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Sub space: Enhancing the spatial awareness of trainee submariners using 3D simulation environments.

Honours Thesis Michael Garrett Faculty of Education and Arts 06 November 2007 Supervisor: Dr. Mark McMahon

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Abstract

Rapid advancements in computer technology have facilitated the development of practical and economically feasible three dimensional (3D) computer-generated simulation environments that have been utilized for training in a number of different fields. In particular, this development has been heavily influenced by innovations within the gaming industry, where First Person Shooter (FPS) games are often considered to be on the cutting edge of gaming technology in terms of visual fidelity and performance. 3D simulation environments built upon FPS gaming technologies can be used to realistically represent real world places, while also providing a dynamic and responsive experiential based learning environment for trainees. This type of training environment can be utilized effectively when training within the corresponding real world space may not be safe, practical, or economically feasible.

This thesis explores the effectiveness of 3D simulation environments based on FPS gaming technologies to enhance the spatial awareness of trainees in unfamiliar real world spaces. The purpose was to identify the characteristics that contribute to effective learning within such environments. In order to identify these characteristics, a model was proposed representing the interrelationships between, and determinant factors of, the concepts of spatial cognition, learning within a simulation environment, and computer-generated 3D environments.

The Location and Scenario Training System (LASTS), developed by the Royal Australian Navy, was evaluated to determine whether experience within the LASTS environment could benefit trainee submariners on Collins class submarines. The LASTS environment utilises the Unreal Runtime FPS game engine to provide a realistic representation of the Main Generator Room (MGR) on-board a Collins class submarine. This simulation was used to engage trainees in a simplified exercise based on the location of items relevant to a 12 Point Safety Round performed inside the MGR. Five trainee submariners were exposed to LASTS and then required to conduct the same exercise on-board a Collins class submarine. This mode of learning was compared to traditional non-immersive classroom teaching involving five additional trainee submariners who were also required to complete the same exercise inside the MGR. A mixture of qualitative and quantitative approaches to data collection and analysis was used to ascertain the effectiveness of LASTS as well as the contributing factors to this and learners' perception of the value of the environment.

Results indicated that LASTS could be successfully used as a training tool to enhance the spatial awareness of trainee submariners with regard to the MGR on-board a Collins class submarine. LASTS trainees also demonstrated a better spatial understanding of the MGR environment as a

result of their experience compared to trainees who were the recipients of traditional classroom based training. The contributing characteristics of the proposed model were also validated with reference to the data gathered from the LASTS case study. This indicated that the model could be utilized in the design of future 3D simulation environments based on gaming technology in order to facilitate effective spatial awareness training.

Declaration

I certify that this thesis does not, to the best of my knowledge and belief:

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1.1 Background to the Study

Computer-generated simulation environments are well recognized as learning and training tools due to their ability to represent any real or imaginary process, entity, or environment, including it's underlying behavioural characteristics. The use of computer-generated simulations for training purposes implies the application of a responsive system model that can be manipulated and interacted with by the learner, with the objective being the transfer of the skills and knowledge acquired within the simulation to the system being modelled. In this manner, learners can achieve desired learning outcomes that are situated within a culture, context, or activity common to both the simulation environment and the target system.

Advances in computer technology, increased affordability of desktop computers, and the rapid growth of the Internet have facilitated the development of practical and economically feasible three dimensional (3D) computer environments. Although a relatively new technology, 3D environments have been employed in a number of different applications where a three dimensional perspective is beneficial. This three dimensional perspective offered by 3D environments allows them to potentially represent real world three dimensional spaces realistically and more intuitively than other forms of media. 3D environments can thus be used to simulate real world environments to provide learners with a degree of comparable experience before subjecting them to the real world environment.

The technological development of 3D environments has also been heavily influenced by innovations within the gaming industry, where high consumer demand has driven rapid advancements in associated hardware and software technologies. This is particularly evident with regard to First Person Shooter (FPS) games, where the player is provided with a first person perspective of a three dimensional environment. FPS games are typically characterised as being on the cutting edge of gaming technology in terms of visual fidelity and performance, and have amongst the highest of expectations placed upon them by the gaming public. The abilities of 3D gaming technologies, in particular the game engines used to power FPS games, have not gone unnoticed, with proponents of computer based learning recognizing the potential of these technologies to function as simulation environments.

The military, in particular, have made extensive use of 3D simulation environments built on FPS gaming technologies for learning and training purposes. The well renowned American's Army project for example, utilized technology from the FPS game Unreal Tournament to create a realistic infantry simulation designed to increase military recruitment. Technology from Unreal

Tournament has also been proposed as a framework for multi-agent, distributed interactive simulation environments for the U.S military (Manojlovich, Prasithsangaree, Hughes, Chen, & Lewis, 2003). Within Australia, the viability of gaming technology for military simulation has also been recognized by the Australian Department of Defence via the successful application of the Virtual Battlefield Systems (VBS1) project. VBS1 has been used to support support studies into alternative squad level organizations, as well as tactical combined arms training, utilizing technology from the FPS game Operation Flashpoint (Carpenter & White, n.d.).

1.2 Significance of the Study

3D simulation environments allow users to experience real, recreated, abstract or imaginary environments that may be of impractical size, infeasible distance, prohibitive cost, or too significant a hazard to visit in person (Baylis, 2000). Users are able to perform actions within these virtual environments in ways that may not be possible, practical, safe, or ethical to do so in the real world environment being modelled. As such, 3D simulation environments are particularly well suited to training users and preparing them for real world tasks in operational environments that would benefit from some degree of familiarity before real world exposure. Thus, 3D simulation environments can be used to familiarise trainees not only with a specific operation or task within a real world environment, but also the environment itself.

There is an inherent need for awareness of any operational environment in order to elicit effective performance from those whom operate within it. Knowledge of the environment entails recognition and understanding of the spatial relations between one self, the objects within the environment, and the structure or hierarchy of the environment itself. This spatial knowledge of an environment is particularly important in operational environments that rely on individuals being able to travel throughout them efficiently and effectively, while retaining locational knowledge of specific areas and objects within the environment. 3D simulation environments have the potential to recreate these environments realistically, such that this knowledge can be learned within the simulation environment and then transferred to the operational environment. In this fashion, trainees can develop a degree of spatial awareness of the real environment before they are exposed to it for the first time, or enhance and reinforce their already existing spatial knowledge of the environment via experience within the simulation environment.

There is sufficient evidence to suggest that 3D simulation environments are capable of enhancing spatial awareness of real world environments via the transfer of spatial knowledge accumulated within a corresponding virtual environment (see Section 2.2.2 Spatial Learning in Virtual Environments).

1.3 Statement of the Problem

Real world environments may be difficult to set up for instruction, difficult to observe in operation, or may have limited suitable available time, potentially making training prohibitive (Towne, 1995). These limitations can in turn cause problems for trainees by increasing their dependence on supervisory personnel, limiting the range of operational configurations experienced, and obscuring the behaviour of the target system (Towne, 1995), thereby decreasing the effectiveness of the training. Non computer training techniques and other two dimensional forms of multimedia can be insufficient and inconsistent with facilitating the development of spatial cognition in the same way as 3D simulation environments. It should be noted that 3D simulation environments can be used in conjunction with other forms of media and instructional techniques to facilitate spatial awareness of real world environments. However, there is some evidence to suggest that learning and transfer are more effective when instructional support is integrated into the simulation environment (see Section 2.3.2 Learning with Simulations).

1.4 Research Questions

The literature review conducted in Section 2.0 of this document provides a detailed theoretical background which has led to the formation of a set of research questions. These research questions are concerned with determining which characteristics of 3D simulation environments based on gaming technology facilitate spatial learning. The research questions are presented here within the introduction in order to indicate the scope and direction of the research:

Question 1. How can the implementation of a 3D game engine environment contribute to a learner's development of spatial awareness of real world environments?

Question 2. What is the nature and function of spatial cognition and the subsequent formation of spatial representations?

Question 3. What are the characteristics of 3D game engine environments in terms of their ability to support spatial cognition?

2.0 Literature Review

2.1 Introduction

In order to determine the answers to the research questions proposed in Section 1.4, a thorough exploration of spatial cognition, computer assisted learning, and computer-generated 3D environments, including their core principles, is required. These core principles can be used to determine a set of criteria for evaluation. It is also necessary to identify and examine any interrelationships between these concepts in order to determine how spatial learning within a 3D simulation environment can be facilitated.

First and foremost, an understanding as to the nature and function of spatial cognition and the means by which environments are represented spatially is required. The manner in which people perceive, organize, and encode the spatial characteristics of the environments around them as a mental representation also needs to be identified. Furthermore, the environmental factors that contribute to the formation of spatial representations must be determined in order to ascertain how people learn and become familiar with the spatial characteristics of the environments around them. It is also necessary to determine whether computer-generated 3D environments are compatible with, and capable of, facilitating this process.

An understanding as to how people learn within computer-generated simulation environments is also necessary in order to explore how spatial information obtained within a virtual environment can be put to use in the real world. The nature in which this information can be transferred and applied to the real world environment being simulated will also require examination. Identification and recognition of the underlying learning theory that permeates and facilitates this process within computer-generated simulation environments also requires exploration. The role of instructional support, including it's nature and function within simulation environments also warrants discussion.

An examination of the components that constitute a simulation environment in reference to the characteristics of 3D, and real world environments will be fundamental in determining the validity of computer-generated 3D environments to simulate real world spaces. A discussion of the various technologies capable of creating 3D environments, including a detailed examination of gaming technologies, and the capabilities of FPS game engines will also be required. An in depth examination of the characteristics of FPS game engines and their potential contributions to simulating a real world space for the purposes of spatial learning will also be necessary.

Finally, the interrelationship between these concepts will need to be identified in order to

determine a set of broad principles common to each of spatial cognition, computer assisted learning, and computer-generated 3D environments. In this fashion, a model depicting the relationships between spatial cognition, computer assisted learning, and computer-generated 3D environments can be created, detailing the characteristics of 3D simulation environments based on FPS game engines that support spatial cognition. A master set of criteria for evaluation purposes can also be derived by combining previous individual sets of criteria identified for each concept with respect to this model.

