the Elf in the woodland had said. In this way the fairy makes sure that you never stray too far from the game, while allowing the player the freedom to choose their own destiny.

**Figure 3.4**
*Orientation through trilateration and triangulation*

**a) Trilateration**
Where orientation is deduced through the judgment of distance from landmarks. Distance can be calculated through triangulation.

**b) Triangulation**
Knowing the angle of direction from two separate points, and the distance between each point, it is possible to calculate a viewed object's distance using principles of trigonometry.

A series of such triangles can identify location through trilateration – see above.
3.2.4 Goal Recognition
Darken and Sibert (1996) categorise navigation tasks into three activities: the naïve search, the primed search, and exploration. The ‘naïve search’ refers to wayfinding where the traveller is unaware of the goal’s location. A physical world example would be visiting a library to borrow a book and having to ask the librarian for its location. In comparison, the ‘primed search’ is where the location of the goal is known. So again, in the library example, the borrower would already know upon which shelf to find the book. Exploration refers to wayfinding tasks where no goal has been set. An example of exploration is where the borrower visits the library but has not decided upon a particular book. They therefore browse the selection on offer until a title appeals. On some occasions, such as window shopping, the goal is not merely undefined it is non-existent. The exploration itself is the purpose of the activity.

Although wayfinding tasks are mutually exclusive, it is likely that most journeys will incorporate more than one particular activity. For example, it is likely that the library member will use a primed search to find the appropriate section category and then adopt a naïve search to find the appropriate title on the shelf. Or alternatively, the library member might know that they would like a humorous book but have no particular title in mind. They might therefore adopt a primed search to locate the comedy section, and only then would they begin exploration until a suitable publication was identified.

3.3 Supporting spatial learning in virtual environments
Dahlback (1998) identifies two ways in which navigation may be supported in virtual environments. The first is to apply knowledge of spatial cognition in the design of the environment, making it easy to encode. This might include the addition of signage, landmarks, the hierarchical structuring of the environment, and so forth. The second method is to provide navigation aids. Wayfinding tools include maps, coordinate systems, the ability to fly, and so forth. The following section of the thesis discusses each method.
in turn, concentrating specifically on the navigation tools which have already been evaluated for their wayfinding properties.

### 3.3.1 Designing the environment

City planners have long been aware of the impact an environment’s structure has upon encoding performance (Lynch, 1960; Appleyard, 1976). Lynch (1960) refers to the degree to which the environment supports cognitive encoding as the environment’s **legibility**. He argues that an urban landscape becomes more legible if it has an easily identifiable, coherent and organised pattern to it. From the analysis of sketch maps, Lynch identified five coherent properties of the environment: nodes, landmarks, paths, districts, edges.

**Nodes**

Nodes are spots within the environment which possess an ‘intensive foci’ (Lynch, 1960, p47). Nodes may be places where the journey stops or starts – as in junctions between pathways, or a concentration of elements which are the epitome of the district. Depending upon the level of representational hierarchy, the city may be a node of the state map, or an important road junction.

**Landmarks**

For details of what constitutes a good landmark, see Table 3.1.

**Paths**

Pathways are ‘potential lines of movement’ through the environment (Lynch, 1960, p96). Lynch argues that the most legible pathways are those which are straight, with turns that are at 90 degrees. De Jonge (1962) found that people will draw more complete and accurate maps of their environment if it has a regular (i.e., a linear, parallel and perpendicular layout) pathway configuration.
Supporting Spatial Learning in Virtual Environments

Districts

Districts are sub-components of a space. They are defined by some common characteristic. For example, many cities have a China Town district, which will be instantly identifiable by the change in architecture. Clearly identifiable districts aid legibility because they support the chunking of an environment into hierarchical structures. For example, China Town is a district of Los Angeles, which in itself can be seen as a district of the United States of America.

Edges

Edges are boundaries, often between two different areas. They might be between districts, or they might surround the town. Edges are strongest when they are ‘visually prominent, …[and] also continuous in form and impenetrable’ (Lynch, 19670, p62). They work by bounding an area of space, supporting the hierarchy of spatial representations by identifying its outer limits. The water around the island of Manhattan is a good example of a strong boundary which surrounds one of New York’s most famous districts. It is both continuous, and impenetrable without the use of a bridge or boat.

Experimental work evaluating Lynch’s legibility techniques have concluded that they do improve legibility (Ingram & Benford, 1996; Ingram, Benford, & Bowers, 1996). As well as Lynch’s work on environment legibility, it is possible to increase the navigability of an environment by the simple addition of signage.

Signposts

Signposts are perhaps the most effective method for making a space more navigable. If the navigator is lucky enough to have their destination signposted, they can easily find their goal without having to memorise given directions, learn the environment, or interpret abstract tools (i.e. map reading). Because the navigator never has to learn the environment in such situations, it means that they never have to consult their cognitive map – thus removing much of the spatial manipulation associated with navigation, and thereby reducing the individual differences.
McCall and Benyon (1999) identify three primary categories of signage: informational, directional, and warning and reassurance. Informational signs provide information about objects, users and activities within an environment. They might also label a region of space, such as a town or a district within a town. Directional signs guide the navigator along a specific route. They are often hierarchical, in that they become more localised as the navigator progresses through their journey. For example, taking a journey from Swiss Cottage, in London, to Leith, in Edinburgh, the traveller would begin identifying signs saying North. As they progress they might follow signs for Scotland, and then Edinburgh. Once in Edinburgh they would then find signage giving directions to Leith. To identify the hierarchy, signs will often present information in a different colour. For example, in the UK, directions to external towns and cities are given on green signs, whereas directions to local districts are given on white signs. This categorisation allows the traveller to easily attend to only the signage of relevance to their journey. Warning and reassurance signs provide information about the environment. They might inform the traveller that a possible route is currently closed, or that there are road-works ahead.

### 3.3.2 Tools which support wayfinding and cognition

Table 3.2 is a summary of tools that have been used to navigate both physical and virtual environments. The table is the outcome of brainstorming session with colleagues, and a review of relevant literature. As discussed in chapter two, a tool for learning the spatial configuration of virtual environments would be more useful if it could double up as a way-finding tool during the learning process. Table 3.2 identifies tools that have, and have not been evaluated with regards to their wayfinding properties by Darken and Sibert (1993), and shows how they might typically support wayfinding and spatial cognition. It is clear from the table that many of the tools described are suited to navigation rather than the development of the cognitive map. Also, no single tool has been identified that could support each of three stages of Siegel and White's Sequential and Hierarchical model of spatial cognition. The following section will set out the criteria...
of a toolset for spatial cognition, and will identify tools from Table 3.2 which might meet such criteria and become the basis of a tool for spatial learning in virtual environments.

Table 3.2
Benchmark table showing navigation tools, and the navigation processes they support
(items in red have been evaluated for their wayfinding properties by Darken and Sibert, 1993)

<table>
<thead>
<tr>
<th>Tool</th>
<th>Spatial Cognition</th>
<th>Wayfinding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landmark Knowledge</td>
<td>Route Knowledge</td>
</tr>
<tr>
<td>Map</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Grid</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Agents</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Guides</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Teleport</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Ball of String</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sonar</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Compass</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Footprint</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Songlines</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Beacons</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Flyover</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Tools to Support a Landmark-Based Representation

Based upon the spatial cognition literature discussed above, it is clear that an aid to the development of landmark knowledge must meet a series of different criteria. Firstly, any landmark tool must identify useful landmarks. Not all salient items in an environment are useful to the development of route and survey knowledge. The landmark tool should raise the saliency of those items which are helpful to the navigator, so that they stand out from
those that are not so helpful. Secondly, the tool should aid the memory of the landmark item. Forgotten landmarks cannot help the navigator. Thirdly, the landmark tool should show the spatial context of landmarks, so that navigators can identify possible routes to other landmarks in the environment. None of the tools in Table 3.2 could by themselves meet all the criteria listed. However, some of the tools can be applied to different criterion.

To aid the recall of landmark items, it may be possible to apply aspects of ‘songlines’. ‘Songlines’ are intricate collection of lyrics which are learned throughout childhood to identify landmarks along a route. The songs describe how the landscape was created before humans walked the earth. By singing the songs back to themselves, aborigines could use the structure of the songs to navigate the vast deserts of Australia, locate underground water, and find food (Chatwin, 1988). Jim Naureckas (2003) has used the principle of songlines to build a virtual walking tour of Manhattan streets in New York. He takes users along the streets of New York, and provides a history of the buildings that appear on either side of the street. Instead of songs, Naureckas uses web pages to tell the story of New York’s pathways as an aid to remembering the city.

To make it easier for the navigator to see the landmark in context with the surrounding area, it might be possible to use aspects of the ‘flyover’. The ‘flyover’ is either a self-guided, or a planned tour of the environment, which makes use of all three dimensions. The flyover tool has the potential to be powerful because it gives the user multiple viewpoints – both an aerial perspective showing the spatial structure of the surrounding environment, and the perspective from the ground, giving the user the chance to see landmarks from a more common view point.

**Tools to Support Route-Based Representation**

The criteria for supporting route knowledge are similar to the criteria for supporting landmark knowledge. A route knowledge tool must help the navigator to identify their route from one landmark to the next, and it should show the routes in context with other
items within the environment, so that the navigator can see how one route leads onto another. To aid route identification, table 3.1 identifies three possible tools: the songline tool, the ball of string, and the map tool.

Of the three, the ball of string is perhaps the most useful. The ball of string, much like the breadcrumbs of the Hansel and Gretel story (Grimm & Grimm, 2002), works by leaving a trail from one landmark to the next. The line attaches itself to the beginning of the route, and then unrolls behind the traveller. Following the line therefore indicates the route that the navigator has taken. Such a tool might work well when combined with the flyover tool, which would help to show the spatial context of the route travelled, providing a background for metacognition, as the traveller identifies their route within the environment.

**Tools to Support Survey-Based Representation**

A tool to support the development of survey knowledge should meet the following criteria. Firstly, it should demonstrate the spatial relationship between landmarks and routes. Secondly, it should identify where, within the spatial configuration, the navigator can be found. This allows the traveller to map the virtual world, onto their cognitive representation by identifying their orientation. Perhaps the best tool to support the acquisition of survey knowledge is therefore the map. Maps provide an instant visualisation of the spatial relationship between landmarks, and they can easily portray the pathways taken during travel. They can also present the travellers location, and/or orientate the map with respect to the navigator’s field of view.

**3.3.3 The Spatial Learning Tool**

Based upon the criteria listed above, and the contents of Table 3.2, a toolset is proposed which might support wayfinding and the cognition of virtual spaces. The toolset is referred to as the Spatial Learning Tool (SLT), and consists of three components which are thought to support each of the three stages of knowledge acquisition, as identified by

| Navigation |
Siegel and White (1975). The toolset include the ‘Landmark Saliency Component’ (LSC), the ‘Breadcrumb Component’ (BC), and the ‘Map Component’ (MC). An implementation of the SLT can be seen in Figure 3.5.

**Figure 3.5**
An Implementation of the Spatial Learning Tool (SLT)

The Map Component
Rather than explicitly stating where each bookshelf can be found, the map component of the Spatial Learning Tool provides an iconic overview of the virtual environment (as shown in Figure 3.5). The blocks of colour displayed on the map are identical to the colour of the bookshelves they represent. This was considered appropriate for two reasons. Firstly, if the map presented each book section by name, the participant would never need to navigate using the first person perspective, something which has been
shown to be an important component of the development of the cognitive representation (Presson & Hazelrigg, 1984). Secondly, the iconic nature of the map forces the user to engage with their environment. In Piagetian terms, the map gives the navigator a basic structure around which they can ‘assimilate’ incoming information about the environment. Active engagement with the environment while navigating has been shown to enhance the development of the cognitive map (Cheesman & Perkins, 2002). Unless users can map the 2D representation onto the 3D representation, the tool will be of little help in navigation.

The Breadcrumb Component
It is argued above that the unthreading of a ball of string during navigation might aid route identification. The thread would follow behind the navigator, showing the path they had taken. This technique is similar to that used by Hansel & Gretel (Grimm & Grimm, 2002), although instead of a ball of wool, the children dropped breadcrumbs behind them. The use of breadcrumbs as a navigation aid is widely implemented across a range of applications and technologies. On the world-wide-web, breadcrumbs are used to enhance the usability and navigability of a website (Nielsen, 2000). By showing the pathway to the current web-page from a major landmark such as the ‘home page’, users can determine their orientation within conceptual space. The Gecko 201 Global Positioning System device aids orientation by showing users the physical path they have taken to reach their current location (Garmin, 2003). Hospitals (such as the Edinburgh’s Royal Infirmary) provide route information via painted lines on the floor which show the way to the appropriate ward. Users of vehicle tracking systems monitor the delivery of products

**Navigation**
by viewing breadcrumb trails, which show the progress and the route taken by a delivery vehicle. Also, the use of auditory breadcrumbs has also been investigated to see if they might help people find their way out of an environment during disaster situations (Rutherford & Withington, 2001).

The breadcrumb tool evaluated here follows the example used by the Grimm bothers, but has been developed within the context of the environment. Instead of dropping breadcrumbs, during their journey participants automatically leave a train of books behind them. To make the books easier to identify from a distance they were decorated in a bright yellow colour. It is argued above how important it is for the navigator to see the route they have taken from an elevated perspective so that they can process it within the context of other environmental features. As shown in Figure 3.6, the map component is continuously updated to show the location of each “breadcrumb”, and so provides a survey representation of the route travelled.
Figure 3.6
The map component of the Spatial Learning Tool (SLT)

Navigation
Landmark Saliency Component (LSC)
If landmarks form the foundation of the cognitive map (Couclelis, Golledge, Gale, & Tobler, 1987), it is fair to theorise that an imbalance of landmark information across the environment would lead to the development of a skewed cognitive map. This theory is upheld by findings that a person's internalised map of their environment is heavily biased by the distribution of landmarks within the world. Goodey (1971) found that people possess detailed cognitive information of areas close to major landmarks, but can offer very little information about districts distant from landmarks. If we are to offer navigation training to fire-fighters and defence personnel it is essential that procedures are in place to reduce the distortions of the learner's cognitive map. If it were possible to direct the navigator's uptake of landmark items, the provision of evenly balanced landmark information across the environment may reduce the discrepancy of the cognitive map.

The purpose of the LSC is to provide a facility whereby environments can have landmarks imposed upon them through the increase of the saliency of specified items.

The LSC has much in common with the Australian aboriginal songlines. Songlines work by raising the saliency and memory of important landmarks through song. In the same way, the LSC is designed to work by engaging the learner with flagged items within the environment. When an item which has been flagged as a 'landmark' item appears within the navigator's view, it becomes highlighted by the SLT. In highlighting an item the software opens a sub-window, in which the camera focuses on the specified object from an elevated position and slowly rotates around the item (as shown in the top left window of Figure 3.5). At the same time, the map component flashes the location of the landmark, so that the navigator can determine its location in space. While the sub-
window remains open a verbal description of the item is voiced. On first encountering a landmark item the navigator is treated to a full description of the item and a story which gives it an historical context. For example, upon seeing the ‘War’ bookcase, the traveller is told that being a pacifist, the princess had ordered all books on warfare to be burned. On a further two encounters, just the landmark name is given. After the landmark has been identified on three occasions, the landmark saliency component is turned off to avoid user annoyance. The information is presented three times as this is typically how often a televised advert will be seen before it is noticed by the viewer (Dibb, Simkin, Pride, & Ferrell, 2000).

By showing an item, and at the same time reciting a story about it, the LSC applies Paivio’s dual coding theory (Paivio, 1986). The dual coding theory argues for two cognitive subsystems, one which is particularly suited to the processing of non-verbal input, and another which is suited to the processing of language. Memories that are laid down by both subsystems are found to be more robust than from a single subsystem (Paivio, 1986). Therefore, by using both a verbal narrative, and a visual image of the item, the LSC should support the learning of a given artefact within the environment.
Method of Evaluation

Adopting a between-subjects design, participants’ wayfinding and cognition of a virtual environment is compared across 5 conditions (control condition, Spatial Learning Tool, and each sub component of the SLT - LSC, BC and MC). Figure 4.1 presents an overview of the procedure used. The following chapter discusses each aspect of the evaluation procedure in turn, beginning with an overview of the participants, and the apparatus involved.