2.2 Spatial Cognition

Many of the activities we perform on a daily basis are dependent on our ability to recognise and conduct ourselves within the three dimensional environment around us. In order to determine the characteristics of 3D environments that contribute to spatial learning, it is first necessary to undertake a discussion regarding the manner in which knowledge about the objects and locations within an environment and the spatial relations between them are understood and encoded. This process is known as spatial cognition.

2.2.1 The Nature and Function of Spatial Cognition

Spatial concepts and spatial relations play a fundamental role in the cognitive structure at every level of representation, from the perception of objects to the perception of geometry (Olson & Bialystok, 1983). The spatial representation of an environment that is formed as a result of this cognitive process is done so in order to support movement within the environment for the purpose of wayfinding and navigation (Lynch, 1960; Siegel & White, 1975, Tversky 2000). Hart and Moore (1973) state that spatial cognition is "the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought" (p. 248). The process of spatial cognition entails the acquisition and development of cognitive maps, an on-going and iterative process comprising of "a series of psychological transformations by which an individual acquires, codes, recalls, and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment" (Downs & Stea, 1973, p. 9). The cognitive map is a mechanism by which an individual answers two basic questions quickly and efficiently: (1) Where certain valued things are; (2) How to get to where they are from where the individual currently is (Downs & Stea, 1973).

While it is generally agreed that a cognitive map is a mental representation of an external environment, there is some debate as to how they are characterised and encoded. Tversky (2000) notes that opinions on the representation of cognitive maps range from a unified

representation of an environment as a mental image, somewhat similar to a map on paper, to an ad hoc collection of information from different sources put together to solve a problem. She proposes that cognitive representations consist of a collage of information, consisting of overview, view and action knowledge:

At a global level, the traveller needs a mental representation of an area that includes 'here' and 'there' and regions around and between them. Let's call that 'overview' knowledge. Using that, the traveller determines a feasible route. Along the route, and especially at choice points, the traveller needs a representation of the local surroundings, with the information critical to the choice highlighted. Let's call that knowledge 'views.' At yet a finer level, the traveller needs to know how to take each step or each turn of the wheel, maintaining course while avoiding pitfalls and obstacles. We'll refer to that as 'actions'. (p. 24)

Tversky (1993) rejects the notion of a single, coherent maplike cognitive structure, noting that "in many instances, especially for environments not known in detail, the information relevant to memory or judgement may be in different forms, some of them not maplike at all" (p. 15). She argues that in these cases, people's internal representations are more like collages rather than maps, stating that memory and judgement are systematically distorted and potentially contradictory and thus not easily reconcilable in a maplike structure.

Downs and Stea (1973) argue that cognitive maps are *functionally* equivalent to cartographic maps, as opposed to structurally equivalent:

The focus of attention is on a cognitive representation which has the functions of the familiar cartographic map but not necessarily the physical properties of such a pictorial graphic model (Blaut, McCleary, and Blaut, 1970). (p. 11)

They suggest that cognitive maps consist of a mixture of information regarding the *location* and *attributes* of phenomena. Locational information is determined by measures of distance and direction while attributional information consists of descriptive and evaluative information. Thus, an object is identified and defined by a set of attributes and pieces of locational information. The scale of the analysis of the problem at hand defines what is an object, and in turn, what is attributive and locational information, as an object at one spatial scale can become an attribute at another.

The spatial knowledge used in the construction of cognitive maps can be acquired from an environment in a number of different ways. The primary distinction between these sources of spatial knowledge is whether the information comes directly from the environment itself, or from some other secondary source such as a map (Darken & Peterson, 2002; Jansen-Osmann, 2002). Downs & Stea (1973) denote these two types of information sources as *direct* and *vicarious* sources of information. Direct sources are experiential sources that come from first hand involvement in the environment. For direct sources of information, the visual, tactile, olfactory, and kinaesthetic sense modalities combine to provide an integrated representation of the spatial environment (Downs & Stea, 1973). Conversely, vicarious sources of information are selected and filtered through the experience of another, such that the information is distorted, generally in a way that is useful to the individual in their present context (Downs & Stea, 1973).

Research on spatial cognition and cognitive mapping has yielded a number of useful theoretical frameworks, many of which draw from the extensive work of Jean Piaget in this area. As such, a number of these theories focus on the development of spatial cognition in children, but it has been argued that the parallels between the spatial progression in children and adults allows these theories to be applied universally (Siegel & White, 1975; Devlin, 2001).

One of the most widely recognized of these theories is the Landmark, Route, Survey model described by Seigel and White (1975) and Thorndyke and Goldin (1983). This model emphasizes the role of landmarks, or "unique patterns of perceptual events at a specific location" (Siegel & White, 1975, p. 23), which are initially extracted from the environment and act as salient cues that are static and orientation dependent (Darken & Peterson, 2002). Route knowledge subsequently develops as connections between landmarks become established with experience. Landmark and route knowledge is then organized together into highly correlated sets of clusters where topological information about cluster relations is apparent (Devlin, 2001). Finally, an overall coordinated frame of reference develops such that Euclidean properties are available within and across clusters (Devlin, 2001), enabling paths to be generated based on estimated relative distances and directions between any two points (Darken & Peterson, 2002). Werner, Krieg-Bruckner, Mallot, Schweizer and Freksa (1997) summarise accordingly:

Landmarks are unique objects at fixed locations, routes correspond to fixed sequences of locations as experienced in traversing a route; survey knowledge abstracts from specific sequences and integrates knowledge from different experiences into a single model. (p. 42)

While the individual conceptualization and representation of cognitive maps differs throughout the literature, all conceptions of cognitive maps recognise that not all environmental information is represented; much of it is simplified, idealised or omitted all together (Tversky, 2000). Downs and Stea (1973) also support this contention, stating that:

If we compare a cognitive map with a base map of the real world (whether it be an aerial photograph, a cartographic map, or a scale model), we find that cognitive mapping does not lead to a duplicative photographic process with threedimensional colour pictures somehow "tucked away in the mind's eye," nor does it give us an elaborately filed series of conventional cartographic maps at varying spatial scales. Instead, cognitive maps are complex, highly selective, abstract, generalised representations in various forms. (p. 18)

Tversky (2000) argues that because elements within a cognitive map are represented relative to each other and relative to a spatial reference frame, these relations can systematically distort spatial information, such that it becomes schematized. Realising the subjectivity of the individual construction of cognitive maps, Downs and Stea (1973) proposed that cognitive maps could be characterized as incomplete, distorted, schematized, and augmented, suggesting that people behave in a world of their of their own construction, irrespective of the flaws and imperfections in their own cognitive maps.

2.2.1.1 Factors Influencing Spatial Cognition

All theoretical constructs regarding spatial cognition assume the ability of movement between points or landmarks in an environment. Without the ability to move, an individual's spatial representation of an environment is severely limited. Devlin (2001) notes that motor activity is the foundation of perceptual activity, the construction of perceptual space, representational images, and ultimately, how spatial concepts are represented. Siegel and White (1975) also acknowledge the central role of motor activity in the development of spatial representations, noting that "sensory-motor interaction with the spatial environment is necessary for correct perception, for experiencing the world "as it really is" (p. 23). Thus, it can be surmised that the ability to move freely is essential in order for an individual to form a spatial representation of an environment.

For vicarious sources of spatial information, the type of medium employed to present the environment influences the spatial cognition process and the subsequent formation of cognitive representations (Delgarno, 2004; Devlin, 2001). True to Downs and Stea's (1973) discussion on the sources of spatial information, vicarious sources are filtered and thus distorted representations of the environments they represent. This is true for all vicarious sources of spatial information, including written descriptions, maps, photographs and 3D environments. As this research focuses on representing a real world space through a computer generated, three dimensional medium, it is important to note that this representation will always be incomplete

and distorted in some way. However, because the user is able to move and act within the confines of the 3D dimensional environment, they will be able to gain direct and experiential spatial knowledge of the 3D environment itself. Thus, a 3D environment representing a real world space will provide the user with direct spatial knowledge of the virtual environment, but vicarious spatial knowledge of the real world environment that it is representing. The key then lies in presenting a faithful representation of the real world environment with a computer generated 3D environment with as little distortion as possible, such that the cognitive map generated inside the virtual environment can be applied effectively in the real world. This concept of legibility or clarity is defined by Lynch (1960) in terms of the ease with which the elements of a system can be recognized and organized into a coherent pattern. Lynch (1960) states that a legible representation can be visually grasped as a related pattern of recognizable symbols, and suggests that legibility may play a key role in obtaining a sense of spatial control in spatial experience. Kim (2001), citing Kaplan and Kaplan (1983), also contends that legibility is one of the most salient aspects in an individual's effective functioning as it allows the individual to explore the environment extensively without becoming lost. The need for a visually recognizable and legible representation is supported by research by Peruch, Belingard, and Thinus-Blanc (2001) who argue that it is the quality, not quantity, of available virtual information that is more important in the construction of a spatial representation that is to be transferred to a real world environment.

2.2.2 Spatial Learning in Virtual Environments

Having examined the nature and function of spatial cognition and cognitive maps, it is now pertinent to explore the effectiveness of 3D environments in facilitating the development of spatial knowledge. A number of studies have been undertaken in this area examining the veracity of the acquisition of spatial knowledge in virtual environments.

Brooks et al. (1999) conducted a study with an amnesia patient to see if they could be trained in route finding around a hospital ward utilizing a detailed non-immersive 3D environment based on the real unit. The patient practised selected routes within the hospital using both the 3D environment and the real environment itself. Within two weeks, the patient had learned the route practised in the virtual environment, but not the route practised in the real unit. Based on the results of the experiment, Brooks et al. (1999) surmised that training in virtual environments may be an effective means of teaching new information to patients with severe memory impairments, noting that a virtual simulation of a motor skill was sufficient to promote spatial learning. The knowledge gained gained by the patient in the virtual environment was also shown to transfer to the real world environment.