Figure 4.1
The evaluation procedure

**Pre-Test Procedure**
- Participant Demographic Questions
- Spatial Ability Task
- VE Piloting Exercise

**Test Procedure**
- Wayfinding Task #1
- Item Recall Task
- Wayfinding Task #2
- Wayfinding Task #3
- Wayfinding Task #4
- Landmark Knowledge Task
- Route Knowledge Task
- Wayfinding Task #5
- Wayfinding Task #6
- Cognitive Map Task
4.1 Participants

A total of 101 participants were randomly assigned to one of the five conditions. Volunteers were recruited at Edinburgh University and Napier University, and given £5.00 in return for their participation. The result of the recruitment exercise was that many of those involved in the evaluation of the toolset were undergraduate and postgraduate students. This might be considered a poor reflection of the population. However, performance measurements across tasks were normally distributed, giving credence to the validity of the sample.

Although random assignment was implemented, allocation to condition was also weighted by a participant’s spatial ability, their ability to pilot virtual space, and the sex of the participant. A participant would sit the pre-test, and based upon their performance on each task they would then be allocated to a suitable condition. The breakdown of participants across conditions is presented in Table 4.1. Statistical analysis, which is discussed further in later chapters, found no significant difference between the control condition and the test conditions. This suggests that the samples were balanced for pre-test factors.

<table>
<thead>
<tr>
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<tr>
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</tr>
<tr>
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<td>10</td>
</tr>
<tr>
<td>Breadcrumb (BC)</td>
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</tr>
<tr>
<td>Map (MC)</td>
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</table>
4.2 Apparatus

The evaluation of the Spatial Learning Tool involved the implementation of both computer hardware and software. The following section both describes, and justifies, significant aspects of the apparatus employed during the evaluation process.

4.2.1 Hardware

As discussed previously, there is considerable choice in the VR apparatus available to evaluate the toolset. However, virtual environments which enjoy repeated exposure, such as games and on-line recreational worlds, are typically presented on television sets, or desktop monitors. Therefore, in an attempt to achieve ecological validity, a 17" Ilyama Vision Master Pro 450 monitor was used. The size of the monitor was considered most appropriate as it reflected the size of portable television sets commonly used for gaming in bedrooms, and also consistent with the size of monitors used in home computer systems.

To run the experimental software, a desktop IBM compatible PC was used. Based around an Intel Pentium3 processor running at 450 Mhz, with 256 Megabytes of Random Access Memory, and two Voodoo 2 graphic cards working together in SLI, the system represented the top-end specification of a home multimedia PC. Having two graphic cards together allowed us to run at a resolution of 1280 x 1024, while still maintaining 24 frames per second refresh rate (a comfortable speed at which the eye can maintain a persistence of vision).

4.2.2 Software

The use of off-the-shelf gaming applications has become an accepted practice for academic research (Lewis & Jacobson, 2002; Jakobson & Hwang, 2002; Kaminka et al, 2002; Piekarski & Thomas, 2002). This is partly because of the price, but also because of the quality (in that they are optimised to produce high resolution environments at fast
refresh rates), and because they are well supported by a large on-line fan base. This fan base will often develop tutorials, support groups, and example solutions, making it much easier to develop modifications suitable to academic work. After a thorough analysis of the VR software market, the game ‘Unreal’ (Epic Games, 1999) was chosen as the most suitable application for the production of the test environments. Unreal is a first person perspective game. This means that the image produced on-screen reflects the view that the participant would see if they were immersed in the virtual environment – the viewpoint that is typical of VR applications. At the time of the survey, Unreal had just been released, and was one of the most graphically superior engines available.

A further benefit of Unreal over many of the other VR engines was the inclusion of a level editor. The level editor allows developers to populate their own environments with a selection of pre-rendered objects, or objects imported from 3rd party rendering packages – such as 3D Studio Max. It is also possible to add light sources (regular/spot/flicker/strobe/etc) at different levels of luminance, as well as auditory sources or user instructions. Such facilities allow the development of interesting landmarks to populate the test environment.

Although there are level editors that support other VR engines, UnrealEd (the editor for Unreal) has many features that are not common among other similar applications. Firstly, UnrealEd was the first editor to support real-time preview of the level within the editor (see Figure 4.2). Until the release of UnrealEd, the designer had to compile the level and then load it into the VR engine if they wanted to view their changes. The addition of a real-time viewpoint therefore decreases the development time of VEs significantly.

More importantly, UnrealEd gives the level designer access to the underlying game code. Through a C++ based scripting language, called Unreal Script, it is possible to alter the behaviour of nearly all game artefacts. It is possible to change the Artificial Intelligence (AI) script for characters; change the number, position and focal length of view-ports of the virtual environment; and create events that can be triggered through either proximity,

**Method**
or through interaction with the player's avatar. The development of the three navigation components described above required the application and alteration of all such artefacts. For example, the LST required the use of proximity sensors, which when triggered opened a further view-port onto the VE and then circles around the landmark in question.

**Figure 4.2**
A screenshot of test-environment being developed within the Unreal editor (UnrealEd).

(Epic Games, 1999)
4.3 Materials

To evaluate the Spatial Learning Tool, two virtual environments were created. The first was developed to evaluate each participant's navigation performance. This facilitated the equal distribution of navigation skills across test conditions prior to the SLT evaluation. The second virtual environment was created to evaluate the influence the SLT had on the production of a participant's cognitive map.

4.3.1 The Pre-Test Environment

As already discussed, people differ significantly in their ability to pilot virtual spaces. To ensure that each condition was balanced with participants of equal abilities, a pre-test environment was developed. By asking participants to navigate the pre-test environment, it was possible to evaluate their piloting skills. An alternative would have been to train each participant to the same ability. However, this was rejected for a variety of reasons. Firstly, it would have involved significant exposure to the pre-test environment, making an already lengthy evaluation procedure even longer. Secondly, to ensure that piloting errors were not the cause of any difference between conditions, each participant would need to be trained to high level of expertise. This would have meant that many participants would not have qualified to participate, making the period of study much longer. The evaluation of piloting skills, and the subsequent balancing of conditions was deemed more appropriate.

To evaluate the participant's piloting skills, the pre-test environment featured obstacles, such as twisting corridors, a bridge, stairs, and a narrow beam with a drop to either side. See Figures 4.3 – 4.5 for examples of the pre-test obstacles. To reach the goal, participants had to successfully navigate each obstacle in turn. Completion time was taken as a measure of performance piloting skill.
Before we could start evaluating the SLT, the pre-test environment was evaluated to ensure that it could discriminate between good and poor navigators. It was also important to ensure that the pre-test did not take too long to complete, as this was just one of many tests participants would take during the SLT evaluation. It was a concern that if the evaluation process took longer than one hour, participants’ attention might waver and invalidate the results. The evaluation of the pre-test environment involved 15 participants.
who were asked to navigate the environment as quickly as possible. The time taken to travel from the start position, on the ground floor, to the goal on second floor, was recorded. The test revealed that participants would typically fall into one of three categories: fast, average, and slow. The ‘fast’ group usually had extensive experience navigating virtual environments, and would typically take 60-90 seconds to complete the task. The ‘average’ group took approximately 90-120 seconds, and typically included people who regularly used computers. The ‘slow’ group included anyone who took over 120 seconds – usually people who did not spend much time with computers. The maximum time recorded was 187 seconds, which was considered acceptable for the evaluation procedure.

4.3.2 The Test Environment

Choice of Test Environment

In developing a suitable environment to situate the SLT evaluation, various design constraints were considered. The following outlines each constraint and shows why the choice of a virtual library was suitable.

- size and complexity of the environment
  To identify the benefit (or otherwise) the SLT may have on the development of the cognitive map, it was important that the test environment be of a minimum complexity. If the environment is cognitively undemanding, learning may be accomplished without the use of the SLT. Darken and Sibert (1993) classify a complex environment as one which is of such size and complexity that participants cannot see its configuration from a single vantage point. Although the test environment must be challenging to learn, it is also important that it is not overly complex. Participants must be able to encode most features of the environment during the evaluation process.
Supporting Spatial Learning in Virtual Environments

Libraries are often complex spaces. They provide a large reserve of reading material within a limited and finite space. This typically means that the configuration of the library is less about usability for the user, and more about space maximisation. The shelving is often above eye level, making it difficult to see the spatial configuration of the environment. Also, with space being limited, there are often very few landmarks to aid orientation. The complexity of library navigation is evident by the number of library tours students are given as they enter academic life, and also the number of navigation aids libraries provide – such as maps, signposts, catalogues and shelf mark classification systems.

- **ecologically validity**

If the results of the SLT evaluation are to be generalised across other environments, it was important that the test environment be representative of places people use on a regularly basis – both when navigating virtual worlds and the real world. The choice of a virtual library was particularly apt, because there are examples of libraries both in the real world, and in the virtual world (Piguet & Peraya, 2000).

- **semantic associations**

The purpose of the evaluation was to determine whether the presence of SLT was beneficial to the development of a participant’s cognitive representation of the environment. It was therefore important that the test-environment did not provide extra information to aid participant navigation, otherwise it would be difficult to judge the effect the SLT was producing. A technique people often employ when navigating spaces is semantic association. As described in Chapter 3, this is where the navigator uses non-spatial knowledge to locate their goal. For example, having products arranged in alphabetical order allows the shopper to locate produce without learning the layout of the store. In such a scenario, the shopper would not have to rely on their memory of the store’s
configuration to locate items. The shopper can instead use their linguistic knowledge of the alphabet to find items on their shopping list.

Within a given section, (such as fiction, science, art, etc) libraries and bookstores are often organised semantically. Often books will be arranged in alphabetical order based on the surname of the book's author. However, the location of a particular section is largely dependent upon available space – rather than any rule-based protocol. Therefore, although one might use semantic association to find the book by author name, they must first locate the appropriate category of books, and the location of the required section is not typically supported by semantic association. This is a further reason why the library context was chosen for the SLT evaluation.

**Choice of Configuration**

Having identified a context of the test-environment, the next stage was to identify a suitable spatial configuration. One possibility was to model the test environment on one of Scotland's libraries or bookstores. However, with participants being local to Scotland, it was a concern that they might already be familiar with any chosen environment. Therefore the decision was taken to develop a novel environment.

In developing a new environment, decisions had to be made about its configuration. The first decision to consider was whether the environment should comply with Lynch's design heuristics (see Chapter 3 for an overview of Lynch's work). Applying Lynch's conventions should make encoding an environment much easier, which might mask the benefit of the SLT, making it less likely to identify an advantage. However, if the SLT was only shown to work when the environment was badly designed, questions would be raised about the validity of the evaluation. Therefore the design of the virtual library followed many of Lynch's guidelines for supporting navigation.

**Method**
Supporting Spatial Learning in Virtual Environments

- Pathways
  The ‘pathways’ were designed to express a ‘visual hierarchy’. The larger pathways run between each of the book sections, and smaller pathways are used within a section. This use of path hierarchy was designed to aid orientation. This should make it instantly recognisable whether the navigator is ‘inside’ or ‘outside’ of a district (i.e., book topic area).

- Districts
  Districts are unified regions of an environment (Lynch, 1960, p103). They can be unified by continuation of colour, texture, floor surface, lighting, façade detail, planting, or silhouette. In the context of a city they are the neighbourhoods – such as Queens, The Bronx, etc. They help the navigator to deconstruct the space into smaller, more manageable chunks, and thereby aid learning.

When designing the library environment, bookshelves were treated like mini districts. Each book category was unified by a single colour. In the environment the top of each bookshelf was shaded one of five different colours: green, red, light blue, dark blue and yellow (see Figure 4.6). Bookshelves containing books of the same category were rendered in the same colour. This allowed the navigator to identify just 21 book categories, rather than 54 individual bookshelves. It would have been better if each book section had had a unique colour association. However, technical limitation of the software package dictated the maximum number of colours that could be used. In an effort to overcome this limitation, no adjacent bookshelves were of the same colour.

- Landmarks
  The choice of landmarks, and their placement within the environment was informed by Lynch (1960) and Vinson (1999). Landmarks were chosen that were distinct from the rest of the environment, and also each other; they were all
concrete objects, which are easier to learn than abstract items such as art (Vinson, 1999); and they were all asymmetrical in shape, so that they could be used to work out the navigator’s orientation.

The virtual library environment contained four designer-defined landmark items – a monk statue, an area with tables and chairs, a water feature, and an empty bookshelf (see Figure 4.6). The landmarks were evenly distributed throughout the environment, so that the participant would not develop a skewed representation of the environment (see Figure 4.7). Every book section was adjacent to at least one landmark, making it easier for the participant to draw an association between the two, and thus remember the bookshelf location.

To determine whether the landmark saliency tool worked effectively, a low saliency landmark was included. The war bookcase is a landmark item, which is different from other bookshelves in that it does not contain any books. However, it has low saliency because, compared to the other landmarks included in the library, it is not distinct from the other objects in the environment.

As well as landmark items, the environment also contained two orientation devices: a stained glass window, and the library entrance. This thesis makes the following distinction between landmarks and orientation devices. Landmarks are designed to aid both orientation and learning, whereas orientation objects are specifically for orientation purposes. The stained glass window is positioned high on the north wall. With the environment being indoors, it was considered appropriate to replace natural orientation devices such as the sun. The entrance desk is located on the south wall of the library. The doors were purposely large to aid identification from a distance – and thus support orientation.
- **Edges**

  The bookshelves produce 'edges', linear elements that structure the library into five rows of book shelves. The wall also acts as a 'boundary' to the library, although with only one bound area, this is a less significant component of the design.
Figure 4.6
Landmarks and orientation devices

Monk Statue

The Monk statue is a man-made artefact which is placed between the bookshelves for ‘religion’ and ‘computing’. The statue stands before a flickering flame. The flame can be heard from a distance, supporting orientation through another modality.

Tables and Chairs

Thirteen chairs are arranged around four tables. On each table is a burning candle. The area has been created as a place for people to read the magazines that are on the bookshelf to the north of the landmark. Other surrounding shelves include Sport, Wildlife and Law.

Water Feature

The water feature is surrounded by large plants – which tower above the bookshelves, thus supporting orientation; and a table with three chairs. Adjacent book sections include Careers, History, Transport, Biography, Wildlife, Law and Health.
Empty book section on ‘War’

To determine whether the landmark saliency tool is working effectively, a low saliency landmark has been included. The war bookcase only differs from other bookshelves by virtue of not carrying any books.

Stained-glass window

The stained glass window is an orientation device, and therefore at such a height that it can easily be identified from most locations within the library. This makes navigation and orientation much easier, as it gives the navigator a fixed reference point.

Library Entrance

The library entrance is also an orientation device. It can be found on the South wall, between ‘entertainment’ and the ‘home and gardening’ book shelves. The doors are tall enough to be seen from most vantage points, again aiding in navigator orientation.
Supporting Spatial Learning in Virtual Environments

An added benefit is that the library maps well onto modern city design. A city consists of several suburbs connected by a network of major roads. The larger roads allow quick access to housing estates and shopping centres, where smaller roads provide access to individual shops and houses. As can be seen in the map of the library (Figure 4.7), each section of books is much like a simplified version of a housing estate. You have large open pathways that quickly take the heavy traffic to their suburb (bookshelf). Therefore, if the tools work in the library, their effect may well generalise to a city environment.

The actual configuration of the library (see Figure 4.7) evolved through a series of rapid prototypes. Each prototype was evaluated by six people (3 males, 3 females). The criterion for prototype evaluation was whether participants could perform a typical task, and also learn the environment within six, five-minute sessions\(^1\). The initial environments were too easy to learn, and required extra complexity through the addition of more bookshelves. The final environment was found to provide enough challenge, without being too hard for the average participant.