A study by Osberg (1997) focussed on improving the spatial processing skills of neurologically impaired children via experience in 3D learning environments. The study evaluated the effect of designing and experiencing a virtual world as a spatial processing skill enhancement method, and as an aid to cognitive development. Three dimensional design software was used by the children to develop puzzle pieces that were combined into a cohesive whole at the end of the study. Osberg (1997) concluded that the results of the study were consistent with the hypothesis that intensive 3D processing culminating in a virtual experience could enhance spatial processing skills and that virtual reality exhibited potential as a setting for multi-perceptual, experiential learning. The author suggested that "the intensive training may have encouraged these children to contemplate spatial issues in a manner not previously experienced, and may have created deeper spatial understanding through the opportunity to directly manipulate objects and navigate through a 3-D environment" (on-line).

In a study by Arthur, Hancock and Chrysler (1997), participants were examined on their ability to reproduce a complex spatial layout of objects having experienced them previously under different viewing conditions, including a free binocular virtual condition, a free binocular real-world condition, and a static monocular real-world condition. The results obtained suggested that representations formed from the experience of virtual objects did not differ significantly from that of the actual objects. Arthur, Hancock and Chrysler (1997) suggested that this provided evidence that the spatial representation resulting from interactions with small-scale virtual environments was comparable to real-world experience.

Peruch, Belingard, and Thinus-Blanc (2000) performed a review of studies which examined the transfer of spatial knowledge from virtual to real environments. The authors documented that a number of studies in this area had revealed that the properties of spatial representations were globally the same in virtual and real environments and that transfer of skill and/or spatial knowledge occurred to a partial or large extent. Peruch, Belingard and Thinus-Blanc (2000) then performed their own study using a non-immersive virtual environment in order to evaluate to what extent virtual training could compare to real training. Two groups of participants were used in the study, one group was allowed to explore a virtual representation of a university campus, while the second group explored the real world equivalent, after which both groups were tested in the virtual and real environments consecutively. The results obtained demonstrated that the transfer of spatial knowledge from a virtual to a real environment was possible to a certain extent:

It appears that training in a pure visual mode (using a desk-top system) may be sufficient to acquire a coherent mental representation. Moreover, this representation is less well elaborated but may be as performant as the representation that may be

acquired in the real environment. It is likely that a representation coming from a virtual experience may benefit from real-world experience. In other words, spatial knowledge acquired in a virtual environment (on a pure visual basis) could be used optimally in real conditions (that is, in situations more natural and rich with respect to the variety of available information). (p. 262)

A study by Waller, Hunt and Knapp (1998) examined training in six different environments (no training, real world, map, VE desktop, VE immersive, and VE long immersive) and then asked participants to apply route and configurational (survey) knowledge in a real world maze environment. The study demonstrated that training in a virtual environment allowed people to develop useful representations of a large scale navigable space. Waller, Hunt and Knapp (1998) found that short periods of virtual environment training were no more effective than map training, but virtual environment training eventually surpassed real world training with sufficient exposure to the training environment.

Identifying the distinguishing characteristics of 3D learning environments and their contributions to spatial learning was the focus of a study by Delgarno (2004). The study used versions of a 3D environment modelled on a chemistry lab to test the assertion that the smooth display of view changes, smooth display of object motion, user control of view position and direction and object manipulation characteristics of 3D environments contributed to spatial learning. Results indicated that smooth display of view changes were found to contribute to spatial learning in some but not all circumstances, and that user control over view position and direction contributed to spatial learning only when the task carried out in the environment was closely aligned with the desired learning outcomes. Delgarno (2004) concluded that the environment allowed tasks to be performed that directly aligned with the desired learning outcomes.

Finally, Conroy (2001) provides an excellent discussion of a number of studies that explored spatial knowledge acquisition in virtual environments. She examined studies by Goldin and Thorndyke (1982) and Witmer, Bailey, Knerr, and Parsons (1996) that concluded that simulation environments could act as adequate substitutes for real-world spatial knowledge learning. Conroy also documented a number of studies that argued that navigation and the spatial knowledge acquired in real and virtual worlds was comparable (Darken and Sibert, 1993; Ruddle, Payne, Jones, 1998; Tlauka and Wilson, 1996).

2.2.3 Summary

In summary, the formation of cognitive maps is a process by which the spatial information of an environment is internalized as a mental representation, the structure and formation of which is debated amongst scholars. The spatial information of an environment is acquired via the visual, tactile, olfactory, and kinaesthetic sensory modalities, the quality and legibility of which is an important factor in the formation of spatial representations. The ability to move freely throughout the environment is fundamental to the spatial cognition process and the subsequent formation of cognitive maps.

There is a significant body of literature that supports the contention that 3D environments can foster the development of spatial knowledge in a manner consistent with real world environments. Furthermore, there is also evidence to suggest that spatial knowledge obtained within a 3D environment can be transferred to a real world environment, making them suitable environments for training purposes.

The key aspects of spatial cognition can be represented diagrammatically as follows:



Spatial Cognition

Figure 1: Diagrammatic representation of the key aspects of spatial cognition.

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The criteria for evaluating these key aspects can be derived accordingly:

Aspect	Criterion for evaluation
Movement within the environment	Degree of movement permitted within the environment
Legibility of the environment	Ease with which elements within the environment are recognized
Quality of spatial information	Level of distortion between virtual environment and real environment
	Quality of locational and attributional information of phenomena within the environment

Table 1: Criteria for evaluating the key aspects of spatial cognition.

2.3 Learning with 3D Simulation Environments

Having established the manner in which spatial knowledge is constructed, it is now pertinent to explore the manner in which this information can be transferred from a simulation environment to a real world environment.

A simulation exists in order for knowledge learned in the simulation environment to be transferred to the real world system (Towne, 1995). Representing the system and it's underlying behaviour serves to facilitate this objective, with the assumption being that a faithful representation will encourage knowledge transfer between the simulation environment and the real world system (see Section 2.4.1 for a more detailed examination of the nature and function of simulation environments). Alexander, Brunye, Sidman, and Weil (2005) measure the success of a simulation based on this degree of knowledge transfer and note that "simulator training is only valuable if skills addressed and improved in the virtual environment are required in the operational environment" (p. 2). It is the contention of this research that computer-generated 3D simulation environments are suitable for representing real world environments for the purpose of transferring spatial knowledge obtained within the virtual environment and as such, it is necessary to examine how these environments facilitate the transfer of knowledge to the real world systems they represent. A number of scholars (Delgarno, Hedberg, & Harper, 2002; Withers, 2005) contend that 3D environments exhibit the potential to transfer knowledge obtained within the virtual environment to similar real world environments via the concept of situated learning.

2.3.1 Situated Cognition

The concept of situated learning draws from Brown, Collins and Duguid's (1989) theory of

situated cognition, which argues that knowledge is situated within the activity, context and culture in which it is developed and used. Keh, Chang, Lin and Hsu (2005) write that situated learning is a contextual learning that takes place in problem solving environments that are authentic rather than decontextualized. In support of this, Dobson, Pengelly, Sime, Albaladejo, Garcia, Gonzales and Maseda (2001) state that for the development of performative expertise, learning is best achieved, has greater chance of application, and is most likely to transfer when situated amongst that which shares the operational goal to which the learning is aimed. Thus it can be surmised that learning transfer is most effective between environments that share a common activity, operation or learning goal, and are similarly related in terms of context and culture. Based on this reasoning, a 3D simulation environment seeking to facilitate the transfer of spatial knowledge should employ activities or operations consistent with those within the real world environment it is representing. Dobson et. al. (2001) expounds on this idea, stating that "when learning is situated within a community of practice the development of knowledge and of competence to perform well at an enterprise are manifestations of the active interplay between experience and ability" (p. 548). This is further reinforced by Brown, Collins and Duguid (1989) who argue that activities and situations are integral to cognition and learning, and that learning should be embedded in activity to make deliberate use of the social and physical context of the environment. Keh, Chang, Lin and Hsu (2005) conclude that situated learning seeks to build a contextual, real-life and high interactive practice environment, noting that "this kind of learning environment can clearly build a simulated real-life situation learning environment" (p. 66).

2.3.2 Learning with Simulations

The idea of learning being dependent on the negotiation of meaning through practice (Dobson et. al, 2001) is consistent with the ideas set forth in simulation based learning theory regarding the importance of setting tasks or objectives as part of the learning process. In support of this, Withers (2005) argues that learners cannot be completely self-directed in their pursuit of the learning objective, and require scaffolding. Tait (1994) also states that learners generally require support in generating and testing hypotheses which can be achieved via the provision of appropriate learning tasks.

Clearly, there is a need for some type of instructional framework or support within a simulation environment in order for it to fulfil an instructive role in a satisfactory manner (Van Rosmalen, 1994; Tait, 1994; Withers, 2005). This can take the form of an explicit procedural assignment that sets out the learning objectives and questions to be resolved, whereby the students conduct experiments on the simulation to answer questions (Njoo and De Jong, 1993). Jonassen, Howland, Moore and Marra (2003) argue that it is the nature of this task that best determines the

nature of the learning the user will complete, and that in order for users to learn meaningfully, they must be wilfully engaged in a meaningful task. This is consistent with Alexander, Brunye, Sidman, and Weil's (2005) earlier comment on the need for skills addressed in the simulation environment to be required in the real world environment in order for the simulation to be successful. Delgarno (2004) also supports this contention in arguing the advantages of 3D learning environments in opposition to other forms of multimedia:

The advantages of such environments over video depends on the degree to which the environments allow tasks to be performed that directly align with the desired learning outcomes. If such tasks can be identified then learning advantages can occur, but only if learners are explicitly advised to undertake these tasks either through guidance provided within the environment or as part of supporting materials. The free learning exploration of a 3D environment with no explicit task advice is unlikely to lead to learning advantages over video or interactive multimedia. (p. ix)

Thus, the nature of the assignment must have some relevance not only to the real world system, but also to the learning objective in order to be successful. For example, a 3D simulation environment of a university campus might require the user to locate a list of classes on the virtual campus consistent with their daily timetable in order to increase their spatial awareness of the real world campus environment.