\(^1\) Previous studies (Sykes, 1999) suggest that most people can learn the configuration of a medium sized environment within 6 short trials.
4.4 Procedure

Each participant underwent a battery of tests which lasted approximately one hour. The protocol for this evaluation study was quite elaborate. Participants engaged in a series of pre-tests, questionnaires, the tool evaluation, and a post-test to appraise the participant’s
4.4.1 Participant Demographic Questions

The evaluation began with a series of questions to ascertain each participant's demographic details such as the name, sex and age of the participant, and to determine the participant's self rating of their navigation ability (see Appendix). Questions revolved around the participant's ability to read a map, and their ability to learn the layout of a new city. The purpose of such questioning was to determine whether people had an accurate impression of their own navigation skills. Comparison of participant perception and participant performance on spatial tasks could prove useful in the selection process of any follow up studies. Currently participants are tested to ascertain their spatial skills, and this can take considerable time. If perception of ability correlates positively with actual task performance, the spatial testing phase could possibly be removed from the process.

4.4.2 Spatial Ability Task

Upon completing the questionnaire, participants sat two tests which were devised to determine their spatial ability, and their ability to navigate around a Virtual Environment. As discussed in Chapter 3, individual differences affect performance with respect to spatial tasks and one's ability to manipulate the computer interfaces. Therefore the results from the cognitive tests were used to ensure equal distribution of abilities between conditions.

The paper and pencil test (Ekstrom et al., 1976) was used to determine a participant's spatial ability. The test consists of multiple choice questions where the participant is shown how a piece of paper has been folded and where a hole was inserted. The participant is then required to decide which of the 5 possible answers correctly represents the same piece of paper when it is unfolded. This requires the participant to perform
various forms of spatial visualisation in order to determine the location of the holes. An example of a test question is shown in Figure 4.8. Participants were given a battery of 20 questions, which were split over two consecutive trials, each containing 10 questions. Participants were allowed a maximum of 3 minutes to complete each of the two sessions. The test was marked by collating the number of correctly answered questions, and the participants were made aware of their performance at the end of the experiment.

**Figure 4.8**

*An example of the spatial test questions (Ekstrom et al., 1976)*

The paper is folded and a hole is made

The correct answer is 'D'

Answers

A  B  C  D  E

4.4.3 VE Piloting Exercise

To test participants' ability to move around a computer simulated environment using the cursor (arrow) keys, a practice VR environment was constructed. To increase the level of involvement a story was constructed around the experiment involving a witch. Participants were asked to guide themselves from the ground floor of a virtual environment, to the top floor, where a witch was waiting to offer them a job. To help them find the witch they were instructed to follow markers that would lead the way. The
time taken to reach the witch was recorded. If a marker was missed, or the participant displayed confusion regarding the route to follow, guidance was offered by the experimenter in the form of verbal directions. The environment was designed to include obstacles that would require skilful manoeuvring by the participant. Therefore the time taken to complete the task was used as an indicator of the participant’s ability to navigate Euclidean space using a keyboard.

4.4.4 Wayfinding Task

As discussed previously, although some use VR as a spatial training aid, most people’s experience of Virtual Environments is goal directed. Rather than trying to learn the environment, they are shopping for clothes, slaying dragons, looking for social contact, etc. Such people need help to learn their environment to aid navigation. To ensure ecological validity, participants were therefore given a task during the evaluation of the tools – one that should become easier as participants learn the configuration of the environment. Therefore any environmental learning was implicit.

In keeping with Darken and Sibert’s (1993) evaluation of navigation tools, the navigation task involved exploration of the environment, target identification, and then returning to the starting point. The task was chosen to fit the context of the environment. Participants were asked to locate books in the virtual library. Their task was repeated over six trials, with different books required each session. The trial began from the library entrance (as shown in Figure 4.7). Participants were asked to collect three books. They were given both the title of the book they must find, and also the section in which it could be found. Books were placed around the library, such that each participant must explore the whole of the environment to complete all of the trials. Each book could be found near a different landmark, which also ensured that all of the landmarks were seen over the six trials.
To navigate, participants used the cursor keys on a standard PC keyboard. The up and down arrow were used to move the navigator forward and backward through the virtual library. The left and right arrows allowed the participant to look around and change their direction of movement. To take a book from the bookshelf, the participant had to move towards the item until their avatar connected with it. Confirmation of successful pickup was provided by both a sound, and a message which was displayed on the screen.

When all three books had been gathered, the participant was asked to return to the entrance and pass the books to the librarian. This was done by standing in front of the desk, whereupon the software automatically checked through the participant’s inventory. If they had the required books, the session terminated. If the participant did not have all of the books necessary to complete the task, they were reminded of which items were still needed and asked to go back and locate them.

During each trial, a score was displayed in the top left-hand corner of the screen. The score represented the number of junctions (decision points), the participant had crossed during their journey. Each participant was made aware that the counter reflected their score. They were asked to find a route which was as direct as possible between each book, and thereby produce a better score. It was never explicitly stated that the score represented the number of junctions crossed until the evaluation was complete. When asked at the end of the evaluation, most participants were unaware of how their score was calculated.

Using the junction counter as a measure of route efficiency was considered more appropriate and likely to be more accurate than recording task completion time. Task completion time is dependant upon the user’s piloting skills, as well as their cognition of the environment. Between decision points there is little reason to refer to one’s cognitive map, and therefore time differences between junctions would be an artefact of piloting skill, rather than navigation ability. Piloting from one decision point (junction) to the next might be a straight path for one participant, but a slow meandering route for another.

Method
Previous work using both junctions crossed and task completion time as a measure of route efficiency found a strong, positive correlation between the two measures (Sykes, 1999).

4.4.5 Item Recall Task

To determine the extent of a participant's learning after the first session, a test was given to explore the level of landmark knowledge – the first stage of spatial learning (Siegel & White, 1975). The test required participants to freely recall as many items from the environment as they could remember. They were provided with a sheet of paper containing room for 28 items, and they were asked to write down everything that they noticed in the library during trial one. The purpose of this task was to identify whether the LSC significantly increased the number of landmarks remembered, in comparison to the other tools.

4.4.6 Landmark Knowledge Task

After trial four, participants were given a brief questionnaire to determine the fidelity of their mental representation of the library. Participants were given a location within the library, and an orientation. They were then asked to identify the surrounding bookshelves. A mark was awarded for each correct answer. For example, one of the questions places the participant at the water fountain, looking towards the stained glass window. The participant has to state which bookshelf is behind, and which is to their right. The locations used always placed the participant beside a 'landmark', making it easier for the participant to identify the location. The purpose of the test was to identify the level of landmark knowledge, and the associations made between bookshelves and the landmarks midway through the experiment.
4.4.7 Route Knowledge Task

Immediately after the landmark questionnaire, participants were tested on their route knowledge. A questionnaire was given asking participants to describe the shortest route between two locations. The start point was given by indicating both location and orientation. Participants were awarded a score based on the level of accuracy of their answer. A score of 3 was given for a direct route, a score of 2 given for a less direct route, and a score of 1 if the route given led to within 2 book sections of the goal. The purpose of this test was to identify the level of route knowledge participants had attained midway through the experiment.

4.4.8 Cognitive Map Task

The Cognitive Map Task was used to determine the fidelity of the participant’s mental map at the end of the evaluation process. Many researchers have used sketch maps to the fidelity of a person’s cognitive representation of the environment (Appleyard, 1969; Appleyard, 1970; Evans, 1980; Lynch, 1960). They are convenient and quick to administer, and studies have found them to be a reliable measure (Billinghurst & Weghorst, 1995; Blades, 1990). However, sketch maps are not without their disadvantages. They not only measure the cognitive map, but also the participant’s drawing ability and their memory for item recall (Golledge, 1976; Blades, 1997). This makes them difficult to score, and raises concerns about between-subject comparisons.

In an effort to harness the advantages associated with sketch maps, while avoiding the disadvantages, a new method of evaluation has been implemented in this study. On completion of all six trials, participants were given an incomplete map of the library (see Figure 4.9). The map depicts the locations of the entrance and the stained glass window. The remaining items of the library were given on a scatter board. Participants were asked to take an item from the scatter board and place it on the map. As each item was added to the map, a note was taken of its ordinal position. In line with Garling, Salert, and Boöök (1997) who argue that order of items drawn on a sketch map may provide extra
information of a person’s cognitive map, it is theorised that those items that participants are most familiar with will be placed on the map earlier than more obscure items. This procedure continued until all items had been removed from the scatter board. Where participants could not identify the location of an item, they were asked to place it as best they could. At the end of the evaluation the participant’s map of the environment was photocopied and a mark was calculated for both absolute and relative positioning of items. Details of the scoring procedure are given in Chapter 5.
Figure 4.9
The scatter-board used on the cognitive map task
The evaluation of the Spatial Learning Tool (SLT) focuses on two specific elements of navigation: wayfinding, and the development of the cognitive map. It has been hypothesised that the wayfinding components which constitute the SLT would also support one of the three stages of Siegel and White’s (1975) Sequential and Hierarchical model of environmental learning. The Landmark Saliency Component (LSC) was designed to support the development of a landmark-based representation by increasing the saliency of landmarks in the virtual environment. The breadcrumb component was designed to support the realisation of a route-based representation, by highlighting a participant’s path through the environment. The map component was added to provide the navigator with an instant survey view of the environment.

To evaluate whether the Spatial Learning Tool is beneficial to both wayfinding and to the development of the cognitive map, a between-subjects design has been applied. Participants were recruited to one of two groups. The control group navigated the test environment without the aid of any peripheral support. The Spatial Learning Tool group were given the SLT to support their navigation of the test environment. Performance measures for each group have been compared to identify potential benefit gained by using the SLT. A list of the tasks is provided in Figure 4.1. The following chapter presents statistical comparison between conditions for each task.

5.1 Pre-test Results

To ensure conditions were appropriately balanced, participant assignment was based upon their performance on the pre-test procedures. Participants were asked to provide demographic details, they were required to sit a spatial ability test, and they were given a VE piloting exercise. To confirm that the conditions were balanced, an independent sample t-tests was carried on both the VE piloting task score and spatial task score, with
condition as the grouping factor. No significant difference was found suggesting that the conditions were appropriately balanced. An overview of participant performance on the pre-test procedures is given in Table 5.1.

Table 5.1
An overview of the participants taking part in the tool evaluation
(Standard Deviation provided in brackets)

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</table>

5.2 Test Results
As shown in Figure 4.1, the evaluation of the Spatial Learning Tool involved a series of tasks. The test procedure included the wayfinding task, the item recall task, the landmark knowledge task, the route knowledge task, and the cognitive map task. The results of each are described below.

5.2.1 Item Recall Task
The SLT was designed such that it should increase the saliency of specified items within the environment. By doing so, it should enhance the learning and memory of landmarks, the basis upon which other environmental knowledge is founded. If the tool worked as planned, one would expect participants to freely recall significantly more landmark items when the SLT is available. It is therefore hypothesised that participants from the SLT condition should recall significantly more landmarks than participants from the control condition.

As can be seen in Table 5.2, the number of landmarks recalled did increase when the SLT interface was present. It is also interesting to note that the standard deviation was smaller
for the SLT condition, which shows slightly less variance in participant performance. A 2-tailed independent sample t-test revealed a significant difference between the number of landmarks recalled in the control condition and the SLT condition ($t=-2.282, p=0.028$).

| Table 5.2 |
| The number of landmark items recalled by participants across the control and SLT conditions |
| Mean (S.D.) | Maximum Score | Minimum Score |
| Control condition (n=20) | 2.45 (1.19) | 5 | 0 |
| SLT condition (n=20) | 3.25 (1.02) | 5 | 2 |

### 5.2.2 Landmark Knowledge Task

It has been hypothesised that using the Spatial Learning Tool would increase the quality of the navigator’s landmark-based representation of the environment. If this is the case, one would expect a significant improvement on the landmark knowledge task for those participants who were given the tool, compared to those participants given the control condition.

As part of the task, participants were asked to name bookshelves adjacent to the monk statue and the water fountain. Unfortunately, depending on the exact position imagined by the participant, there were possibly two different bookshelves on the right of the water fountain. On this basis, the reporting of either bookshelf was considered to be a positive score.
The results of the landmark knowledge task are given in Table 5.3. Here it can be seen that participants who experienced the Spatial Learning Tool showed a small improvement in the task. However, although the improvement was in the direction predicted, an independent sample t-test found no significant difference. Although SLT had aided the identification of landmark items (as shown in the landmark recall task), there is no evidence to suggest that participants developed an association between bookshelves and their neighbouring landmark.

5.2.3 Route Knowledge Task
The route knowledge task was designed to elicit a measure of participants’ knowledge of pathways within the test environment, and their ability to determine an efficient route between two given points. The score recorded was based on the quality of the answer provided. If the route described was generally inaccurate, but in the right general direction, one point was awarded. If the route described would lead somewhere close to the destination, a score of 2 was awarded. If the route led to the exact location, a score of 3 was awarded.

As shown in Table 5.4, the SLT has no positive effect on route knowledge formation. Rather, a small negative effect was identified. Participants who experienced the SLT scored, on average, 1.1 points lower than participants from the control group. A two-tailed independent sample t-test found no significant difference between the two scores at \( p=0.05 \) level \((t=2.006, p=0.052)\). This suggests that rather than supporting the advance of

<table>
<thead>
<tr>
<th>Table 5.3</th>
<th>A comparison of landmark knowledge task scores across the control and SLT conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Control condition (n=20)</td>
<td>1.05 (1.00)</td>
</tr>
<tr>
<td>SLT condition (n=20)</td>
<td>1.30 (1.42)</td>
</tr>
</tbody>
</table>

Results: SLT
route knowledge, the SLT may in fact hinder the development of a route-based representation of the space.

### Table 5.4
<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Maximum Score</th>
<th>Minimum Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control condition (n=20)</td>
<td>3.75 (1.77)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>SLT condition (n=20)</td>
<td>2.65 (1.69)</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

#### 5.2.4 Wayfinding Task
The wayfinding task involved 6 trials, where participants were asked to locate three books within the test environment. As a measure of performance, the number junctions crossed during each trial was recorded. With the SLT incorporating three different wayfinding tools, it was hypothesised that wayfinding would be improved when it was made available.

**Normalising and Cleaning the Book Retrieval Data**
Because the minimum number of junctions crossed differs between each trial (owing to different book locations within the environment) the raw figures were normalised to facilitate comparison over trials. To normalise the data, the lowest score recorded for each trial was subtracted from every participant’s score for that trial. Therefore the normalised score represents how many junctions a participant crossed, above the minimum found necessary to perform the task successfully. All data given hereafter for the Book Retrieval Task will have been normalised and therefore referred to as the ‘nScore’.

The normalised score has also been adjusted to cater for outliers in the data-set. It is argued that outlying data is not a reflective value, either being too large or too small given the other items in the data set. Outliers here are defined as data items which fall beyond three standard deviations from the mean. For example, where the mean is 10, and
the standard deviation is 2, any figure below 4 or above 16 is considered an outlier. Where this was found to be the case, the outlying value was replaced with the mean for that sample. All data discussed throughout has been normalised and cleaned as described above.

**Task Performance**

The box plots shown in Figure 5.1 and data given in Table 5.5 present a comparison between the SLT and control condition for the wayfinding task. The first item of note is the significant learning effect evident across the six trials. The number of junctions passed through is shown to have decreased over the six trials, suggesting that participants were able to learn the configuration of the environment over the period of the experiment. Also evident is the reduced variability between participants across trials, evident by the decreasing interquartile range (shown in Figure 5.1). A repeated measures ANOVA confirmed that participant performance improved significantly over trials for participants on both the control condition \((F(1, 19) = 35.1, p<0.000)\) and on the SLT condition \((F(1, 19) = 30.1, p<0.000)\). Of particular interest is the difference between the two conditions – especially during the early trials. Participants who experienced the SLT performed better than those from the control group throughout the evaluation, although the difference is most pronounced during the first two trials. As shown in Figure 5.1, the variability of performance decreased considerably with the introduction of the SLT.
To determine whether these differences were statistically significant, a 2(condition) x 6 (trial scores) way repeated measures ANOVA was carried out. ‘Condition’ was found to be a significant differentiator at the 95% confidence level ($F(1,38) = 4.63$, $p=0.038$). It is noted that the flooring effect of the experiment, where participants can not score below 0,
but have no maximum, results in a skewed distribution. This means that the traditional assumptions for carrying out parametric statistics are not met. However, as Glass et al. (1972) point out, parametric tests are robust and not seriously affected by failure to meet assumptions, which probably explains why Breckler (1990) and Micceri (1989) found that over 80% of journal papers do not now address these assumptions. Following the lead of my peers, parametric assumptions will not be tested within this thesis.

5.2.5 Cognitive Map Task

The purpose of the SLT was to aid the development of the navigator's mental representation of the environment. As discussed above, a series of components have been created to support the different stages of development from a mainly landmark-based representation, to a survey representation. With the SLT providing a survey view in the form of a map, it was expected that this will help participants to formulate their own internal representation of the environment.

During the cognitive map task, it was clear that decisions made when designing the environment had a significant affect on people's memory of it. For example, the landmark items 'water feature' and 'table and chairs' share a common element – they both include at least one table and three chairs. A small, but significant number of participants appear to have confused the two landmark items and had mistaken the 'table and chairs' landmark for the single table that could be found beside the water fountain. As shown in a participant's map below (Figure 5.2), participants would therefore occasionally misplace the 'table and chairs' to be next to, or occasionally on, the water feature landmark.

There is also evidence that semantic or lexical overlap can affect a person's memory for an environment. During the cognitive map test it was noticed that many participants (20% of the control condition, and 10% of test condition) would confuse the bookshelves 'transport' and 'travel' (see Figure 5.3). However, it seems as though participants do not simply switch their cognitive representations of the two items. In such cases 'transport'
replaces the position of 'travel', and 'travel' appears to be randomly placed on the scatter board as though they have no recollection of ever seeing it.

It would be sensible to presume that during the cognitive map task, those items most familiar to the navigator would be placed earlier, as participants should have more confidence with regard to their position. Consequently, if landmarks become more salient through the introduction of the landmark saliency component of the SLT, we would expect that they would appear much earlier in the map placement order. Figure 5.4 presents the mean placement order of each landmark item with respect to each condition. It is clear from the graph that both groups placed landmark items earlier in the placement order of 22. However, there is also a small difference between the two conditions in this regard. During the SLT evaluation landmarks were consistently placed earlier than they were during the control condition.

Results: SLT
Supporting Spatial Learning in Virtual Environments

**Figure 5.2**
Confusing landmark items on the cognitive map task

**Figure 5.3**
Confusing lexical or semantic similarities on the cognitive map task

Results: SLT
Analysis of participant maps suggests that SLT participants were not only more likely to place landmarks onto the map earlier in the sequence, but they were also better informed as to their absolute position of the landmarks compared to the control group. As is shown in Figure 5.3, 60% of the SLT participants correctly identified the location of ALL landmarks, compared to 45% of the control group.
Although SLT participants appear to have a better understanding of landmark item location, there is little evidence to suggest that their performance can be generalised to the other items in the environment. Figures 5.6 and 5.7 show both absolute positioning, and relative positioning of items on the scatter board. In doing so the figures present an indication of what a 'collective' cognitive map would look like – if such a thing were to exist. The data overlaying the items and their positions informs the reader of how many participants (as a percentage) correctly identified a particular aspect of the environment. Connecting lines between environment items reflect the relative map score, and indicate the percentage of participants who placed the neighbouring items together on their scatter board. For example, in Figure 5.5, 45% of the control group placed 'health' beside 'magazines', and 80% placed 'water' beside 'careers'. Connecting lines that are red indicate that 50% or more of the participants from that condition placed those items...
together. If the connecting red line is medium thickness, then it indicates that 70% or more placed the items together. If the line is very thick, the connection between the two is much stronger and 90% or more participants have placed them together.

There is also a figure, in brackets, below each item. This signifies the percentage of participants who correctly placed the item on the scatter board. Therefore, on graph 5.5, it can be seen that 100% of the participants positioned ‘home/garden’ in the correct place, and that only 55% of the control group place ‘transport’ in the correct place. As discussed above, 20% of the control group actually placed ‘transport’ in the location where ‘travel’ belongs. You might also notice that some items have boxes around them. The thin lined boxes inform the reader that at least 70% of the participants correctly identified the absolute position of that item. The thick red line signify that 90% or greater were able to locate the absolute position of the item.

Comparing the two graphs (Figure 5.5 and Figure 5.6), it can be seen that there are many more boxes of differing levels of thickness on the control group graph, than there is on the SLT graph. This shows that absolute positioning was better when the SLT was not used. There are also more medium and thick red lines, which also suggest that participants on the control condition performed better on relative positioning. However, what is particularly interesting is that if you look at the landmark items (tables, water, war, monk) they generally have thicker and more red connections on the SLT condition, compared to the control condition. This suggests that the landmark saliency component could be having an affect on the associations that are made between landmarks and the surrounding bookshelves. The landmarks are also more frequently placed in the correct absolute position (except for the monk statue), although this is very small difference, and unlikely to be statistically significant. However, Figure 5.5 suggest that participants on the control condition did not use ‘war’ and ‘tables’ as landmark items, but instead used the ‘wildlife’ bookcase – which is associated with many of its neighbouring bookcases. Wildlife is an interesting choice because it is almost equidistant between ‘tables’ and ‘chairs’, and reduces the number of landmarks needed to represent the environment to just 3 – rather than the 4 that are made more salient by the LSC.
Table 5.6 shows the absolute and relative position scores for each condition, and also the overall 'map score'. To determine the absolute position score, a 5cm marker was placed on the position where the item actually appeared in the environment. If at least 40% of the item that was placed by the participant appears within the marker, then a point is awarded. In practice, this meant that a point was awarded if an item was placed either in the actual spot where it belongs or in a spot normally housing a direct neighbour. Alternative methods for scoring were attempted, but this method was chosen because it produced the most 'normal' distribution of scores. The total number of points available was 22.
Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures beside connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: SLT
To determine the relative score, a mark was awarded if the item was positioned beside an appropriate neighbour – regardless of whether either was actually in the correct location. This meant that if the participant had a route or landmark based representation, they would still receive points for their association of items within the environment, even if the location was not exact. The total number of relative points available was 55. The score sheet can be found with other test material in the Appendix. Unsurprisingly, there is a strong positive correlation between the two scores. Pearson’s two-tailed correlation test
has shown this to be a significant correlation ($r=0.89$, $p<0.000$). If a participant does well on the absolute test, then they are very likely to represent the appropriate relational information.

It is clear from Table 5.6, which shows a breakdown of participant performance on the map task, that the SLT had little bearing overall on the quality of the cognitive map. The distribution of map scores is much the same for each condition. This was supported by the outcome of independent sample t-tests which found no significant difference between conditions with respect to the absolute or relative position scores.

<table>
<thead>
<tr>
<th>Table 5.6</th>
<th>Participant performance on the map task, broken down by condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Map Score (as a %age)</td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Control Condition</td>
<td>61.3 (17.1)</td>
</tr>
<tr>
<td>SLT Condition</td>
<td>55.2 (19.2)</td>
</tr>
</tbody>
</table>

5.3 Conclusion

The evaluation of the Spatial Learning Tool has shown that there are areas where it could be of benefit, and areas where it seems to be failing. As a tool for wayfinding, the SLT appears to be very useful – especially during the early sessions, where the participants are entering a novel environment. Not only does the presence of the SLT appear to decrease the number of junctions passed, but it reduces the variability of the group.

Results: SLT
However, it appears that the SLT fails to properly support cognition of the environment. Results regarding the development of the cognitive map are very mixed. At the landmark level of representation, the tool appears to be of benefit. It seems to increase the saliency of landmarks, although poor performance on the landmark questionnaire seems to suggest that participants fail to associate surrounding bookshelves. If it is not the cognitive map that is supporting wayfinding in the early sessions within the virtual environment, one might expect that the map component of the SLT is being used instead. However, the fact that participants do not possess a survey representation after six sessions of interacting with the map appears to suggest that the map was largely ignored by participants. The problem at this stage of evaluation is that the SLT has so many components it is hard to determine which components are supporting the tool, and which ones might be a hindrance. There is therefore much value to be gained from the evaluation of each component in isolation. This will allow identification of components that work, and those that do not.
Results: Components of the SLT

This chapter provides a summary of the results for the evaluation of each component of the Spatial Learning Tool. The chapter is split into three sections: analysis by condition, where each component is evaluated against the control condition and the SLT condition; analysis by sex, where we look at the effect of each component on male and female participants separately; and finally an analysis of how participants might be wayfinding, whether via their cognitive map or otherwise.

6.1 Analysis by Condition

There are several criteria for evaluating components of the Spatial Learning Tool. Firstly, there is the question of whether or not each component is working as has been predicted – i.e., does its presence support spatial learning. If the component is working as predicted, does it also aid the overall development of the cognitive map, or does it instead hinder the development of other cognitive representations of the environment. Thirdly, it is important to determine how the component in isolation compares to the SLT overall. If a single component alone is more effective at supporting cognitive development, then there may be sufficient argument for it to replace the SLT.

6.1.1 The Landmark Saliency Component

The Spatial Learning Tool is not merely the result of three discrete components ‘bolted’ together. Often one component of the SLT will enhance another. For example, the map component supports the landmark saliency component by indicating the landmark’s location from a survey perspective. This therefore has consequences with regard to the isolation of each component. Just how much of the component can, and should be isolated
for the evaluation is a significant issue. With respects to the landmark saliency component, the aspects being appraised are as follows (as shown in Figure 6.0):

- as the player approaches a designated landmark item a secondary window will open showing the landmark from a raised perspective, thus placing it in context with its surrounding items. The camera revolves around the landmark, providing the participant with a 360 degree view of the surrounding landscape.
- while the secondary window is open, a narrative is given about the landmark to aid memory and saliency of the item.

**Figure 6.0**

*The Landmark Saliency Component (LSC)*

**Pre-test Results**

To ensure the LSC condition was appropriately balanced with the control and the SLT conditions, participants were assigned based upon their performance on the pre-test procedures. The breakdown of performance is shown in Table 6.1, where it can be seen that each condition was balanced. An independent sample t-test carried out between the control condition and the LSC condition found no statistically significant difference between participant’s spatial task scores, or VE piloting scores. This was repeated for the

**Results: Components of SLT**
SLT and the LSC conditions, where it was also found that there was no significant difference between conditions. This suggests that conditions were suitably balanced.

### Table 6.1

*An overview of the participants taking part in the LSC evaluation*

<table>
<thead>
<tr>
<th></th>
<th>TOTAL number of participants</th>
<th>Number of MALE participants</th>
<th>Number of FEMALE participants</th>
<th>Mean VE PILOTHING score</th>
<th>Mean SPATIAL TASK score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control condition</strong></td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>127.4 (44.0)</td>
<td>13 (3.2)</td>
</tr>
<tr>
<td><strong>SLT condition</strong></td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>105.6 (37.9)</td>
<td>13.3 (4.4)</td>
</tr>
<tr>
<td><strong>LSC condition</strong></td>
<td>21</td>
<td>11</td>
<td>10</td>
<td>117.4 (67.5)</td>
<td>14.4 (3.1)</td>
</tr>
</tbody>
</table>

**Test Results**

The following section reports on the results of the LSC evaluation. Results are discussed for each task in turn.

**Item Recall Task**

The LSC has been designed to increase the saliency of specified items within the environment. It is theorised that in doing so, participant will better remember the items and use them as landmarks. Therefore, if the SLT is working as planned, it would be expected that participants will freely recall significantly more landmark items when the LSC is available, and therefore the LSC condition will report a significantly higher number of landmark items than will be reported during the control condition.

As can be seen in Table 6.2, in comparison to the control condition, the number of landmarks recalled did increase when the LSC was present. It is also interesting to note that, as on for the SLT evaluation, the standard deviation was smaller for the LSC condition, which shows slightly less variance in participant performance. A 2-tailed independent sample t-test revealed a significant difference between the number of landmarks recalled in the control and LSC conditions.
landmarks recalled in the control condition and the LSC condition ($r = -2.540, p = 0.015$). It can also be seen that there is little difference between the SLT and LSC conditions (as confirmed by an independent sample t-test, which found no statistical significant difference).

Table 6.2
The number of landmarks recalled by participants across the control, SLT and LSC conditions

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Maximum Number Recalled</th>
<th>Minimum Number Recalled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control condition (n=20)</strong></td>
<td>2.45 (1.19)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td><strong>SLT condition (n=20)</strong></td>
<td>3.25 (1.02)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td><strong>LSC condition (n=21)</strong></td>
<td>3.29 (0.90)</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

**Landmark Knowledge Task**

The landmark knowledge task has been implemented to identify evidence of early cognitive map development. It is argued that those participants who are aware of the important structures in the environment (i.e., landmark items) should perform better than those participants who are not so fortunate. As the LSC has been developed to increase landmark saliency, it is expected that the presence of the component will positively influence participant performance on the LSC condition. Details regarding how the task was scored are covered in Chapter 5, and will not be repeated in this chapter.

Results: Components of SLT
Table 6.3 shows a slight improvement of scores for participants who experience the LSC, when compared to participants from the control condition and the SLT. However, although the improvement is in the direction predicted, any enhancement is very small, and an independent sample t-test did not find the difference to be statistically significant. This therefore suggests that although LSC, like the SLT, had aided the identification of landmark items, this alone did not help participants to create associations between bookshelves and their neighbouring landmark.

**Route Knowledge Task**

The route knowledge task has been designed to identify whether participants are aware of routes between various landmarks. With the LSC aiding the memory of landmark items – the foundation of route-based knowledge, the presence of the LSC should contribute to the cognitive formation of routes through the environment. Therefore, on this test, we should expect to see participants perform better if they are from the LSC condition, than if they are from the control condition.

It can be seen in Table 6.4, that like the SLT, the LSC appears to have a detrimental affect on route knowledge acquisition. Participants who experienced the LSC scored, on average, 1.1 points lower than participants on the control group. A two-tailed independent
sample t-test found no significant difference between the participant’s scores from the control, and from the LSC condition. There is also little difference between the SLT and the LSC conditions.

<table>
<thead>
<tr>
<th>Table 6.4</th>
<th>A comparison of route knowledge task scores across the control, SLT and LSC conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Control condition (n=20)</td>
<td>3.75 (1.77)</td>
</tr>
<tr>
<td>SLT condition (n=20)</td>
<td>2.65 (1.69)</td>
</tr>
<tr>
<td>LSC condition (n=21)</td>
<td>2.62 (2.18)</td>
</tr>
</tbody>
</table>

**Wayfinding Task**

Wayfinding, to a large extent, benefits from the quality of the cognitive map. The LSC has been designed to aid the development of the cognitive map – specifically landmark knowledge acquisition. Therefore it is expected that this will aid wayfinding, particularly during the early trials where landmark knowledge is likely to be the discriminating factor of participant performance. Therefore, if the LSC is working in the way in which it was designed, it is expected that participants from the LSC condition are likely to perform better, and thus cross significantly fewer junctions compared to those participants from the control condition.

Figure 6.1, and Table 6.5, provides a comparison between participant performance on the wayfinding task. The first item to note is the significant learning effect for participants on the LSC condition. The number of junctions that participants traversed when complete the task decreased over the six trials. A one-way repeated measures ANOVA confirmed that...
participant’s performance improved significantly over trials for participants on the LSC condition \( (F(1, 20) = 17.97, p<0.000) \).

Figure 6.1 clearly shows that participants on the LSC condition did not perform as well as those participants on the SLT condition. A 2 (condition [LSC/SLT]) x 6 (trial score) way repeated measures ANOVA found a significant effect of condition \( (F(1, 39) = 5.0, p = 0.03) \), suggesting that the difference between the LSC and SLT conditions is indeed statistically significant. A similar comparison between LSC and the control condition found no statistically significant difference.