Withers (2005) and Van Rosmalen (1994) argue that this instructional support framework needs to be interwoven into the simulation environment itself, such that the interface has two functions; allowing the learner to operate the simulation and helping the learner to learn from using the simulation. Sweller, Van Merrienboer, and Paas (1998) present a similar argument, suggesting that the integration of instructional information reduces the demand on working memory and consequently, cognitive load. Some of the technologies used to construct 3D simulation environments are well equipped to handle these requirements. The scripting languages inherent in most 3D First Person Shooter (FPS) game engines, for example, allow for a set of objectives to be outlined, user performance responded to and measured, and feedback provided, all within the simulation environment (see Section 2.4.3 for a detailed discussion on 3D FPS game engine technology).

2.3.3 Constructivism

Situated learning and the provision of assignments or tasks as a form of instructional support rely on the ability of simulation environments to foster the development of learning via direct

action within the instructional environment. This learning structure encourages active participation by the learner within the simulation environment, with an emphasis on *doing* rather than *collecting* and *processing* information (Withers, 2005). This experiential type of learning is one of the prominent features of constructivist learning theory, the key assumptions of which are outlined by Merrill (1991) as follows:

- knowledge is constructed from experience;
- learning is a personal interpretation of the world;
- learning is an active process in which meaning is developed on the basis of experience;
- conceptual growth comes from the negotiation of meaning, the sharing of multiple; perspectives and the changing of our internal representations through collaborative learning; and
- learning should be situated in realistic settings; testing should be integrated with the task and not a separate activity.

Examining Merrill's assumptions, it is evident that constructivism shares some characteristics in common with situated learning and assignment based instructional support within simulation environments. Situated learning and the concept of negotiated meaning are key in both constructivist and situated cognition theories. Integrated testing is a common facet of constructivism and assignment based instructional support. These commonalities would suggest that constructivism makes for an appropriate learning theory with regard to virtual environments.

The experiential learning method in constructivism is also consistent with the exploratory nature of 3D simulation environments (De Jong, Van Joolingen, Swaak, Veermans, Limbach, King, & Gureghian, 1998; Winn, 1993). Mantovani (2001) writes:

The attraction that constructivists have for Virtual Reality is that VR provides the perfect tool or technology to apply their theories in the "real world". The attraction that VR supporters have for constructivism is that it provides a philosophical foundation for their activities (p. 210).

Delgarno (2004), citing Rieber (1992), concurs, suggesting that simulation environments are popular with constructivists for two reasons: (1) they provide a realistic context in which learners can explore and experiment, allowing the learner to construct their own mental model of the environment, and (2) the inherent interactivity allows learners to see immediate results as they create models or try out their theories about the concepts modelled. Within the field of constructivism, there are different opinions as to the nature of knowledge and the manner in which it is constructed. The degree of explicit instruction and the degree of social interaction that is necessary depends on the learning domain, specific learning outcomes, and the individual characteristics of the learner (Delgarno, 2004). Realising this, Moshman (1982) identified three different interpretations of constructivism: exogenous constructivism, endogenous constructivism and dialectical constructivism. Delgarno (2004), citing Moshman (1982), describes these accordingly:

- Exogenous constructivism is the view that formal instruction, in conjunction with exercises requiring learners to be cognitively active, can help learners to form representations which they can later apply to realistic tasks.
- Endogenous constructivism emphasizes the individual nature of each learner's knowledge construction process, and suggests that the role of the teacher should be to act as a facilitator in providing experiences which are likely to result in challenges to learner's existing models.
- Dialectical constructivism is the view that learning occurs through realistic experience, but that learners require 'scaffolding' provided by teachers or experts as well as collaboration with peers.

At first glance, the exogenous interpretation of constructivism would seem most appropriate to the research at hand, though the elements of dialectical constructivism relating to realistic experience and scaffolding also seem appropriate. Applefield, Huber and Moallem (2000) offer some clarification, stating that in exogenous constructivism, there is an external reality that is reconstructed as knowledge is formed, while dialectical constructivism views the origin of knowledge construction as being a result of the social intersection of people. Doolittle (1998) suggests that knowledge in exogenous constructivism learning is the process of building accurate internal models or representations of external structures in the real world, while dialectical constructivism defines learning as the process of building representations of external structures in light of the individual's beliefs, culture, prior experiences and social interactions.

Being that this research is concerned with constructing cognitive spatial maps of real world places via experience within a corresponding simulation model, it would seem that the exogenous interpretation of constructivism is the most appropriate learning theory to adhere to. Delgarno (2004) acknowledges this selection, noting that 3D environments with integrated instructional support are consistent with applications of exogenous constructivist theory. This can be further justified by noting the consistencies between the exogenous interpretation of constructivism, integrated assessment instructional support and situated learning. Based on these consistencies, it can be surmised that there is a need for learning to be situated in a a

simulation environment that accurately reflects the real world environment it models, while also containing integrated and context-specific instructional support.

2.3.4 Summary

It has been demonstrated that the theories of situated cognition and exogenous constructivism rely on a simulation environment that is contextually similar to the real world environment it represents. This reinforces the need for the realistic and authentic representation of real world spaces that 3D environments can provide. Furthermore, by utilizing 3D FPS game engine technologies, instructional support can be embedded into the simulation environment via the provision of inbuilt scripting languages, which allows for behavioural responses to user actions by the virtual environment to be catered for.

The key aspects of learning within a simulation environment can be represented diagrammatically as follows:



Learning Within a Simulation Environment

Figure 2: Diagrammatic representation of the key aspects of simulation based learning.

The criteria for evaluating these key aspects can be derived accordingly:

Aspect	Criterion for evaluation
Authenticity of simulation environment	Degree of similarity between simulation environment and real world environment in terms of context and culture
Situated tasks	Extent to which set tasks are situated relative to tasks within the real world environment
Integrated instructional support	Degree to which instructional support is integrated into the environment

Table 2: Criteria for evaluating key aspects of learning within a simulation environment.

2.4 3D Environments

Having ascertained the manner in which learning is conducted in computer-generated simulation environments, and that the theory of situated cognition allows for knowledge to be transferred between environments that are contextually similar, an examination of 3D environments and their ability to represent real world spaces is now required. This examination is conducted in light of the nature and function of simulations and a comparison of the characteristics of various 3D environment technologies to real world environments.

2.4.1 3D Environments as Simulations

From an instructional perspective, a simulation can be used to model any real or conceptual system in order to facilitate a learning objective (Mason & Rennie, 2006). Simulations can be used to represent a range of different scenarios, from a highly detailed, microscopic view of a small part of a system, to a broad macroscopic view of a system as a whole. A system may also be represented by a simulation in any number of ways, from a simple text based model to a fully immersive virtual reality environment. Regardless of the manner in which a simulation models a system, the goal remains the same: to represent system behaviour and respond to user actions such that knowledge learned in the simulation environment can be transferred to the real system (Towne, 1995).

With this in mind, it becomes important to determine the type of simulation environment to employ that can effectively represent the behaviour of the system and respond to user actions in regard to the knowledge that needs to be transferred. As this research is concerned with transferring spatial knowledge of a simulation environment to a corresponding real world environment, it is necessary that the type of simulation employed be able to model the behaviour and faithfully mimic the reactions of the real world three dimensional space (Di Carlo, 2003). It is the contention of this research that a 3D environment is an appropriate choice

for this task.

This contention can be justified by examining the individual components of a simulation with regard to 3D environments. Towne (1995) suggests that a simulation consists of two components: (1) a perceptible and operable representation of the real system, and (2) an underlying system model that expresses the way in which the representation reacts to action upon it (p. xxv). This is consistent with Williams' (2003) measure of a simulation environment in terms of it's physical and functional fidelity. Thus, we can determine the effectiveness of a 3D environment to simulate a real world space in accordance with the authenticity of the interface and underlying behavioural model.

The degree of fidelity required to perceivably represent a system is dependent on whether the representation needs to be highly realistic, and reflect the characteristics and properties of the real system with great accuracy, or merely at a level that suggests what happens in the real world (Towne, 1995; Wilson, 1997). Not all simulations are required to be high fidelity environments, and the level of fidelity required should be determined in reference to the desired learning outcome and the environment that is being modelled (Alexander, Brunye, Sidman, & Weil, 2005). In virtual environments, there is an increased reliance on the visual senses to provide information due to the fact that many other sensory cues are not present (Wilson, 1997), and this is especially true for desktop environments. Spatial knowledge and learning however, is formed from the combined interpretation of the visual, tactile, olfactory, and kinaesthetic sensory modalities, which is a complementary process (Downs & Stea, 1973). It is therefore logical to assume that the visual information presented by a 3D environment should be of as high a quality as possible to compensate for the lack of tactile, olfactory, and kinaesthetic information provided. Visually, the 3D environment should provide a detailed, accurate and realistic representation of the real world space it models in order to provide as much spatial information via the sensory modalities as possible.

Malhorta (2002) notes that the simulation of lighting conditions is one of the key aspects in creating a visually realistic representation of a real world environment. This is facilitated in 3D environments via the application of global (view-independent) and local (view-dependent) illumination methods which can be used to accurately recreate lighting conditions within a real world space. Shadows are also used within 3D environments to enhance realism, and are especially significant with regard to spatial awareness as they provide depth and perspective cues (Malhorta, 2002).

The ability to texture models and other geometric shapes also allows 3D environments to enhance the sense of visual realism with respect to the real world system being modelled. A
study performed by Peruch, Belingard & Thinus-Blanc (2000) demonstrated that spatial learning was affected by the amount and/or quality of information available in a virtual environment. They compared performance in a 3D virtual environment using textured and untextured geometric solids. Results showed that direction and travel distance errors were smaller in the environments that featured textured geometric shapes.

Research (Delgarno, 2004; Delgarno and Hedberg, 2001, Ptoska, 1995) suggests that the potential for realism inherent in 3D environments can establish a greater sense of presence and immersion, which in turn can facilitate a greater transfer of knowledge. Sadowski and Stanney (2002) elaborate on the relationship between realism and immersion, noting that the potential for realism in 3D environments serves to focus the user's attention within the virtual environment, enhancing involvement and thereby increasing presence. Schmidt and Young (1987) also support the connection between realism, immersion and knowledge transfer, but contend that positive learning transfer from the virtual world to the real world is possible only when similar stimuli and responses are available within the virtual environment. This concept of learning transfer being reliant on the relevance and authenticity of the stimuli and response of the simulation environment is consistent with Williams' (2003) measure of a simulation environment in terms of it's physical and functional fidelity.