![Figure 6.1](image_url)

*The mean number of junctions crossed by participants over the six trials of the wayfinding task – split by condition*

Results: Components of SLT
Table 6.5

\[
\begin{array}{ccccccc}
\text{Trial} & \text{Mean (SD)} & \text{Trial} & \text{Mean (SD)} & \text{Trial} & \text{Mean (SD)} & \text{Trial} & \text{Mean (SD)} \\
1 & (13.1) & 2 & (19.1) & 3 & (7.6) & 4 & (10.0) \\
\text{Control} & 24.2 & 21.2 & 12.7 & 11.9 & 12.4 & 7.3 \\
\text{condition (n=20)} & & & & & & (4.1) \\
\text{SLT} & 19.0 & 11.9 & 11.1 & 11.0 & 9.0 & 6.8 \\
\text{condition (n=20)} & (7.6) & (7.5) & (6.8) & (8.7) & (8.3) & (4.7) \\
\text{LSC} & 22.1 & 16.6 & 16.8 & 14.1 & 13.7 & 8.8 \\
\text{condition (n=20)} & (13.7) & (15.78) & (9.9) & (9.1) & (11.3) & (5.5) \\
\end{array}
\]

Cognitive Map Task

It would be reasonable to presume that, during the cognitive map task, those items most familiar to the navigator would be placed onto the scatter-board earlier. This is because participants are likely to have more confidence with regard to their position. Consequently, if landmarks become more salient through exposure to the LSC, we would expect that they would appear much earlier in the map placement order. Figure 6.2 presents the mean placement order of each landmark item with respect to each condition. It is clear from the graph that there is a difference between the control and the LSC conditions in this regard and that during the LSC evaluation landmarks were consistently placed earlier than they were during the control condition. It is also interesting to note that for those landmark items that proved to be less obvious to participants in the control and SLT conditions (‘Table’ and ‘War’), were placed earlier onto the scatter board by participants on the LSC condition. This is supported by the increase in their location of the landmark items (both absolute and relative) shown in Figure 6.8.
Figure 6.2
Bar chart showing mean placement order of landmark items onto the scatterboard - split by condition

Results: Components of SLT
Table 6.6
Placement order of landmark items onto the scatter-board

<table>
<thead>
<tr>
<th></th>
<th>Landmark #1 (WATER)</th>
<th>Landmark #1 (TABLE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Max</td>
</tr>
<tr>
<td>Control condition</td>
<td>7.9 (6.4)</td>
<td>22</td>
</tr>
<tr>
<td>SLT condition</td>
<td>4.1 (4.8)</td>
<td>21</td>
</tr>
<tr>
<td>LSC condition</td>
<td>4.3 (5.5)</td>
<td>21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Landmark #1 (WAR)</th>
<th>Landmark #1 (MONK)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Max</td>
</tr>
<tr>
<td>Control condition</td>
<td>10.6 (6.6)</td>
<td>21</td>
</tr>
<tr>
<td>SLT condition</td>
<td>8.4 (5.2)</td>
<td>18</td>
</tr>
<tr>
<td>LSC condition</td>
<td>7.1 (5.1)</td>
<td>21</td>
</tr>
</tbody>
</table>

Analysis of the maps produced by participants suggests that SLT participants were not only more likely to place landmarks onto the map earlier, but they were also better informed as to their absolute position of the landmarks compared to the control group. As is shown in Figure 6.3, 67% of the LSC participants correctly identified the absolute location of ALL landmarks, compared to just 45% of the control condition.
Figures 6.5 and 6.6 show great similarities between the maps produced by the LSC participants and the participants from the SLT condition. The both have clear nodal points based upon the landmark items. This is based upon the strength of association with neighbouring features of the environment (i.e., thickness and colour of lines) and the frequency of correctly identifying the absolute placement of landmark items. However, comparing of Figure 6.4 and Figure 6.6 differences can be noted between the maps produced by participants on the LSC and the control conditions. Figure 6.6 suggests that LSC participant’s memory is more focused around the landmark items. They did well at identifying the absolute position of all landmark items - over 70% of participants correctly placed each landmark item. Also, if we look at the red lines radiating from the map items, it is suggestive that LSC participants used landmark items to determine the relative location of other items as landmarks appear to often have stronger and more frequent relational links to neighbouring bookcases (i.e., links above 50%). This is especially true

Results: Components of SLT
of the ‘War’ and the ‘Tables’ landmarks, which saw a large improvement in the associations made with neighbouring landmarks. In contrast, Figure 6.4 shows that control group participants did not focus so much on the pre-specified landmark items, although they did produce better maps overall – with stronger, more appropriate associational ties, and absolute positioning.

Although the graphs in figures 6.5 and 6.6 suggest a difference in participant’s cognitive map of the environment dependent upon the condition experienced, this is not supported by statistical analyses. Table 6.7 shows that participants from the control condition performed better on both the absolute and the relative positioning of items onto the scatter-board, although independent sample t-tests did not identify any statistically significant differences between the three conditions (Control, SLT, and LSC).

<table>
<thead>
<tr>
<th>Table 6.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant performance on the cognitive map task, broken down by condition</td>
</tr>
<tr>
<td>(Standard Deviation provided in brackets)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Map Score</th>
<th>Relative Position Score</th>
<th>Absolute Position Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(as a % age)</td>
<td>(out of possible 55)</td>
<td>(out of 22)</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Mean</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>condition</td>
<td>61.3</td>
<td>88</td>
<td>30</td>
</tr>
<tr>
<td>(n=20)</td>
<td>(17.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SLT</strong></td>
<td>55.2</td>
<td>84</td>
<td>15</td>
</tr>
<tr>
<td>condition</td>
<td>(19.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LSC</strong></td>
<td>56.3</td>
<td>92</td>
<td>26</td>
</tr>
<tr>
<td>condition</td>
<td>(18.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n=21)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results: Components of SLT
Figure 6.4: Absolute and relative scores for the control condition

Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures next to connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: Components of SLT
Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures next to connecting lines indicate percentage of participants who correctly identified the relationship between map items.
Figure 6.6: Absolute and relative scores for the landmark saliency component

Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures next to connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: Components of SLT
6.1.2 Breadcrumb Component

In isolating the central characteristics of the breadcrumb component, it was decided that participants would not be given a survey view of the environment. Using the map, the SLT shows breadcrumbs within context of the surrounding environment. However, it is clearly inappropriate to include the map component when evaluating the breadcrumb component in isolation. Therefore, the breadcrumb component evaluated is as shown in Figure 6.7, a series of books that appears behind the participant during each of the wayfinding trials.

![Figure 6.7](image)

*Figure 6.7*

The breadcrumb component, where books are dropped to mark the path taken

Pre-test Results

A breakdown of performance on the pre-test is shown in Table 6.1, where it can be seen that each condition was balanced by gender, spatial ability and piloting skill. An
independent sample t-test carried out between the control condition and the LSC condition found no statistically significant difference between participant’s spatial task scores, or VE piloting scores. This was repeated for the SLT and the LSC conditions, where it was also found that there was no significant difference between conditions. This suggests that conditions were suitably balanced.

**Table 6.8**

An overview of the participants taking part in the breadcrumb component evaluation

<table>
<thead>
<tr>
<th></th>
<th>TOTAL number of participants</th>
<th>Number of MALE participants</th>
<th>Number of FEMALE participants</th>
<th>Mean VE PILOTING score</th>
<th>Mean SPATIAL TASK score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control condition</strong></td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>127.4 (44.0)</td>
<td>13 (3.2)</td>
</tr>
<tr>
<td><strong>SLT condition</strong></td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>105.6 (37.9)</td>
<td>13.3 (4.4)</td>
</tr>
<tr>
<td><strong>Breadcrumb condition</strong></td>
<td>20</td>
<td>11</td>
<td>9</td>
<td>134.3 (59.8)</td>
<td>13.3 (3.5)</td>
</tr>
</tbody>
</table>

**Test Results**

The following section reports on the results of the breadcrumb component evaluation. Results are discussed for each task in turn.

**Item Recall Task Results**

The breadcrumb component was not specifically designed to aid the saliency or memory of landmark items, although by identifying routes between items it might be expected that landmarks are implicitly learned. However, Table 6.9 shows that there is little difference between the control group’s recollection of landmarks and that of the breadcrumb condition. A two-tailed independent sample t-test found no significant difference between the breadcrumb condition and the control condition. However, a similar test did identify a statistically significant difference between the breadcrumb condition and the SLT condition ($t=2.04, p = 0.048$).
Landmark Knowledge Task

Again, the breadcrumb component was not designed to aid landmark knowledge, and it is therefore little surprise to find no real difference between the control condition and the breadcrumb condition on the landmark knowledge task (see Table 6.10). A small, but not statistically significant difference is noted between the breadcrumb condition, and the SLT condition.

| Table 6.9 |
The number of landmarks recalled by participants across the control, SLT and breadcrumb conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean (SD)</th>
<th>Maximum Number Recalled</th>
<th>Minimum Number Recalled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control condition</td>
<td>2.45 (1.19)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLT condition</td>
<td>3.25 (1.02)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>2.60 (0.99)</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results: Components of SLT

| Table 6.10 |
A comparison of landmark knowledge task scores across the control, SLT and breadcrumb conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean (SD)</th>
<th>Maximum Score</th>
<th>Minimum Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control condition</td>
<td>1.05 (1.00)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLT condition</td>
<td>1.30 (1.42)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>1.00 (0.86)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>(n=20)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Route Knowledge Task

With the breadcrumb component of the SLT having being designed to aid route knowledge acquisition, it was predicted that the presence of the breadcrumb component would increase a person’s performance when learning routes. However, as can be seen in Table 6.11, it appears that the breadcrumb component, like the SLT, had a negative affect on a person’s performance on the route knowledge task. A two-tailed independent sample t-test did not show a significant difference between the control condition and the breadcrumb condition at $p=0.05$ confidence level, although with a $p$ value of $p=0.055$ ($t=1.985$) it was approaching significance.

<table>
<thead>
<tr>
<th>Table 6.11</th>
<th>A comparison of route knowledge task scores across the control, SLT and breadcrumb conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Control condition (n=20)</td>
<td>3.75 (1.77)</td>
</tr>
<tr>
<td>SLT condition (n=20)</td>
<td>2.65 (1.69)</td>
</tr>
<tr>
<td>Breadcrumb condition (n=20)</td>
<td>2.50 (2.19)</td>
</tr>
</tbody>
</table>

The Wayfinding Task

Figure 6.8 gives a performance comparison between the breadcrumb condition, the control condition, and the SLT condition for the wayfinding task. The first item to note is the significant learning effect. A one-way repeated measures ANOVA confirmed that participant’s performance improved significantly over trials for participants on the breadcrumb condition ($F (5, 15) = 4.203$ $p=0.002$). However, as shown in Figure 6.8 and
Table 6.12, there is little difference between conditions, confirmed by the results of a 3 (condition) x 6 (trial score) way ANOVA ($F(2,57)=2.283, p=0.111$).

**Figure 6.8**

The mean number of junctions crossed by participants over the six trials of the wayfinding task – split by condition

<table>
<thead>
<tr>
<th></th>
<th>Trial 1 Mean (SD)</th>
<th>Trial 2 Mean (SD)</th>
<th>Trial 3 Mean (SD)</th>
<th>Trial 4 Mean (SD)</th>
<th>Trial 5 Mean (SD)</th>
<th>Trial 6 Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control condition</strong></td>
<td>24.2 (13.1)</td>
<td>21.2 (19.1)</td>
<td>12.7 (7.6)</td>
<td>11.9 (10.0)</td>
<td>12.4 (9.56)</td>
<td>7.3 (4.1)</td>
</tr>
<tr>
<td><strong>SLT condition</strong></td>
<td>19.0 (7.6)</td>
<td>11.9 (7.5)</td>
<td>11.1 (6.8)</td>
<td>11.0 (8.7)</td>
<td>9.0 (8.3)</td>
<td>6.8 (4.7)</td>
</tr>
<tr>
<td><strong>Breadcrumbs condition</strong></td>
<td>18.8 (10.9)</td>
<td>18.3 (10.8)</td>
<td>15.5 (9.5)</td>
<td>12.8 (11.4)</td>
<td>9.7 (8.8)</td>
<td>10.2 (7.1)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Table 6.12, there is little difference between conditions, confirmed by the results of a 3 (condition) x 6 (trial score) way ANOVA (F(2,57)=2.283, p=0.111).

**Figure 6.8**

*The mean number of junctions crossed by participants over the six trials of the wayfinding task – split by condition*

<table>
<thead>
<tr>
<th></th>
<th>Trial 1 Mean (SD)</th>
<th>Trial 2 Mean (SD)</th>
<th>Trial 3 Mean (SD)</th>
<th>Trial 4 Mean (SD)</th>
<th>Trial 5 Mean (SD)</th>
<th>Trial 6 Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control condition</td>
<td>24.2 (13.1)</td>
<td>21.2 (19.1)</td>
<td>12.7 (7.6)</td>
<td>11.9 (10.0)</td>
<td>12.4 (9.56)</td>
<td>7.3 (4.1)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>19.0 (7.6)</td>
<td>11.9 (7.5)</td>
<td>11.1 (6.8)</td>
<td>11.0 (8.7)</td>
<td>9.0 (8.3)</td>
<td>6.8 (4.7)</td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>18.8 (10.9)</td>
<td>18.3 (10.8)</td>
<td>15.5 (9.5)</td>
<td>12.8 (11.4)</td>
<td>9.7 (8.8)</td>
<td>10.2 (7.1)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Cognitive Map Task

The use of the breadcrumb component is likely to increase the saliency of certain places in the environment—especially those that are nodal points (i.e., major junctions with many pathways) such as the water feature, the monk statue. Standing at either of these landmarks the participant is likely to notice a number of pathways leading towards and away from their position. The use of breadcrumbs could reinforce the pathways by making them more salient. Figure 6.9 and Table 6.13 show that these ‘nodal point’ items were placed on the map earlier in the breadcrumb condition than in the control condition. This is also reflected in the cognitive maps produced, which are dominated by the large nodal points. War is less of a nodal point, and might thus provide less information to the navigator regarding routes and pathways because it is not a junction. Also, because of the height of the bookcase, it is difficult to see all of the routes coming to and from the landmark item from any vantage point.

<table>
<thead>
<tr>
<th>Table 6.13</th>
<th>Placement order of landmark items onto the scatter-board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landmark #1 (WATER)</td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Control condition</td>
<td>7.9 (6.4)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>4.1 (4.8)</td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>4.3 (5.2)</td>
</tr>
<tr>
<td>Landmark #1 (WAR)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Control condition</td>
<td>10.6 (6.6)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>8.4 (5.2)</td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>12.8 (6.5)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Table 6.14
Participant performance on the map task, broken down by condition
(Standard Deviation provided in brackets)

<table>
<thead>
<tr>
<th></th>
<th>Map Score (as a %age)</th>
<th>Relative Position Score (out of possible 55)</th>
<th>Absolute Position Score (out of 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>Control condition</td>
<td>61.3</td>
<td>88</td>
<td>30</td>
</tr>
<tr>
<td>(n=20)</td>
<td>(17.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLT condition</td>
<td>55.2</td>
<td>84</td>
<td>15</td>
</tr>
<tr>
<td>(n=20)</td>
<td>(19.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>57.0</td>
<td>89</td>
<td>25</td>
</tr>
<tr>
<td>(n=20)</td>
<td>(20.3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results: Components of SLT
Although participants from the breadcrumb condition appear to have a better understanding of landmark item location, there is little evidence to suggest that their performance can be generalised to other items in the environment. It is clear from Table 6.14, and Figures 6.10 & 6.12, which show a breakdown of participant performance on the map task, that the breadcrumb condition had little bearing on the quality of the cognitive map. The distribution of map scores is much the same regardless of the condition. This was supported by the outcome of an independent sample t-test which found no significant difference between conditions with respect to any of the map scores.
Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures beside connecting lines indicate percentage of participants who correctly identified the relationship between map items.
Figure 6.11: Absolute and relative scores for the SLT

Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures next to connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: Components of SLT
Figure 6.12: Absolute and relative scores for the breadcrumb component

Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures beside connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: Components of SLT
6.1.3 Map Component

The map component was developed by taking the SLT and removing each of the previously evaluated components. The map component represents the features that have so far not been evaluated. Figure 6.13 provides an example of the map component features. You will notice that the map contains aspects of both the breadcrumb component and the landmark saliency component. The map component shows the route taken, and also the location of landmark items when the participant is close by.