Having acknowledged the potential of 3D environments to represent real world spaces on a perceptible level, it is now necessary to assess 3D environments in terms of their ability to operate and behave consistent with real world space. Examining Williams' (2003) descriptions of physical and functional fidelity, we see that this includes the manipulation and feedback of the interface, as well as the modelling of behavioural responses within the virtual environment.

For any given simulation, the behaviours modelled within the virtual environment must be contingent on the particular outcomes and goals in mind, as it is infeasible and inefficient to model all possible outcomes and scenarios within a simulation environment (Wilson, 1997). This research is interested in the transfer of spatial knowledge from a simulated environment to a real world system, and not the inner workings or interplay of objects within the real world system. Thus, the simulation environment need only model the physical properties of the real world environment itself, together with behaviour consistent with the manner in which an individual would move through the real world environment. To determine the validity of 3D environments to model a real world system in this manner, it is first necessary to determine the main characteristics of 3D environments, which Delgarno and Hedberg (2001) provide as follows:

- An environment modelled using 3D vector geometry, meaning that objects are represented using x, y and z co-ordinates, describing their shape and position in 3D space.
- Dynamic rendering of the user's view of the environment depending on their position in 3D space.
- Dynamic rendering of the user's view as the user moves freely through the environment.
- A minimum degree of interaction with some of the objects within the environment, in that they respond to user action (e.g. a button, door etc.).

Examining these characteristics, it is evident that 3D environments share characteristics in common with real world three dimensional spaces. Both environments use three dimensional Euclidean geometry to describe the objects within them, and as such, 3D environments can be used to construct scale representations of real world spaces, given appropriate plans or schematics. As such, dimensions, perspective and relative distances between objects within the virtual environment can be consistent with those in the real world. The formation of spatial representations of environments relies in part on information pertaining to the distance and direction of objects (see Section 2.4.1), thus a scale virtual representation will provide a more useful spatial representation to the real world environment. However, the extent to which this information can be applied in the real world environment can be constrained by the fact that the user is viewing a three dimensional environment on a two dimensional viewing plane, such as the screens embedded in a head-mounted-display, or a desktop monitor.

The dynamic rendering characteristics of 3D environments provide immediate visual feedback to the user and, combined with the 3D vector geometry environment model, create the illusion of free movement within the virtual environment. This is achieved via the rotation and translation of the user's viewpoint within the 3D model in accordance with the manipulation of the mouse, keyboard or joystick in a non-immersive, desktop 3D environment, or head-mounted-display, data gloves or other sensory devices within an immersive, virtual reality environment. This ability allows users to freely look and move throughout a 3D virtual environment in a manner consistent with a three dimensional real world space.

The degree of interaction with objects required within the environment is typically dependent on the learning outcome and the real world environment being modelled (Jonassen, Howland, Moore, & Marra, 2003). In typical 3D environments, the user is able to interact with the environment simply by looking around or moving within it with the display updating accordingly. With regard to spatial learning, the only interactivity required in addition to this is the inclusion of objects that facilitate or restrict movement throughout the environment, such as doors, ladders or lifts. These can be modelled to scale specification as required and need only exhibit behaviour that suggests what happens in the real world environment.

2.4.2 Immersive and Non-immersive 3D Environments

Having ascertained the potential of 3D environments to simulate real world spaces, it next becomes necessary to determine the type of 3D environment to employ for this purpose. Different types of 3D environments exhibit attributes important to the simulation of real world spaces to varying extents at different costs and with varying levels of flexibility (Wilson, 1997), all of which are largely dependent on the technology used. Thus, 3D environments are broadly categorized according to the type of technology used in their construction as either immersive or non-immersive environments.

Brooks, McNeil, Rose, Greenwood, Attree & Leadbetter (1999) characterize immersive environments as those that use head-mounted helmets, data gloves and body suits to present visual, auditory and tactile sensations of the computer-generated environment. Conversely, Brooks et. al. (1999) characterize non-immersive 3D environments as those that rely on mouse, keyboards and joysticks as control devices, with visual and auditory aspects of the computergenerated environment presented via computer monitors or projectors. It is worth noting that some 3D environments fall between these two categories. The Fish Tank VR project (Ware, Arthur & Booth, 1993), for example, employed passive head tracking sensors similar to those seen in immersive environments, but utilized a standard desktop monitor for display purposes.

In order to decide between an immersive or non-immersive 3D environment, it is necessary to evaluate the abilities of each with regard to the overall objective (Peruch, Belingard, & Thunis-Blanc, 2000). Wilson (1997) describes this process as a number of explicit design decisions and concessions where the characteristics of the system are constrained by available finances and technical limitations. Thus, the decision between utilizing an immersive or non-immersive environment for the purposes of spatial learning can be made on a financial and technical basis.

One of the common complaints levelled at immersive systems relate to their expense (Taxen & Naeve, 2001; Lewis & Jacobson, 2002), which Whitton (2003) attributes to the absence of a high-volume market or any incentive for cost reduction for hardware such as head-mounted-displays and data gloves. Non-immersive based systems in comparison, are much more cost effective, making them accessible to more than just the military, universities and other institutions with significant financial resources. As commercial graphics cards have become increasingly more powerful, common desktop computers have become more capable of adequately supporting an increased number of 3D simulation applications (Lisle & Sartor, 1997). A number of studies have shown that low-cost pc orientated virtual environments have

performed equally as well as immersive environments many times more expensive (Tam, Maurel, Desbiens, Marceau, Malowany & Granger, 1998; Jansen-Osmann, 2002).

While it is generally accepted that non-immersive environments offer significant cost advantages over immersive environments, the technical capabilities of each system provide more grounds for debate when deciding which type of environment to employ. Numerous studies (Whitton, 2003; Cambell & Wells, 1994) have shown that the head-mounted-displays used in immersive 3D environments provide a greater sense of presence and immersion than computer monitors or projectors, owing to user view restriction, stereoscopic imaging and head tracking abilities. (Delgarno, 2004). However, it is worth noting that a number of researchers have made a distinction between physical (or objectively measurable) and psychological (or subjectively reported) immersion (Delgarno, 2004). It can be argued that while non-immersive environments lack the potential for physical immersion exhibited by immersive environments, they do exhibit potential for psychological immersion (Robertson, Card, & Mackinlay, 1993).

Robertson, Czerwinski and Van Dantzich (1997) further note that non-immersive virtual environments lack the peripheral vision afforded by head-mounted displays in immersive environments, which can result in users being unaware of their surroundings or location within the virtual space, however Campbell & Wells (1994) contend that this is advantageous as it allows for quicker manipulation of the viewpoint and ease of movement. Robertson, Czerwinski & Van Dantzich (1997) point out that head-mounted-displays can suffer from poor display resolution, display jitter and lag between head movement and display response, which are not problems seen in non-immersive alternatives which typically exhibit higher resolution and frame rates (Cambell & Wells, 1994).

Non-immersive environments can also suffer from a lack of natural or intuitive interaction metaphors within the virtual environment. Marshall & Nichols (2004) attribute this to the need for a combination of interfaces, a physical interface for control devices, such as mice or keyboards, and the virtual interface, usually comprising of a screen overlay, toolbar or prompts embedded within the virtual environment. Immersive environments on the other hand allow the user to utilise hardware that presents a potentially more intuitive control interface to that of a mouse or keyboard, and thus the possibility for more natural interaction metaphors. Tate & Sibert (1997) conducted a study using a "fly where you point" metaphor, whereby the user was able to point where they wanted to move to while still being able to look freely within the environment. Similarly, Mavrikios, Karabatsou, Fragos & Chryssolouris (2006) expound the benefits of using the more natural control interfaces available in immersive environments for complex manual tasks in their study which simulated welding processes inside a virtual environment. The control interfaces of non-immersive environments do offer some advantages

however, as they take advantage of users previous experience with desktop computers and their peripherals (Marshall & Nichols, 2004; Robertson, Card & MacKinlay, 1993).

With regard to spatial learning, opinion is divided as to whether immersive or non-immersive environments are better suited to this task. Several studies conclude that both immersive and non-immersive environments enhance spatial awareness and understanding, but there is no clear and quantifiable advantage in using one over the other (Schnabel & Kvan, 2003; Patrick, Cosgrove, Slavkovic, Rode, Veratti, & Chiselko, 2000). Other research contends that immersive environments hold the advantage under certain conditions, with research by Mizell, Jones, Slater and Spanlang (2000) indicating that immersive environments have an advantage over non-immersive environments when the displayed object or environment surrounds the subject. Rosebrock and Vamplew (1999) conclude in their study on spatial knowledge in immersive and non-immersive environments that body movement within immersive environments sufficiently stimulates the spatial senses to enhance spatial knowledge, without requiring a simulated walking action. Alternatively, there is some evidence to suggest non-immersive 3D environments are better suited to spatial learning than their immersive counterparts. A study by Henry and Furness (1993) compared estimated room dimensions and object orientation judgements between real, immersive and non-immersive environments. Their results showed that immersive environment users underestimated the size of environments, which they attributed to the limited field of view and distortion around the edges of head-mounted-displays.

It can be argued that immersive environments offer significant advantages in terms of control, presence and immersion, but there is evidence to suggest that this may come at the cost of possible ergonomic issues, such as cyber sickness and other mental and physical side effects (Stanney, Kennedy & Kindon, 2002; Wilson, 1997; Robertson). Non-immersive 3D environments can be seen to be significantly more cost-effective, and there is evidence that suggests a potential for psychological immersion and capability as facilitators of spatial learning, although the effectiveness of this in comparison to immersive environments is not completely clear. Further study is needed in order to provide more definite answers as to which type of environment is superior on a technical basis. However, for the purpose of this research, non-immersive 3D environments will be focussed on due to the ability to utilize existing gaming technology to create three dimensional simulation environments.