Figure 6.13

The map component
Pre-test Results

To ensure the map condition was appropriately balanced with the control and the SLT conditions, participants were assigned based upon their performance on the pre-test procedures. The breakdown of performance is shown in Table 6.15, where it can be seen that each condition was balanced. An independent sample t-test carried out between the control condition and the map condition found no statistically significant difference between participant’s spatial task scores, or VE piloting scores. This was repeated for the SLT and the map conditions, where it was also found that there was no significant difference between conditions. This suggests that conditions were suitably balanced.

<table>
<thead>
<tr>
<th>TOTAL number of participants</th>
<th>Number of MALE participants</th>
<th>Number of FEMALE participants</th>
<th>Mean VE PILOTING score</th>
<th>Mean SPATIAL TASK score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control condition</strong></td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>127.4 (44.0)</td>
</tr>
<tr>
<td><strong>LST condition</strong></td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>105.6 (37.9)</td>
</tr>
<tr>
<td><strong>Map condition</strong></td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>108.2 (40.7)</td>
</tr>
</tbody>
</table>

Test Results

The following section reports on the results of the map component evaluation. Results are discussed for each task in turn.

**Item Recall Task**

The map component contains aspects that may aid the memory of landmark items. As discussed above, when participants are near a landmark item, its location is displayed on the map. However, as shown in Table 6.16, that there is little difference between the control group’s recollection of landmarks and that of the map condition. Independent
sample t-test found no significant difference between the map and the control conditions. However, a similar test found a statistically significant difference between the map condition and the SLT condition with respect to landmark recall (t=-3.462, p=0.001).

<table>
<thead>
<tr>
<th>Table 6.16</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of landmarks recalled by participants across the control, SLT and map conditions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Maximum Number Recalled</th>
<th>Minimum Number Recalled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong> condition (n=20)</td>
<td>2.45 (1.19)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td><strong>SLT</strong> condition (n=20)</td>
<td>3.25 (1.02)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Map</strong> condition (n=20)</td>
<td>2.20 (0.89)</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

**Landmark Knowledge Task**

Table 6.17 shows the distribution of landmark knowledge scores across conditions. It can be seen that, the scores on the landmark knowledge task improved on the map condition. However, an independent sample t-tests did not reveal any statistically significant differences between the map condition and either the control condition or the SLT condition.
Table 6.17
The distribution of landmark knowledge task scores across the control, SLT and map conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean (SD)</th>
<th>Maximum Score</th>
<th>Minimum Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control condition</td>
<td>1.05 (1.00)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>SLT condition</td>
<td>1.30 (1.42)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Map condition</td>
<td>1.10 (1.55)</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

**Route Knowledge Task**

With the map component showing routes between items within the environment, it would be natural to predict that the map component would increase a person’s performance when learning routes between landmarks. However, as can be seen in Table 6.18, it appears that the map component has a negative affect on a person’s performance on the route knowledge task when compared to the control condition. A two-tailed independent sample t-test found that this was a statistically significant effect ($t = -2.67, p=0.011$).

Table 6.18
The distribution of route knowledge task scores across the control, SLT and map conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean (SD)</th>
<th>Maximum Score</th>
<th>Minimum Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control condition</td>
<td>3.75 (1.77)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>SLT condition</td>
<td>2.65 (1.69)</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Map condition</td>
<td>2.10 (2.13)</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Wayfinding Task

Figure 6.14 and Table 6.19 show the distribution of nScore across the 6 trials for the control, SLT and the map conditions. The first item to note is the significant learning effect. A repeated measures ANOVA confirmed that participant’s performance improved significantly over trials for participants on the map condition \((F (1,19) = 35.7, p<0.000)\).

Also of interest is how similar the distribution of nScore for the SLT and the map conditions are (see Figure 6.14). This suggests that the map component of the SLT is responsible for the significant wayfinding improvement found in Chapter 5. However, a series of 2 (condition) x 6 (trial score) way ANOVAs found no statistically significant difference between the map condition, the SLT condition, or the control condition.

<table>
<thead>
<tr>
<th></th>
<th>Trial 1 Mean (SD)</th>
<th>Trial 2 Mean (SD)</th>
<th>Trial 3 Mean (SD)</th>
<th>Trial 4 Mean (SD)</th>
<th>Trial 5 Mean (SD)</th>
<th>Trial 6 Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control condition</td>
<td>24.2 (13.1)</td>
<td>21.2 (19.1)</td>
<td>12.7 (7.6)</td>
<td>11.9 (10.0)</td>
<td>12.4 (9.56)</td>
<td>7.3 (4.1)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>19.0 (7.6)</td>
<td>11.9 (7.5)</td>
<td>11.1 (6.8)</td>
<td>11.0 (8.7)</td>
<td>9.0 (8.3)</td>
<td>6.8 (4.7)</td>
</tr>
<tr>
<td>Map condition</td>
<td>22.2 (10.3)</td>
<td>13.1 (9.4)</td>
<td>13.5 (8.26)</td>
<td>11.7 (11.2)</td>
<td>9.5 (6.4)</td>
<td>6.0 (4.8)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Cognitive Map Task

In showing the absolute position of landmark items, it was hypothesised that the map component would increase the saliency of landmark items, and therefore have a positive influence on the placement order of landmark items. However, as is shown in Figure 6.15 and in Table 6.20, this was not the case. It is clear from the graph in Figure 6.15 that the presence of the map component does not appear to influence the order in which landmark items are placed onto the scatter-board.
Table 6.20
Placement order of landmark items onto the scatter-board

<table>
<thead>
<tr>
<th>Landmark #1 (WATER)</th>
<th>Landmark #1 (TABLE)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean (SD)</strong></td>
<td><strong>Max</strong></td>
</tr>
<tr>
<td>Control condition</td>
<td>7.9 (6.4)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>4.1 (4.8)</td>
</tr>
<tr>
<td>Map condition</td>
<td>6.8 (5.6)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Landmark #1 (WAR)</th>
<th>Landmark #1 (MONK)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean (SD)</strong></td>
<td><strong>Max</strong></td>
</tr>
<tr>
<td>Control condition</td>
<td>10.6 (6.6)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>8.4 (5.2)</td>
</tr>
<tr>
<td>Map condition</td>
<td>11.0 (5.9)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
The map component of the SLT should provide participants with an instant survey representation of the environment – allowing participants to bypass landmark and route representations. However, it can be seen from Table 6.21 that this is not the case. Participants from the map condition performed worse on every measure of their cognitive map compared to the control condition. Independent sample, two-tailed t-test showed that participants on the cognitive map task were significantly ($t=2.290, p=0.028$) worse when identifying the absolute position of the items compared to the control condition.

It is also interesting to note that the maps produced by participants from the map condition (Figure 6.18) do not appear to focus as heavily upon the prescribed landmark items. The more minor landmark items, war and the tables, for example, are not as closely associated with their neighbouring bookshelves for map participants, then they are for SLT participants (Figure 6.17).

<table>
<thead>
<tr>
<th>Table 6.21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant performance on the map task, broken down by condition</td>
</tr>
<tr>
<td>(Standard Deviation provided in brackets)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Map Score (as a %age)</th>
<th>Relative Position Score (out of possible 55)</th>
<th>Absolute Position Score (out of 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Control condition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=20</td>
<td>61.3</td>
<td>88</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>(17.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SLT condition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=20</td>
<td>55.2</td>
<td>84</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>(19.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Map condition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=20</td>
<td>50.8</td>
<td>97</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>(17.9)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results: Components of SLT
Figure 6.16: Absolute and relative map scores for the control group

Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures beside connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: Components of SLT
Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures next to connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: Components of SLT
Figure 6.18: Absolute and relative scores for the map component

Figures in brackets refer to the percentage of participants who correctly identified the absolute position of the map item.

Figures beside connecting lines indicate percentage of participants who correctly identified the relationship between map items.

Results: Components of SLT
6.1.4 Summary of Condition Effects

In summarising the condition effects, the main evaluation criteria outlined at the beginning of this chapter are addressed. This section looks at whether the components work as predicted, and asks whether each component aids or hinders participant performance when wayfinding, or in their memory of the environment. Finally the individual components are compared to the SLT. This is to determine how their effect when experienced in isolation differs to when experience as part of a group.

Table 6.22

Summary of component evaluation results (in comparison to the Control condition)

<table>
<thead>
<tr>
<th></th>
<th>Wayfinding</th>
<th>Cognitive Map</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Item Recall</td>
<td>L/mark Quest.</td>
</tr>
<tr>
<td><strong>LSC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Significantly Improved</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td><strong>Breadcrumb</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Significantly Improved</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Map</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Significantly Improved</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Table 6.22 provides a summary of how the different components compare against the control condition. The landmark saliency component appears to work as predicted. When compared to the control condition, participants on the LSC freely recalled significantly more landmark items. They also did better, although not significantly so, on the landmark knowledge task. There is also evidence to suggest that the increased saliency of the landmark items may have had an effect on the development of a participant’s cognitive map. Figure 6.6 shows that the relational association between items was heavily influenced by the saliency of the item. Landmark items appear to act as nodal points in a participant’s representation of the environment. For example, the monk statue was associated with each of its neighbouring bookshelves by at least 50% of the LSC participants.

In comparison to the LSC, the breadcrumb component did not deliver much in the way of improvement on the wayfinding task. There is evidence of within subject learning of the environment over the six trials. However, this was significant for all conditions. There is evidence to suggest that the breadcrumb component might aid the saliency of significant junction points, where many pathways can be identified. Figure 6.9 shows that the landmarks beside the two larger junctions (the water feature and the monk statue) were placed onto the scatter-board much earlier than they were in the control condition. Where the breadcrumb component should have offered clear benefit, was the route knowledge task. However, participants who used the breadcrumb component generally did worse on this task than participants on the control condition.

The benefit of the map component is also brought into question, as no significant improvement has been identified against the control condition. Where the map component should have been of particular help is the cognitive map task, where participants can demonstrate their survey knowledge of the environment. However, the inclusion of the map component did not improve either the absolute, or the relative positioning of items onto the scatter-board. It is also interesting to note that the map component did not significantly aid wayfinding. This is surprising because the map component supports
orientation by showing participant location. This would allow participants to find their way to the start position when they have located the last book.

Table 6.23 shows how the conditions compare against the SLT. Although no significant differences were identified between the SLT and its components in isolation, participants on the LSC condition generally outperformed SLT participants on all but two of the tests. It is also interesting to note that the performance of map condition participants was generally poorer than participants of the SLT on all measures.

<table>
<thead>
<tr>
<th></th>
<th>Item</th>
<th>L/mark</th>
<th>Route</th>
<th>Wayfinding Between condition</th>
<th>Cognitive Map Placed Order</th>
<th>Abs. Score</th>
<th>Rel. Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LSC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Significantly</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Improved</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Breadcrumb</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Significantly</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Improved</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Map</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Significantly</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Overall, it appears that, in isolation, the SLT's components do not generally work as predicted. Apart from limited success of the LSC on the free-recall of landmark items, no other improvements on any of the between condition tests were significant for any of the components. Also, participants on the SLT generally performed better than participants who experience just a single component. This suggests that the SLT is indeed more than just the sum of its parts.

6.2 Analysis by Sex

The main purpose for the evaluation of each sub-component of the SLT is to identify how participants were supported when wayfinding. The SLT did not aid performance in any of the cognitive map measures, which suggests that increased performance might not be the result of an increase in the quality of the cognitive map. Tables 6.22 and 6.23 suggest that no single component is responsible for the increased performance on the wayfinding task. All three components, when evaluated independently, fail to show significant improvement above and beyond the control condition. However, it is interesting to note that both the map and the LSC conditions do show some improvement over the control condition.

In Chapter 3, various differences between the sexes with respect to wayfinding and spatial cognition were identified. Females appear to use landmark information more than males, and males use geometric measures more than females. If this is indeed the case, it is possible that different components of the SLT will be applied in different measures by males and females. One might expect females to respond better to landmark based component (such as the LSC), and males to the map based components (such as the map condition). If this is the case, it could explain why improvements in map and LSC conditions were not significant. If males perform better when the map component is present and worse on the LSC condition - and the reverse is true for females - then the combined affects would cancel each other out. The following section takes the reader through an analysis of the sex difference data, and asks whether the individual

Results: Components of SLT
components of the SLT affect males and females differently when wayfinding, and also in the development of their cognitive map.

### 6.2.1 Landmark Saliency Component

**Wayfinding**

As shown in Figure 6.19 and Table 6.24, females typically performed better on the wayfinding task than their male colleagues on the LSC condition. As on the SLT condition, the big difference can be found in the early stages of the wayfinding task. An analysis of variance over the full 6 trials [2 (sex) x 6 (trial score) way repeated measures ANOVA] identified a statistically significant \(F (1,19)= 6.0, p=0.024\) difference between male and female performance on the wayfinding task.

A comparison of female performance on the LSC and the control conditions (as shown in Figure 6.20) confirms that females did better on the LSC condition – particularly during the very early trials (trials 1 and 2). However, a repeated measures ANOVA did not find this to be a statistically significant difference [2 (condition) x 2 (Trial1, Trial2) way repeated measures ANOVA, \(F (1,18) = 2.82, p=0.111\)]. That the component had an affect early in the wayfinding task, rather than toward the end is to be expected. Firstly, by the end of the evaluation procedure, each participant will have experienced the environment six times. After six exposures, most participants have learned the basic configuration of the environment, regardless of the condition (as indicated by the wayfinding score on the final trial). Also, the LSC is designed to increase landmark saliency, and should therefore support landmark knowledge acquisition, which Siegel and White (1975) argue occurs as the first stage of learning an environment.
Figure 6.24

The mean number of junctions crossed by participants over the six trials of the Wayfinding Task – split by SEX.
Table 6.24

<table>
<thead>
<tr>
<th></th>
<th>Trial 1 Mean (SD)</th>
<th>Trial 2 Mean (SD)</th>
<th>Trial 3 Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>22.4</td>
<td>26</td>
<td>28.2</td>
</tr>
<tr>
<td>Female</td>
<td>(9.0)</td>
<td>(16.5)</td>
<td>(22.5)</td>
</tr>
<tr>
<td>SLT condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>18.1</td>
<td>19.9</td>
<td>13.8</td>
</tr>
<tr>
<td>Female</td>
<td>(7.9)</td>
<td>(7.7)</td>
<td>(7.3)</td>
</tr>
<tr>
<td>LSC condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>26.0</td>
<td>17.9</td>
<td>25.2</td>
</tr>
<tr>
<td>Female</td>
<td>(13.2)</td>
<td>(13.5)</td>
<td>(16.6)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Figure 6.21 shows a breakdown of performance on the wayfinding task for males only. It is clear from this graph that there is little difference between male’s performance across the Control and the LSC conditions, but considerable difference between the LSC and SLT. To determine whether this difference is statistically significant a 2 (condition) x 6 (trial score) way repeated measures ANOVA was carried out on the male score. It was found that there is a significant difference between LSC and SLT conditions for male participants \(F(1, 19) = 8.3, p = 0.01\). This again suggests that males are not helped by the presence of the LSC.

Results: Components of SLT
Figure 6.22 shows the distribution of map score for males and females across conditions (see Table 6.25 for breakdown of cognitive map sub-tasks). It can be seen that cognitive map scores mirror the scores on the wayfinding task. There is a large difference between male and female map scores on the LSC condition, with females performing better than the males. An independent sample t-test reveals a statistically significant difference between male and female performance on the cognitive map task. Female participants on the LSC condition were significantly better than the males at placing items in the correct absolute position ($t=-1.74, p=0.049$).

**Cognitive Map**

Figure 6.22 shows the distribution of map score for males and females across conditions (see Table 6.25 for breakdown of cognitive map sub-tasks). It can be seen that cognitive map scores mirror the scores on the wayfinding task. There is a large difference between male and female map scores on the LSC condition, with females performing better than the males. An independent sample t-test reveals a statistically significant difference between male and female performance on the cognitive map task. Female participants on the LSC condition were significantly better than the males at placing items in the correct absolute position ($t=-1.74, p=0.049$).
However, although females on the LSC perform better than males on the LSC, they actually perform worse (although not significantly so) than female participants on the control condition. This therefore implies that the LSC had a negative effect on male performance on the cognitive map task, rather than a positive affect on female performance.

Figure 6.22
Bar chart showing participant map score split by sex and condition

Table 6.25
Participant performance on the map task, broken down by condition and sex

<table>
<thead>
<tr>
<th></th>
<th>Map Score</th>
<th>Relative Position Score</th>
<th>Absolute Position Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(as a %)</td>
<td>(out of possible 55)</td>
<td>(out of 22)</td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Control condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>57.4</td>
<td>24.4</td>
<td>15.5</td>
</tr>
<tr>
<td>Female</td>
<td>65.3 (13.7)</td>
<td>(5.9)</td>
<td>(3.8)</td>
</tr>
<tr>
<td>SLT condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>53.6</td>
<td>25.0</td>
<td>13.6</td>
</tr>
<tr>
<td>Female</td>
<td>56.7 (19.5)</td>
<td>(9.0)</td>
<td>(5.3)</td>
</tr>
<tr>
<td>LSC condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>50.1</td>
<td>23.1</td>
<td>12.8</td>
</tr>
<tr>
<td>Female</td>
<td>63.1 (17.4)</td>
<td>(8.4)</td>
<td>(4.6)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
6.2.2 Breadcrumb Component

**Wayfinding**

Figure 6.23 and Table 6.26 show the performance of breadcrumb participants on the wayfinding task, split by sex. It can be seen that overall males perform better than females on the breadcrumb condition. A repeated measures ANOVA with 'sex' as the between subjects factor found the difference to be statistically significant ($F(1,18) = 4.4, p = 0.05$).

![Figure 6.23](image)

*The mean number of junctions crossed by participants over the six trials of the wayfinding task – split by SEX*

Results: Components of SLT
Table 6.26

<table>
<thead>
<tr>
<th></th>
<th>Trial 1 Mean (SD)</th>
<th>Trial 2 Mean (SD)</th>
<th>Trial 3 Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Control condition</td>
<td>22.4</td>
<td>26</td>
<td>28.2</td>
</tr>
<tr>
<td></td>
<td>(9.0)</td>
<td>(16.5)</td>
<td>(22.5)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>18.1</td>
<td>19.9</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>(7.9)</td>
<td>(7.7)</td>
<td>(7.3)</td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>15.7</td>
<td>22.4</td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td>(9.3)</td>
<td>(12.1)</td>
<td>(8.5)</td>
</tr>
</tbody>
</table>

The graphs shown in Figure 6.24 and Figure 6.25 suggest that the breadcrumb component might be aiding male performance, and hindering female performance on the wayfinding task. In Figure 6.24 the distribution of male nScore across trials on the breadcrumb condition bears more similarity to the distribution for the SLT condition, than the control condition. However, a 2 (condition) x 2 (trial1, trial2) way repeated measure ANOVA for male participants found no statistically significant difference between the breadcrumb and the control condition ($F(1,19) = 4.3, p=0.053$).

Figure 6.24 shows that female performance of on the wayfinding task was poorer on the breadcrumb condition than either the SLT of the control condition. A 2 (condition) x 2 (trial1,trial2) way repeated measure ANOVA for female participants found no statistically significant difference between the breadcrumb and the control condition ($F(1,17) = 0.05, p=0.826$), or the SLT ($F(1,17) = 1.93, p = 0.183$).
Figure 6.24

The mean number of junctions crossed by FEMALE participants over the six trials of the wayfinding task – split by condition

Results: Components of SLT
Cognitive Map

Figure 6.26 and Table 6.27 provide a comparison of mean map scores across conditions, for male and female participants. It is interesting to again note that the condition appears to have an affect on the cognitive map of its participants. Males appear to do better, and females appear to do worse. However, independent sample t-tests did not find the difference between the breadcrumb and control conditions to be statistically significant for either male or for female participants. Nor was there a significant difference between male and female map scores on the breadcrumb condition.
Table 6.27
Participant performance on the map task, broken down by condition and sex

<table>
<thead>
<tr>
<th></th>
<th>Map Score (as a %age)</th>
<th>Relative Position Score (out of possible 55)</th>
<th>Absolute Position Score (out of 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Control condition</td>
<td>57.4 (13.7)</td>
<td>65.3 (19.8)</td>
<td>24.4 (5.9)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>53.6 (19.5)</td>
<td>56.7 (19.9)</td>
<td>25.0 (9.0)</td>
</tr>
<tr>
<td>Breadcrumb condition</td>
<td>60.8 (21.1)</td>
<td>52.4 (19.3)</td>
<td>29.1 (11.8)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
6.2.3 Map Component

Wayfinding

Figure 6.27 and Table 6.28 show that male participants generally performed better on the wayfinding task than did female participants on the map condition. However, as confirmed by a 2 (sex) x 6 (trial score) way repeated measures ANOVA, the difference between male and female distributions of nScore were not found to be significant.

Results: Components of SLT
Table 6.28

Performance on the wayfinding task split by sex for the control, SLT and the map conditions

<table>
<thead>
<tr>
<th>Trial 1 Mean (SD)</th>
<th>Trial 2 Mean (SD)</th>
<th>Trial 3 Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Control condition</td>
<td>22.4 (9.0)</td>
<td>26 (16.5)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>18.1 (7.9)</td>
<td>19.9 (7.7)</td>
</tr>
<tr>
<td>Map condition</td>
<td>20.6 (10.1)</td>
<td>23.9 (10.9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 4 Mean (SD)</th>
<th>Trial 5 Mean (SD)</th>
<th>Trial 6 Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Control condition</td>
<td>14.4 (12.4)</td>
<td>9.5 (6.6)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>11.3 (11.1)</td>
<td>10.6 (5.9)</td>
</tr>
<tr>
<td>Map condition</td>
<td>10.6 (11.6)</td>
<td>12.8 (11.2)</td>
</tr>
</tbody>
</table>

Figure 6.28 shows that that male performance on the map condition was similar to the performance of participants from the SLT condition, in that both are distinct from the control condition. A 2(condition) x 6(trial score) way repeated measures ANOVA found that the difference between male performance on the map and the control condition was approaching statistical significance (F(1,18) = 3.99, p= 0.061).
While the map component appears to be of benefit to males, it can be seen in Figure 6.29 that the conditions which have the map component as part of the interface do not have an affect on Female performance on the Wayfinding task. Figure 6.29 shows that the distribution of scores across the 6 trials for interfaces which support the map component are much the same as the control condition – suggesting that they have little or no affect. The similarity of distributions was supported by a 3(condition) x 6(trial score) repeated measures ANOVA which did not identify a significant difference between conditions.

Results: Components of SLT
Cognitive Map
The map scores for male and female participants on the map condition are shown in Figure 6.30 and Table 6.29. It can be seen that for males, there was very little difference in the maps produced, when compared to the control and the SLT conditions. However, females appear to do much worse on the map condition, although independent sample t-tests found no significant difference between males and females. However, females did perform significantly worse than they did on control conditions. This was confirmed by independent sample t-tests, which compared female map scores on the map condition, against scores obtained by female participants on the control condition. Both the absolute score ($t=2.51, p=0.022$), and the relative score ($t=2.47, p=0.024$) were found to be significantly different across conditions.
Table 6.29  
Participant performance on the map task, broken down by condition and sex

<table>
<thead>
<tr>
<th></th>
<th>Map Score (as a %)</th>
<th>Relative Position Score (out of 55)</th>
<th>Absolute Position Score (out of 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Control condition</td>
<td>57.4</td>
<td>65.3</td>
<td>24.4</td>
</tr>
<tr>
<td>(13.7)</td>
<td>(19.8)</td>
<td></td>
<td>(5.9)</td>
</tr>
<tr>
<td>SLT condition</td>
<td>53.6</td>
<td>56.7</td>
<td>25.0</td>
</tr>
<tr>
<td>(19.5)</td>
<td>(19.9)</td>
<td></td>
<td>(9.0)</td>
</tr>
<tr>
<td>Map condition</td>
<td>55.6</td>
<td>46.1</td>
<td>26.1</td>
</tr>
<tr>
<td>(21.2)</td>
<td>(13.4)</td>
<td></td>
<td>(11.5)</td>
</tr>
</tbody>
</table>

Results: Components of SLT
Analysis of participant performance with respect to sex revealed interesting differences. Females performed significantly better than males on both the wayfinding task, and the cognitive map task of the LSC condition. However, the affect was reversed for the map task where females performed generally poorer than males on the wayfinding task, and significantly poorer than males on the cognitive map task. This finding is in keeping with the literature discussed in Chapter 3 which argues that females are better suited to landmark based information, and would therefore appreciate the benefit awarded by the LSC.

Sex difference may well account for the lack of difference found in the last section when looking at the LSC and the map condition against the control data. As shown in Figure 6.31, on the LSC condition female wayfinding performance is typically better, although
not significantly so, compared to their performance on the map condition. Male performance however follows a reverse pattern. Male performance on the LSC condition is much the same as their performance on the control condition, and significantly improved when they receive the map condition. Therefore, on any evaluation where a combined sample is used, either for LSC or the map condition, the male and female scores will cancel out the effect of each other.

Despite differences between the sexes, it is important to note that no statistically significant improvement was noted beyond the control condition for either sex, on any of the conditions. The presence of a component often lowered performance on a task rather than increased it – as was the case for female participants who did significantly worse on the cognitive map task of the map condition. However, there were notable exceptions. Improvement in male wayfinding approaches significance on the breadcrumb (p=0.053) and the map (0.061) conditions. With a larger sample size it is quite likely that male improvement would have reached statistical significance.

**6.3 How do participants find their way?**

It has been shown that despite significant improvements in wayfinding, there has been no significant improvement in the quality of the maps produced during the Cognitive Map Task. Initial interpretation might lead one to conclude that this naturally implies wayfinding improvements were not the result of the navigator having a superior mental representation of their environment. However, there are many other, equally valid explanations.

It is possible that the Cognitive Map Task does not offer the sensitivity necessary to identify subtle differences between mental representations. However, looking at any of the ‘collective’ graphs throughout this chapter it is clear the graphs show noticeable differences between conditions. For example, the collective mental map of participants who were exposed to conditions where the LSC was present (i.e., the LSC [Figure 6.6], and the SLT condition [Figure 6.5]) is very different from the graphs were the LSC was
not present (i.e., the Control [Figure 6.4], the Breadcrumb [Figure 6.12], and the map conditions [Figure 6.18]). When the LSC was present, people appear to use the pre-selected landmark items to punctuate their environment. The Landmark items are clearly the nodal points of their cognitive map, as they are heavily associated with their surrounding neighbours, and are often placed in the correct location. Participants on conditions where item saliency is not manipulated tend to use the Wildlife bookcase as a nodal point, rather than the War bookcase or the Tables. In doing so, such participants reduce the number of nodal points to just 3 items, rather than the 4 flagged by the LSC. It is therefore clear that the Cognitive Map Task is sensitive enough to identify differences in maps produced across the conditions.

The lack of significant improvement in Cognitive Map Task scores is likely to be caused by the late point at which the task is implemented within the evaluation procedure. The point at which the SLT components make their most significant contribution is during the first two trials of the Wayfinding Task. By the end of Trial 3, the Wayfinding Task score falls dramatically. By Trial 3 it is typically half of the score obtained on Trial 1. By the end of Trial 6 participant knowledge of the environment is much the same, regardless of condition. This is reflected in the small variance of Wayfinding Task scores on Trial 6. It is therefore perhaps not surprising to find that their mental representations are also not significantly different by the end of Trial 6 either. Had the Cognitive Map Task been implemented at the end of Trial 2, instead of Trial 6, it is possible that the condition affect could have been identified.
Without the benefit of cognitive map task data at the end of Trial 2, it is hard to determine whether increased wayfinding was caused by people following a more complete cognitive map. However, a one-tailed Pearson test of correlation found that early performance on the Wayfinding task\(^1\) significantly correlates with a person’s cognitive map task score ($r = -.288, p = .002$). This may suggest a causal link, in that participants are relying on their cognitive map to navigate space. However, this also co-occurs with a significant correlation between both scores and spatial test score, which implies that both cognitive map scores and wayfinding scores are merely mediated by spatial ability.

Table 6.30 shows correlations split by condition. It can be seen that most conditions are tending towards the 95% confidence level, when correlating cognitive map task with wayfinding. However, the same is not true of the correlation between spatial task score and wayfinding. If a person’s ability to find their way in the environment does not correlate with spatial test score, we can assume that spatial ability was not a factor in finding one’s way during those trials. Therefore, a remaining significant correlation between wayfinding and map score would suggest that people are using their mental

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\(^1\) Early wayfinding performance is calculated by adding together a participant’s score on Trial 1 and Trial 2, and dividing the sum by 2.

**Results: Components of SLT**
representation to navigate their way around the environment. The only condition where this was the case is the LST condition. However, a similar pattern exists with the map condition—although the correlation between scores was only approaching significance.

Results: Components of SLT
Discussion

This, the final chapter of the dissertation, is organised into five sections. The first section provides a review of the work carried out, providing an overview of the project within the context of the research questions. The second section takes the reader through the results of the experimental work, and reflects upon the answers to the research questions. The third section is a discussion on the contribution made by the experimental work. The fourth section discusses ways in which the work could be taken further. The final section provides the reader with a short conclusion.

7.1 Framing the Work

Virtual Reality is a relatively new technology which provides users with the opportunity to interact with computers spatially. This is a particularly significant advancement for computing, as much of human interaction with the world is carried out spatially. Any tool which makes human-computer interaction more natural should see benefits in user acceptance and ease of use. This explains why many industries, particularly those involving data visualisation and training, have been keen to adopt VR technology. However, a negative side-effect of spatial computing is the common feeling of disorientation. This typically occurs because the fidelity of sensory information provided by VR tools is currently poorer than that which we experience in the real world. To counter such problems, there has been much research into the use of wayfinding tools to ease navigation in virtual environments. Such tools are particularly suited to short, one-off journeys in virtual worlds. However, the use of wayfinding tools incurs cognitive and temporal overheads, as people stop and attend to them during navigation. Therefore, a more continued and extensive experience of virtual space would benefit from wayfinding tools which also support the development of a cognitive map. Such tools would be of particular benefit to users of 3D video games, and people who frequent the extensive list of VRML worlds now available.
To support spatial cognition of virtual environments, three wayfinding tools were identified which might support each of the three stages identified by Siegel and White’s ‘Sequential and Hierarchical’ model of spatial cognition. The first is landmark based, which occurs on initial exposure. This is where we notice salient features of an environment. The second is route-based, where we learn pathways between salient features first noticed. The third is a survey-based representation, where pathways are spatially organised, allowing us to predict the outcome of routes not previously travelled. Three wayfinding tools were identified which were thought to support each cognitive representation:

- Songlines, where items of the environment are made more salient by their identification in story form, was considered a likely solution to aid landmark recognition.
- Breadcrumbs, where the user is made aware of the paths taken, was considered applicable to the development of route knowledge.
- A map, which provides an overview of the terrain, was considered appropriate for the development of a survey representation.

Having identified tools which might support both wayfinding and cognitive map development, a working prototype was developed and then evaluated. The tools were evaluated when used together, and also individually. This made it possible to identify which, if any, of the tools had made a significant impact on user performance. The evaluation involved a between-subjects design, where participant navigation of a virtual environment was compared when tools were (and were not) available. Users were asked to navigate a virtual space on 6 occasions. To rate wayfinding performance, a measure of route efficiency was recorded. Between trials, participants were given tasks to evaluate their representation of the virtual space. After the final trial, participants were asked to create a map of the virtual environment to determine the fidelity of their survey representation of the environment.

Conclusions
7.2 Discussion of Results

Analyses of the results suggest that the presence of all components together (i.e., the SLT condition) had a significant effect on wayfinding performance. During the first two trials, participants from the SLT condition typically chose more efficient routes than their colleagues experiencing the control condition. There was also much less variability in participant performance, with most participants crossing less than 30 junctions on trial 1, and 27 on trial 2 (compared to 50 and 62 respectively for control condition). However, analysis of the user’s cognitive representation does not support the hypotheses that improved wayfinding is the result of an improved cognitive map. Participants from the SLT condition typically produced maps of the virtual environment which were marked poorer (although not significantly so) than participants from the control condition. Analyses of conditions where tools were provided in isolation did not reveal any statistically significant benefit on either the wayfinding task, or the cognitive map task. This implies that no single component of the SLT was responsible for the significant improvement in wayfinding. Instead it appears that the sum of the components produces a greater effect than a single component alone.