2.4.3 Gaming Technologies

Computer games share the same technological parentage as military simulations, though the development of each industry has been remarkably different (Herz & Macedonia, 2002). Although early game development lagged behind that of it's military sibling due to a lack of

financial and institutional support, the gaming industry has nonetheless thrived, with modern estimates of revenue exceeding those of the Hollywood box office (Branch, LaBarre, Szabo, 2006; Snider, 2003). The growth in popularity in games and gaming culture has fuelled an unparalleled period of technological development, where computer games have expropriated the best in hardware and software for themselves, resulting in the most sophisticated, responsive and interactive simulations being built by the engines used to power games (Lewis & Jacobson, 2002). Commercial gaming technology has now superseded military simulation technology (Herz & Macedonia, 2002) to the point where it is now being directly employed in fields such as military applications (Manojlovich, Prasithsangaree, Hughes, Chen, & Lewis, 2003; Bonk & Dennen, 2005; Carpenter & White, n.d.), architecture (Kemp, Kider, & Nazarian, 1998; Malhorta, 2002), scientific research (Lewis & Jacobson, 2002), and simulation and training environments (Tarr, Morris, & Singer, 2003; Wang, Lewis, & Gennari, 2003).

The use of gaming technology in such a wide variety of applications was driven in large part by the development of the game engine; a modular, general purpose component of code which allowed content and functionality to be separated, and thus adapted to a range of different purposes (Lewis & Jacobson, 2002). Game engines consist of a collection of modules of simulation code responsible for the input and output of 3D rendering, 2D drawing, and sound, as well as generic physics and dynamics for the game world (Lewis & Jacobson, 2002). They are abstracted from game logic and level data modules, and are capable of working with different asset libraries (sets of models, textures and sounds), allowing developers great flexibility. Furthermore, game engines remove the need for intimate programming knowledge of 3D graphics APIs such as OpenGL and Direct3D and are usually bundled with development tools, software development kits and scripting languages (Dupire, Topol, & Cubaud, 2005; Herz & Macedonia, 2002), greatly simplifying the development process. 3D First Person Shooter (FPS) game engines in particular, have exhibited the most development in terms of visual quality (Gernmanchis, Cartwright and Pettit, 2005), and are subsequently of most significance to this research.

With regard to simulating real world three dimensional spaces realistically, one of the most significant aspects of the game engine is the rendering module (often referred to as the rendering engine). Lewis and Jacobson identify this as the "crown jewel" (2002, p. 29) which incorporates all of the complex code needed to efficiently identify and render the user's view from a complex 3D environment model. This code is heavily optimized and refined to deliver an acceptable minimum number of frames per second, with Farrell, Arnold, Pettifer, Adams, Graham, & MacManamon (2003) and Delgarno, Hedberg, & Harper (2002) maintaining that anything over fifteen frames per second is acceptable, while Malhorta (2002) suggests that a smooth and interactive frame rate requires twenty frames per second. Dupire, Topol and Cubaud

(2005) argue the importance of frame rates as a visual heuristic within 3D environments, where insufficient frame rates discourage discovery and investigation of the environment. Slater, Linakis, Usoh and Kooper (1996) also suggest that insufficient frame rates reduce immersion, but note that creating a more realistic, and therefore, immersive environment usually requires increased load on the rendering hardware in the form of greater environmental quality and detail. Clearly, in the realistic simulation of 3D environments, there is a need for high levels of visual detail to be presented at an acceptable frame rate. 3D FPS game engines are particularly well suited to this task as they are designed to handle the high visual and performance demands placed upon them by gamers.

The suitability of 3D FPS game engines to realistically represent real world spaces can be further demonstrated by examining other applications of the technology outside of gaming. In their study on geospatial virtual environments, Gernmanchis, Cartwright and Pettit (2005) implemented the FarCry game engine in order to model a virtual representation of a large-scale urban environment. A 3D FPS game engine was selected because it offered a "more interactive, realistic and hence a more engaging environment" (Germanchis, Cartwright, & Pettit, 2005, p. 1). Alternatively, Shiratuddin and Thabet (2002) used the Unreal Tournament game engine to create an office walk through for visualizing construction projects. Examining both Gernmanchis, Cartwright and Pettit (2005), and Shiratuddin and Thabet (2002), we can determine a set of characteristics of 3D FPS game engines that facilitate the modelling of a virtual representation of a real world environment:

- Ability to model a true 3D environment, including objects, architecture and landscape.
- Allows the user real-time movement around the virtual environment. Collision detection within the environment is built in.
- Allows the user to interact with the model, facilitated by the immediacy of the system to respond to user actions at a realistic frame rate.
- Offers powerful graphics quality without diminishing performance to an unsatisfactory level.
- Realistic environment visualization achieved via photo-realistic texturing, real-time dynamic lighting, shadows, real-time reflective and mirrored surfaces, colours and shade variances.

Evidently, 3D FPS game engines are more than capable of delivering a high fidelity, realistic representation of a real world environment on an inexpensive desktop computer system. Users are able to move freely throughout the virtual environment and interact with the environment itself and the objects within it, the behaviours and presence of which can be specified using the accompanying development tools. These characteristics, combined with the comparatively low-

cost and over the counter availability, make 3D FPS game engines an ideal application for developing 3D simulation environments on a standard desktop system.

2.4.4 Summary

It has been argued that 3D environments based on FPS game engines are a valid means for simulating real world environments based on their ability to represent three dimensional spaces at a high visual quality while maintaining a frame rate that allows the user fluid control of the virtual environment. The high visual fidelity inherent in environments constructed using FPS game engines has the potential to enhance realism and facilitate a sense of presence and immersion within the virtual environment. Furthermore, it is generally well accepted that both immersive and non-immersive 3D environments exhibit the potential to enhance spatial awareness and understanding of a virtual environment.

The key aspects of non-immersive FPS 3D environments can be represented diagrammatically as follows:



3D Environments

Figure 3: Diagrammatic representation of the key aspects of 3D environments.

The criteria for evaluating these key aspects can be derived accordingly:

Aspect	Criterion for evaluation
Three dimensional representation	Ability to which the environment can model objects, architecture and landscape in three dimensions
High visual fidelity	Quality of textures, lighting, shadows and reflections
Immediate system response	Frame rate equal to, or exceeding, twenty frames a second
User control	Real time movement and interaction within the simulation environment
	Quality of collision detection

Table 3: Criteria for evaluating key aspects of 3D FPS simulation environments.

2.5 Contributing Factors to Spatial Learning within a 3D Simulation Environment

Having discussed the nature and function of spatial cognition, the manner in which learning occurs within simulation environments, and the technical aspects of 3D simulation environments it is now possible to identify a set of criteria that contribute to enhancing spatial awareness of real world environments.

Enhancing spatial awareness of a real world environment using a virtual representation relies on the formation of a cognitive map that can be transferred and used within the real world environment. The effectiveness of this process is contingent on the accuracy of the cognitive map that is formed relative to the real world environment and the extent to which the spatial knowledge acquired in the virtual environment is transferred. It is therefore necessary to provide as accurate a simulation of the real world environment as possible, both physically and functionally, in order to minimise the disparity between the cognitive map formed in the virtual environment, and one that would be formed in the real world environment. This is consistent with the theory of situated cognition that suggests that learning is situated, and that transfer is possible between environments that are similar in context, culture and operation.

Because non-immersive 3D environments rely predominantly on the provision of visual information, there is a need for high visual fidelity in the simulation environment in order to faithfully represent the real world space realistically. The high visual fidelity inherent in non-immersive 3D environments, particularly those that utilize FPS game technologies, creates a potential for a realistic environmental depiction, increasing the sense of presence, immersion, and ultimately facilitating the transfer of knowledge. High visual fidelity is also necessary for the generation of cognitive maps that rely on high quality and legible representations from

which to extract spatial information about the environment.

The ability to look, move and interact freely in three dimensions while receiving immediate system feedback is also necessary in order to simulate a real world space at a functional level. In this manner, users can act directly within the virtual environment in much the same fashion as they would in a real world three dimensional space, facilitating experiential based learning consistent with situated cognition and constructivist learning theories. The formation of cognitive maps also relies on the ability to move within the environment while gathering spatial information in three dimensions.

Consistent with constructivist, situated cognition and simulation based learning theories, there is also a need for learning to be structured around a meaningful task that is contextually relevant to the real world environment and the knowledge that needs to be transferred. Behavioural responses of the system to user actions consistent with a simple task or assignment integrated into the simulation environment can be facilitated via the scripting languages included in FPS games.

Thus, it can be surmised that the following characteristics of non-immersive 3D simulation environments that utilize FPS game technology contribute to enhancing spatial knowledge of the real world environments they represent:

- User control, including the ability to look, move and interact freely throughout the environment.
- 3D representation, including the ability to model 3D objects and environments.
- High graphical fidelity, allowing the legible and realistic depiction of real world environments.
- Immediacy of feedback, whereby dynamic rendering provides the illusion of fluid motion.
- Integrated instructional support, whereby contextually relevant tasks or assignments can facilitate the transfer of knowledge to real world environments.

These characteristics can be seen as broad principles in regard to the transfer of spatial knowledge obtained with a 3D FPS simulation environment to the real world environment on which it is modelled. These broad principles form the relational core between spatial cognition, learning within simulation environments, and 3D environments. The combination of these principles with the key aspects of each of these concepts (as depicted by Figures 1, 2, and 3) can be represented diagrammatically as follows:

Spatial Cognition



Learning Within a Simulation Environment

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3D Environments

Figure 4: Interrelationship between spatial cognition, learning within simulation environments, and 3D environments, with broad principles common to all three concepts in the centre.

A complete set of criteria for evaluation can be derived from Tables 1, 2, and 3 accordingly:

Table 4: Criteria for evaluating primary principles of 3D environments for the transfer of spatial	
knowledge to real environments.	