When reviewing the literature on environmental knowledge acquisition it became apparent that differences exist between males and females. Females appear to favour the use of physical objects as landmarks for piloting, whereas males are equally comfortable using unique configurations of space to punctuate the environment. It was hypothesised that the difference in landmark preference by females might explain why when none of the evaluated components produced significant improvements in wayfinding or cognitive map development. If females responded particularly well to the LSC component and not the map component, and the reverse was true for males, the benefit of a single component would be less pronounced. In contrast, the SLT consists of both the LSC and the map component, and therefore provides support to both males and females within a single tool.

Comparisons between male and female performance for each component of the SLT offered some support for this hypothesis. Large, and mostly significant, differences were
found between male and female performance on wayfinding and map scores. Females did significantly better than males on the LSC condition, but were generally poorer than males on the map and breadcrumb conditions. However, although significant differences were found between the sexes, participants never performed significantly better than the control condition participants of the same sex. Therefore participants were only ever significantly hindered by the inclusion of a specific component, never significantly supported by it.

Such findings may be an effect of the number of participants involved in the evaluation process. Females did perform better on the wayfinding task during the LSC condition compared to the control condition – just not significantly so ($p = 0.111$). Males also produced better wayfinding scores on the map and the breadcrumb conditions – although this was again a statistically insignificant improvement (map: $p = 0.061$; breadcrumb: $p = 0.053$). Sex differences were never part of the original remit when evaluating the tools, which is why care was never taken to ensure suitable numbers for cross-sex comparisons. However, with performance in the direction hypothesised, it seems possible that with the inclusion of more participants these tests may have reached statistical significance. There is therefore a need for further investigation of sex-differences beyond this thesis.

Although the SLT was found to significantly improve wayfinding, the cognitive map task failed to identify any improvement to a participant’s mental representation of the environment. It is tempting to conclude that wayfinding improvements are not the result of cognitive map development. However, there are a variety of reasons why an effect was not detected. Firstly, it is possible that the cognitive map task is not sensitive enough to distinguish the differences in participant’s cognitive representation of the environment. However, analysis of scatter-board configurations suggests that this is not the case. In comparing Figure 6.4 and Figure 6.6 it can be clearly seen that the collective map appears structurally different between the LSC and control conditions. The differences are distinct, and follow the pattern hypothesised. Figure 6.4 visibly illustrates how the LSC has influenced the use of ‘landmark’ items, and that they appear as central pillars of the cognitive map.

Conclusions
Another possibility is that pre-selecting landmarks for participants is not beneficial. Rather than using the ‘War’ bookcase or the ‘Tables’ as a landmark, Figure 6.4 implies that control condition participants were more likely to adopt the ‘Wildlife’ bookcase as a landmark. Ninety-five percent of control condition participants correctly located the ‘Wildlife’ bookcase on the scatter-board, and it is also strongly associated with its surrounding bookshelves. By using ‘Wildlife’ rather than ‘Tables’ and ‘War’, participants reduced the number of landmarks needed to remember the environment down to just 3 items – as oppose to the 4 items flagged in the LSC condition.

A further possibility is that the cognitive map task was given too late in the evaluation procedure to discriminate between conditions. The point at which the components are most beneficial is during the first two trials. From trial 3, participants have started to grasp the layout of the environment, and wayfinding scores drop by approximately half the initial score obtained in trial 1. By trial 6, there is little variance in wayfinding scores, regardless of the condition. At this point all participants appear to have learned the layout of the environment, and have a functional representation of it. In hindsight, moving the cognitive map task to the end of trial 2 would have yielded more interesting results, and such a manipulation would clearly be an interesting extension of the work presented here.

7.3 Contributions
There are a variety of areas where this thesis has made a contribution to the disciplines of HCI. Firstly, and perhaps least significantly, the thesis adds further evidence to show that people can develop a survey representation through exposure to virtual environments. As discussed in chapter 3, evidence until this point has been inconclusive. However, various results obtained during this project suggest that participants do develop a survey representation. For instance, referring back to the LSC evaluation, participants were asked to place items onto the scatter-board. If they had a route based representation, it would be expected that participants would place items onto the scatter-board in the order they appear on a given route. However, this was not the case. For all conditions
participants were likely to begin by placing the more familiar items (i.e., landmark items). Although landmark items are located in different areas of the scatter-board, on the LSC condition 67% of participants correctly placed ALL landmark items onto the scatter-board. This suggests that they had at least a rudimentary survey representation of the environment.

A more significant contribution is the analysis of the cognitive map. Until this thesis, the author is unaware of any other examples where scatter-boards have been used to determine the state of a person’s cognitive representation of the world. As discussed in Chapter 4, scatter-boards are a useful tool when researching the state of a person’s cognitive map as they are less dependant upon artistic ability. Scatter-boards also support more informative ways to present cognitive map data. Developed specifically for this thesis, the graph shown in Figure 6.4 clearly presents a detailed representation of the map task data. Producing a collective map makes it easier to visually compare the impact different conditions have on how people represent the environment.

Where this body of work makes a significant contribution is to the field of HCI. The thesis describes the design and the evaluation of a new tool for learning the spatial configuration of virtual environments. It has been shown that the SLT will significantly aid wayfinding, and although any benefit to cognitive map development is not conclusive, there is supporting evidence to suggest that the components of the SLT might affect the development of the cognitive map, which in turn supports wayfinding.

7.4 Further Work

As reported earlier, there is need for further work to re-evaluate the SLT and each its components. The experimental work presented here was limited by having administered the cognitive map task too late in the procedure. In the evaluation the cognitive map task was given after the final trial, a point when all participants, regardless of condition, appear to have a working representation of the space. Significant differences in wayfinding occur during Trial 1 and Trial 2, which is when the cognitive map task might
show differences in mental representations. Further work might also look at other wayfinding tools and their impact on cognitive map development.

Having evaluated the SLT in just a single virtual environment, issues are instantly raised concerning the generalisability of findings to other virtual spaces. There are many differences between virtual environments which might make the SLT unsuitable on some occasions. Many virtual environments support 3-dimensional navigation, where the user can move up and down. In such an environment there is little need for a map tool, because the user could increase altitude to gain a survey perspective of the space. Such piloting is also likely to impact on the wayfinding strategy employed by the navigator. In circumstances where the navigator can obtain a high perspective where places of interest are visible, the possession of a cognitive representation might not be beneficial. Also many game environments include portals, where the user is instantly transferred to places of interest, without the need for piloting. Clearly there is a need for a full review of virtual environments, and the wayfinding strategies they afford. This would allow us to then identify applicable spaces for the SLT.

Should further evaluation find benefit in using the SLT to improve the cognitive representation of virtual spaces, there are many other areas where the tools might also prove beneficial. The work described in this thesis concentrates specifically upon supporting spatial learning in virtual environments. However, if the SLT does improve cognitive development in virtual worlds, it could benefit the rapid training of real world spaces. Already there is much research on the transfer of learning from virtual worlds to real worlds, where military personnel have used VR to learn the configuration of physical space. However, although the cognitive representation produced by navigating virtual spaces is reportedly better than when using a map (Waller et al., 1998), it currently takes over an hour to train people in VR (Goerger et al., 1998). In such situations, the SLT might increase the rate at which people learn the configuration of real world spaces.

On a similar note, it has been argued that wayfinding tools for real world spaces might also benefit the navigation of information spaces (Benyon, 1998, Shum, 1990). If further...
evaluation of the SLT proves successful, it would be interesting to apply the same technology to semantic spaces. For example, a common complaint when playing expansive video games is that players lose their way within the game. They do not necessarily get physically lost, but instead lose the narrative thread, become disorientated with in the game space, and are unsure of their immediate goals. Clearly, the SLT would not transfer to conceptual space in its current form, but the principle behind each component could be re-engineered. The breadcrumb tool could be represented by a newsreader, who gives a recap on the story so far; the conceptual game space could be mapped out as a series of dramatic episodes; and so forth.

7.5 Conclusions
A tool designed to support spatial learning in virtual environments was developed to prototype, and then evaluated. Analyses suggest that the SLT is beneficial for wayfinding in the test environment. However, owing to methodological issues, it was not possible to determine whether wayfinding improvement was the result of an enhanced cognitive representation. It is therefore recommended that the tool is re-evaluated in light of the suggestions raised – particularly the movement of the cognitive map task to an earlier point in the procedure, and an increase in participants to allow better evaluation of cross-gender effects.
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**References**


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Supporting Spatial Learning in Virtual Environments


Appendix
Library Experiment

Thank-you for agreeing to help with the library experiment. Your time and input is very much appreciated. Hopefully, this experiment should only take an hour.

In this experiment you will be entering another world. It is not too different from our own, but in this world you will be expected to work in a library. So far, so normal. However, the difference between this library and any other is that this library is managed by a witch.

But before we get in to all of that, we first need to know a little more about you....

Demographics

Name: Rosie Pragnell
Sex: Female
Age: 19

Have you played Quake, Half-Life, Unreal or any similar type of games before? (please circle your chosen answers)
- Yes / No

If YES,
- How often, on average, would you say you play?: Daily / Weekly / Monthly

How would you rate you ability to learn the layout a new city:

How would you rate your map reading Skills:

Spatial Test

Now we would like to check your spatial skills.... your answers can be recorded below...

Spatial Test 1 (3 minutes): please circle the correct answer
1. A / B / C / D / E
2. A / B / C / D / E
3. A / B / C / D / E
4. A / B / C / D / E
5. A / B / C / D / E
6. A / B / C / D / E
7. A / B / C / D / E
8. A / B / C / D / E
9. A / B / C / D / E
10. A / B / C / D / E

Spatial Test 2 (3 minutes): please circle the correct answer
11. A / B / C / D / E
12. A / B / C / D / E
13. A / B / C / D / E
14. A / B / C / D / E
15. A / B / C / D / E
16. A / B / C / D / E
17. A / B / C / D / E
18. A / B / C / D / E
19. A / B / C / D / E
20. A / B / C / D / E

Scores:
Spatial Test 1: 9/10
Spatial Test 2: 17/20
Finally..... we can now start the experiment........

Task One
Your first task is to find the witch in order to ask her for a job. You will begin your quest in the bowels of a dungeon and you will have to work your way to the top floor in order to find her. If you get stuck, follow the fire lanterns – they will guide you along the way. Be sure to get there as quickly as possible as she is very impatient.

To move around you can press the up, down, left and right arrows on the keyboard. If you have any problems please feel free to ask for help at any time.

Time: 18

Task Two
Well done, you got the job! Now you have to get the books for her. You should always aim to get the books by following a route that is as direct as possible. As it is your first day she will be reasonably tolerant.

The books that she is after are:

<table>
<thead>
<tr>
<th>Book</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Travel</td>
</tr>
<tr>
<td>Photo Monthly</td>
<td>Magazines</td>
</tr>
<tr>
<td>Vikings</td>
<td>History</td>
</tr>
</tbody>
</table>

Note: do not necessarily get the books in the above order. Try to follow a route that is as direct as possible.

Score: 47
Questions:

Please write down as many features of the environment that you can remember. You might remember book titles, shelf sections or other features of the environment.

1. Set-out like a library - titles on each of the rows
2. Home goods, magazines, travel, history
3. Books on ancient Greeks
4. Put wishing in water fountain get a wish
5. War section of books had been moved
6. Witch was standing near entrance/exit
7. Titles of book sections were colored
8. Science, computing
9. Books set out in a grid
10. Didn't seem to be in alphabetical order
11. Voice kept announcing things (female)
12. Different sections were color coded but some were the same as each
13. ore - confusing

M1: 3
55: 6
St: 1
Task Three
The witch needs you to get some more books for her.

The books that she is after are:

<table>
<thead>
<tr>
<th>Book</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web Navigation</td>
<td>Computers</td>
</tr>
<tr>
<td>Professional Cooking</td>
<td>Food</td>
</tr>
<tr>
<td>Catering</td>
<td>Careers</td>
</tr>
</tbody>
</table>

Note: do not necessarily get the books in the above order. Try to follow a route that is as direct as possible.

Score: 33
Task Four
The witch needs you to get some more books for her.

The books that she is after are:

<table>
<thead>
<tr>
<th>Book</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>Sport</td>
</tr>
<tr>
<td>Theatre</td>
<td>Art</td>
</tr>
<tr>
<td>Marketing</td>
<td>Business</td>
</tr>
</tbody>
</table>

Note: do not necessarily get the books in the above order. Try to follow a route that is as direct as possible.

Score: 48
Task Five
The witch needs you to get some more books for her.

The books that she is after are:

<table>
<thead>
<tr>
<th>Book</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking in the Peak District</td>
<td>Transport</td>
</tr>
<tr>
<td>Human Rights</td>
<td>Law</td>
</tr>
<tr>
<td>Gardening and Horticulture</td>
<td>Homes and Gardens</td>
</tr>
</tbody>
</table>

Note: do not necessarily get the books in the above order. Try to follow a route that is as direct as possible.

Score: 24.
We would like you to answer some questions about the library for us....

Q1. If you are standing in front of the monk statue (which overlooks the fire), there are bookcases all around you. Can you name any of the section categories of the bookshelves?

Behind you:  
On your LEFT:  
On your RIGHT:  
In front of you, and to the LEFT of the statue:  
In front of you, and to the RIGHT of the statue:  

Q2. If you are standing at the water feature (underneath the plants) and facing towards the stained-glass window, there is a bookshelf behind you, and another to your right. Can you name the section categories of either of the bookshelves?

Behind you:  LAW  
To your RIGHT:  

Q3. Imagine that someone new to the library began your journey at the START POSITION. Can you give directions to them on how to reach the SPORT section. Please detail all the twists and turns, and list all the bookshelves they will pass on both their left and right hand side.

Go STRAIGHT ON FOR ABOUT 3 TWO BLOCKS ON YOUR LEFT  
TURN LEFT  

Q4. Imagine that someone new to the library began your journey between the HISTORY and the CAREERS section looking towards the trees. Can you give directions to them on how to reach the COMPUTER section. Please detail all the twists and turns, and list all the bookshelves they will pass on both their left and right hand side.

Behind them a couple of blocks  

Task Six
The witch needs you to get some more books for her.

The books that she is after are:

<table>
<thead>
<tr>
<th>Book</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Judaism</td>
<td>Religion</td>
</tr>
<tr>
<td>Chemistry</td>
<td>Sciences</td>
</tr>
<tr>
<td>Healthy Eating</td>
<td>Health</td>
</tr>
</tbody>
</table>

Note: do not necessarily get the books in the above order. Try to follow a route that is as direct as possible.

Score: 35.
Task Seven
The witch needs you to get some more books for her.

The books that she is after are:

<table>
<thead>
<tr>
<th>Book</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coping with the</td>
<td>Parenting</td>
</tr>
<tr>
<td>Terrible Twos</td>
<td></td>
</tr>
<tr>
<td>Faery Tales</td>
<td>Children</td>
</tr>
<tr>
<td>African Game</td>
<td>Wildlife</td>
</tr>
</tbody>
</table>

Note: do not necessarily get the books in the above order. Try to follow a route that is as direct as possible.

Score: 21

PLEASE HAND BACK THIS BOOKLET
Map Placement Order

1. WATER
2. TABLE + CHAIRS
3. MAGAZINES
4. SPORT
5. CHILDREN
6. MONK
7. HOME + CON
8. LAW
9. WAR
10. SCIENCE
11. ENT
12. HISTORY
13. FOOD
14. BIO.
15. CAREERS
16. HEALTH
17. BUSINESS
18. TRAVEL
19. WILDLIFE
20. ART
21. HISTORY
22. TRANSPORT
<table>
<thead>
<tr>
<th>Place</th>
<th>Orientation</th>
</tr>
</thead>
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