Primary Principles	Criterion for evaluation
Three dimensional representation	Ability with which to determine locational information of phenomena within the environment (Spatial Cognition component)
	Degree to which three dimensional arrangement of elements relative to assigned tasks in the real world are preserved within the simulation environment (Simulation Learning component)
	Ability to which the environment can model objects, architecture and landscape in three dimensions (3D Environment component)
High visual fidelity	Ability with which to determine attributional information of phenomena within the environment (Spatial Cognition component)
	Degree to which resultant presence and immersion compel undertaking of assigned tasks (Simulation Learning component)
	Quality of textures, lighting, shadows and reflections (3D Environment component)
Immediacy of feedback	Extent to which system response supports free movement and control of viewing perspective within the environment (Spatial Cognition component)
	Extent to which system response supports the undertaking of assigned tasks (Simulation Learning component)
	Frame rate equal to, or exceeding, twenty frames a second (3D Environment component)
User control	Degree of movement and control of viewing perspective (Spatial Cognition component)
	Degree to which controls permit the execution of assigned tasks within the environment (Simulation Learning component)
	Quality of collision detection (3D Environment component)
Integrated instructional support	Degree to which spatial information pertaining to objectives related to assigned tasks can be recognized and recalled (Situated Cognition component)

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Degree to which instructional support is integrated into the environment (Simulation Learning component)
Degree to which the scripting language or developmental tools support the creation of appropriate assigned tasks within the environment (3D Environment component)

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 Table 5: Criteria for evaluating secondary principles of 3D environments for the transfer of spatial knowledge to real environments.

Secondary Principles	Criterion for evaluation
Authenticity of simulation environment	Accuracy with which the context and culture of the real world environment is depicted within the simulation environment (Simulation Learning component)
	Accuracy with which the simulation environment represents the real world environment at a physical and functional level (3D Environment component)
Situated tasks	Degree to which situated tasks enhance spatial knowledge of the environment (Situated Cognition component)
	Extent to which assigned tasks are situated relative to tasks within the real world environment (Simulation Learning component)
Legibility of the environment	Ease with which elements within the environment are recognized (Spatial Cognition component)
	Ability at which elements or objects relative to the assigned tasks can be identified and recognized (Simulation Learning component)
Quality of spatial information	Level of distortion between virtual environment and real environment (Spatial Cognition component)
	Quality and detail of textures and surfaces (3D Environment component)

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3.0 Methodology

3.1 Qualitative and quantitative methods

Before discussing the research design, sampling methods, and analysis techniques employed in the research undertaken as part of this paper, it is first necessary to clearly understand the distinction between qualitative and quantitative research methods. Babbie (1993) defines qualitative research as "the non-numerical examination and interpretation of observation for the purpose of discovering underlying meanings and patterns of relationships" (p. 537). In contrast, Babbie (1993) defines quantitative research as "the numerical representation and manipulation of observations for the purpose of describing and explaining the phenomena that those observations reflect" (p. 537). The difference between these two research approaches can thus be identified as a result of the different methods by which each approach defines problems, and in turn, searches for answers:

Qualitative methods lend themselves to discovering meanings and patterns while quantitative methods seek causes and relationships demonstrated statistically, a theoretical perspective, positivism, that is concerned with facts, prediction, and causation and the the subjective nature of the groups or individuals of interest. Researchers in the qualitative mode seek understanding through inductive analysis, moving from specific observation to the general. Quantitative analysis, on the other hand, employs deductive logic, moving from the general to the specific, i.e., from theory to experience. (Bloland, 1992, on-line)

Thus, it would seem that qualitative and quantitative approaches to research are diametrically opposed. However, adopting a research strategy that utilizes both approaches, which has been described as convergent methodology, or triangulation, can be beneficial (Jick, 1979). In summarizing the literature from proponents of triangulation, Fielding and Schreier (2001) write that "triangulation is possible because, if methods are systematically understood and rigorously used, points of connection can be identified such that both types of methods are addressing the same phenomenon" (on-line). Jick (1979) notes that triangulation exists as a vehicle for cross validation when two or more distinct methods that are used to examine the same dimension of a research problem are found to yield comparable data. This mixed method approach was adopted for the research conducted as part of this paper, although a more qualitative rather than quantitative method was employed.

3.2 Research design

The purpose of this research was to assess the effectiveness of 3D simulation environments based on FPS game engines as an instructional tool to facilitate spatial learning. This assessment was conducted with reference to the set of evaluation criteria derived in Section 2.5 of this document using a case study in conjunction with the Royal Australian Navy (RAN), Australian Submarine Corporation (ASC), and Challenger Tafe, based at the Submarine Training and Systems Centre at HMAS Stirling, Garden Island. The case study examined the LASTS (Location and Scenario Training System) 3D simulation environment developed by the Computer Modelling Group, Navy Platform Systems under the supervision of Training Authority Submarines. The LASTS environment is a non-immersive, desktop environment that utilizes the FPS Unreal Runtime game engine to simulate the Main Generator Room (MGR) of an RAN Collins class submarine.



Figure 5: MGR compartment of a Collins class submarine as depicted in LASTS.



Figure 6: An alternate view of the MGR compartment of a Collins class submarine as depicted in LASTS.

The LASTS environment was examined with reference to the evaluation criteria derived from the model using participants from the Submarine Training and Systems Centre (STSC) based at HMAS Stirling, Garden Island. The twenty-one participants used in the study were selected by STSC from trainee, existing, and ex-submariners within the RAN, as well as training staff from STSC. These participants were then formed into groups as follows:

- Nine participants composed of existing and ex-submariners who were already familiar with the layout of a Collins class submarine, including the MGR (designated Group A);
- Five participants composed of trainee submariners from the Enhanced Selection Process (ESP) program whose previous experience on-board a Collins class submarine was limited (designated Group B1);
- Another group of five trainee submariners from the Enhanced Selection Process (ESP) program whose previous experience on-board a Collins class submarine was limited (designated Group B2);

The previous experience of participants in Group B1 and Group B2 with the MGR of a Collins class submarine was assumed to be limited, given that all participants within these groups were trainee submariners who were not yet qualified. However, it was acknowledged that, given that the ESP submariner training program is voluntary, these trainee participants would most likely

have done some research prior to joining the program regarding life on-board a Collins class submarine and may have come into contact with information about the MGR environment. As such, it was assumed that all participants in Group B1 and Group B2 had some minimal familiarity with the MGR environment, either via a walk-through tour of the submarine or as a result of their own interest prior to joining the program.

In addition to the three groups of participants composed of trainee, existing, and exsubmariners, multimedia developer Andrew Widdis was also asked to participate in the study. Andrew had played a significant role in the development of the LASTS environment, and as such was requested to participate in order to provide a developer's perspective via interview (INT AW). Chief Petty officer Allistair Hogarth was also asked to participate in the study in order to evaluate the performance of participants in Group B1 and Group B2 in undertaking a simplified 12 Point Safety Round (12 PSR) exercise on-board HMAS Collins. The simplified 12 PSR was based on the RAN 12 Point Safety Round, a very specific safety process performed on board Collins class submarines. This simplified version of the 12 PSR required participants to locate a series of items relevant to the complete RAN 12 PSR within the MGR of HMAS Collins. Their performance was assessed by the CPO Allistair Hogarth in accordance with their ability to recognise items, the degree of confidence they exhibited in locating items, and their general knowledge of the MGR compartment. In addition to evaluating Group B1 and Group B2's performance of the simplified 12 PSR, CPO Allistair Hogarth was also asked to participate in an interview in order to ascertain his observations during the performance of the exercise (INT CPO).

3.3 Research Method

The simplified 12 PSR was used as a means by which to compare the spatial awareness of participants in Group B1 and Group B2 as a result of the different types of training each group of participants had received prior to commencing the exercise. Participants in Group B1 were sat at desks in a classroom at STSC and presented with an information booklet containing the names, printed diagrams, and colour photographs of each item included in the simplified 12 PSR, with each item presented on a separate page of the booklet. The printed diagrams consisted of a plan and cross-sectional view of the MGR which denoted the location of the item in question, with the plan diagram depicting the lower or upper deck of the MGR where appropriate. These participants were then informed by Andrew Widdis, (who was present along with this researcher and observing Naval officer Sub Lieutenant Ben Churcher during the training session), that they would be given fifteen minutes to familiarise themselves with the information provided in the training booklets, after which they would be taken down to HMAS Collins and asked to locate the same items in the MGR by CPO Allistair Hogarth. Participants

were also informed that CPO Allistair Hogarth would be assessing their ability to locate each item on a scale of 1 to 10, and that they were free to point out the location of any item at any time without being prompted to do so. At the conclusion of the fifteen minutes, participants were taken down to HMAS Collins and taken one at a time through the MGR by CPO Allistair Hogarth to complete the simplified 12 PSR exercise. CPO Allistair Hogarth scored each participants performance for each item on a separate piece of paper, which was handed to Andrew Widdis once the exercise was completed. At this point, participants were asked to complete a questionnaire, requiring them to provide a score between 0 and 10 in response to a series of questions (QU_B1), and then submit to an interview with this researcher (INT_B1).

Participants in Group B2 were required to undergo the same procedure as those in Group B1 with regards to the simplified 12 PSR exercise on HMAS Collins, subsequent questionnaire (QU B2), and interview (INT B2), but the training they received before the exercise was different. This group of participants were sat in the same classroom as those in Group B1 at desks with computers running the LASTS software environment in the presence of Andrew Widds, this researcher, and the same naval officer observer used for participants in Group B1. Participants were asked to open the map file detailing the virtual MGR in the LASTS environment, and once loaded, were given a five minute overview of the control schema by Andrew Widdis ('W', 'A', 'S', and 'D' keys on the keyboard for moving forwards, left, backwards, and right respectively, mouse for controlling the viewing perspective, and left mouse button over item included in the simplified 12 PSR exercise to display its name on screen). In addition to this demonstration, a reference piece of paper detailing the controls for the LASTS environment was also provided to participants in Group B2. Participants were then informed that they would be given a fifteen minute training session in the LASTS environment to familiarize themselves with the locations of a series of items, after which they would be taken down to HMAS Collins and asked to locate the same items in the MGR by CPO Allistair Hogarth. As with participants in Group B1, participants in Group B2 were also informed that CPO Allistair Hogarth would be assessing their ability to locate each item on a scale of 1 to 10, and that they were free to point out the location of any item at any time without being prompted to do so. Group B2 were also informed that they would be shown the location of the items included in the simplified 12 PSR exercise to be completed in the real world MGR via a walkthrough of the virtual MGR. To this end, Andrew then instructed the participants in Group B2 to follow him around the virtual MGR, using the wall projector at the front of the classroom which was connected to his computer to lead the way through the virtual environment. All participants were instructed to assemble at the same location, and face the same direction in the virtual MGR, before being led through by Andrew, who stopped at each item included in the simplified 12 PSR to state the name of the item and point it out to participants. Participants were also informed that they could click on these items included in the simplified 12 PSR with the left

mouse button to display the name of the item on the screen, but that this functionality was limited to the items included in the 12 PSR exercise only. Once the walk-through had been completed and all participants had returned to the position where the walk-through began, they were given the remaining ten minutes to freely explore the virtual MGR environment. After this time had expired, each participant in Group B2 was then taken aboard HMAS Collins and required to undertake the simplified 12 PSR, questionnaire, and interview in the same manner as Group B1.

The existing and ex-submariners participants in Group A were included in the study in order to evaluate the effectiveness of the LASTS environment in light of their extensive experience onboard Collins class submarines and their familiarity with the MGR. Participants were required to complete the walk-through exercise and freely explore the virtual MGR in the same manner as participants in Group B2. However, the LASTS training session involving participants in Group A was much more informal, with questionnaires and interviews conducted concurrently to the free exploration of the virtual MGR after the completion of the walk-through exercise. Two of the participants involved in this group had to leave prior to being interviewed, such that nine questionnaires were completed, but only seven interviews were conducted.

A number of minor issues occurred during the training sessions for Group B1 and Group B2, the results of which were not included in analysis. During the simplified 12 PSR exercise for participants in Group B1, it was discovered that the picture corresponding to the Halon bottles in the training booklet was actually the pilot air cylinder, resulting in a number of participants indicating the incorrect item. Any results pertaining to the Pilot Air Cylinder or Halon bottles were subsequently not included in analysis. Participants in Group B2 had a similar issue, whereby the location of the Main Generator Room Hatch was not demonstrated to participants during their training with LASTS. As such, these participants were not able to identify the MGR Hatch during the simplified 12 PSR, resulting in any results pertaining to the MGR Hatch being removed from analysis. As a result of these errors, the items that were included for analysis from the simplified 12 PSR exercise were the MGR Bilge Hatch, Aft Submerged Signal Ejector, Aft Submerged Signal Ejector Controller, Emergency Pyrotechnic Locker, and the items collectively designated as Fire Fighting Equipment, consisting of the Halon Release Box, Fire Extinguishers, OCCABA Stowage, and Fire Fighting Hose Reel.

A table can thus be constructed depicting the evaluation criteria, required data, and method by which it will be collected for both the primary and secondary principles of 3D environments that contribute to the transfer of spatial knowledge as presented in Section 2.5 of this document. Note that the number included in parentheses with reference to the collection method denotes the specific interview or questionnaire question used to collect the data for the given evaluation

criteria.

Table 6: Required data and collection methods for evaluating primary principles of 3D

LASTS criterion for evaluation	Required Data	Collection Method
Ability with which to determine locational information of phenomena within the environment (Spatial Cognition component)	Evidence of locational and evaluative knowledge of objectives relative to 12 PSR	QU_B2 (20) QU_B1 (4)
Degree to which three dimensional arrangement of elements relative to assigned tasks in the real world are preserved within the simulation environment (Simulation Learning component)	Scale value from 1 to 10 Detailed description	QU_A (1) QU_B2 (2) INT_A (1)
Ability to which the environment can model objects, architecture and landscape in three dimensions (3D Environment component)	Detailed description Scale value from 1 to 10	INT_AW (24) QU_B2 (3) QU_A (2)
Ability with which to determine attributional information of phenomena within the environment (Spatial Cognition component)	Evidence of locational and evaluative knowledge of objectives relative to 12 PSR	QU_B2 (1) QU_B1 (1)
Degree to which resultant presence and immersion compel undertaking of assigned tasks (Simulation Learning component)	Detailed description	INT_A (2) and (3) INT_B2 (1) and (2)
Quality of textures, lighting, shadows and reflections (3D Environment component)	Detailed description	INT_AW (21) INT_A (4) INT_B2 (3)
	Scale value from 1 to 10	QU_A (3) QU_B2 (4)
Extent to which system response supports free movement and control of viewing perspective within the environment (Spatial Cognition component)	Scale value from 1 to 10	QU_B2 (5) QU_A (4)
Extent to which system response supports the undertaking of simplified 12 PSR (Simulation Learning component)	Detailed description Scale value from 1 to 10	INT_AW (20) QU_A (4) QU_B2 (5)
Frame rate equal to, or exceeding, twenty frames a second (3D Environment component)	Detailed description Scale value from 1 to 10	INT_AW (18) (a) and (b) QU_A (5) QU_B2 (6)
Degree of movement and control of viewing perspective (Spatial Cognition component)	Scale value from 1 to 10	QU_A (6) (a) and (b) QU_B2 (7) (a) and (b)
Degree to which controls permit the	Detailed description	INT_A (5)

environments for the transfer of spatial knowledge

execution of 12 PSR within the environment (Simulation Learning		INT_B2 (4)	
component)	Scale value from 1 to 10	QU_A (7) QU_B2 (8)	
Quality of collision detection (3D Environment component)	Detailed description	INT_AW (16) and (17) INT_A (6) INT_B2 (5)	
	Scale value from 1 to 10	QU_A (8) QU_B2 (9)	
Degree to which spatial information pertaining to objectives related to 12 PSR can be recognized and recalled (Situated Cognition component)	Detailed description	INT_B2 (6) and (7) INT_B1 (1) and (2) INT_CPO (1), (2), (5), and (6)	
	Indication of the performance of Group B2 on 12 PSR	Comparison of simplified 12 PSR for B1 and B2	
Degree to which instructional support is integrated into the environment (Simulation Learning component)	Scale value from 1 to 10	QU_A (9) QU_B2 (10)	
	Detailed description	INT_AW (14)	
Degree to which the scripting language or developmental tools support the creation of appropriate assigned tasks within the environment (3D Environment component)	Detailed description	INT_AW (10), (11), (12), (13) (a) - (d)	

Table 7: Required data and collection methods for evaluating secondary principles of 3D

environments	for	the	transfer	of	spatial	know	ledge

LASTS criterion for evaluation	Required Data	Collection Method
Accuracy with which the context and culture of the real world environment is depicted within the simulation environment (Simulation Learning component)	Detailed description from those already experienced with operations on board a Collins class submarine	INT_A (7)
Accuracy with which the simulation environment represents the real world environment at a physical and functional level (3D Environment component)	Scale value from 1 to 10 for physical and functional Detailed description	QU_A (10) (a) and (b) QU_B2 (11) (a) and (b) INT_A (8) and (9) INT_B2 (8) and (9)
Degree to which situated tasks enhance spatial knowledge of the environment (Situated Cognition component)	Detailed description	INT_AW (9) INT_A (10) INT_B2 (10) INT_CPO (9) and (10)
•	Indication of the performance of Group B2 on 12 PSR	Comparison of simplified 12 PSR for B1 and B2

Extent to which assigned tasks are situated relative to tasks within the real	Scale value from 1 to 10	QU_A (11)
world environment (Simulation Learning component)	Detailed description	INT_A (11)
Ease with which elements within the environment are recognized (Spatial Cognition component)	Scale value from 1 to 10	QU_A (12) QU_B2 (12)
Ability at which elements or objects relative to the 12 PSR can be identified and recognized (Simulation Learning component)	Indication of the performance of Group B2 on 12 PSR	Comparison of simplified 12 PSR for B1 and B2
Level of distortion between virtual environment and real environment (Spatial Cognition component)	Scale value from 1 to 10	QU_A (13) QU_B2 (13)
(Detailed description	INT_A (12) INT_B2 (11)
Quality and detail of textures and surfaces (3D Environment component)	Scale value from 1 to 10	QU_A (14) QU_B2 (14)
	Detailed description	INT_AW (6)

4.0 Results and Analysis

Analysis of the data gathered from the LASTS case study was conducted in accordance with a convergent methodology that incorporated a more qualitative than quantitative analysis due to the limited number of participants involved. A constant comparative approach was employed, such that the differing perspectives of participants could be compared in order to identify any prevalent groups or patterns, emphasizing the identification of trends rather than statistical evidence. Given the multiple perspectives provided by participants utilized in the LASTS case study, a detailed examination of the data was required in order for a complete understanding of the phenomena involved, reflecting the deep, case-orientated nature of qualitative analysis (Sandelowski, 1995; Silverman, 2005). Analysis was performed with the objective of evaluating the ability with which LASTS could enhance the spatial awareness of the MGR, while also validating the model of spatial cognition in 3D simulation environments based on FPS gaming technology presented in this thesis.

Data gathered from participants in Group B1 and Group B2 was used to compare the effectiveness of the LASTS environment to traditional paper based training with regard to its ability to enhance the spatial awareness of the real world MGR. This data, in conjunction with observation data provided by CPO Allistair Hogarth during the simplified 12 PSR exercise, was also examined in order to ascertain the nature of the spatial representations formed by each group of participants as a result of their respective training.

Participants in Group A and Group B2 were used to gauge the effectiveness of the LASTS environment from two differing perspectives; that of individuals highly experienced and familiar with the real world environment being represented, and that of inexperienced individuals who had no existing spatial representation to call upon for the purpose of comparison. Data gathered from participants in Group A was also used to determine the authenticity of the virtual MGR as depicted by LASTS with reference to the real world MGR environment.

Interview data provided by Andrew Widdis was employed during analysis in order to provide a developer's perspective with regard to the technical characteristics and abilities of the LASTS environment. The information provided during this interview also served to demonstrate the potential for this type of technology to be developed beyond a one room simulation of a real world environment.

Analysis proceed in accordance with the three research questions proposed by this thesis with reference to the evaluation criteria developed in accordance with the model. The evaluation

criteria was used to assess the capability of the LASTS environment to act as a training tool for the enhancement of spatial awareness, while also as a means by which to validate each component of the model, along with its determinant factors outlined in the literature review.

4.1 LASTS and Simulation Learning Transfer

Question 1. How can the implementation of a 3D game engine environment contribute to a learner's development of spatial awareness of real world environments?

The first research question aimed to determine whether spatial knowledge could be effectively transferred between a virtual representation and a real world environment, and if so, how this could be achieved. An examination of the literature relevant to this question revealed that, in order for this to occur, learning needed to be situated in a simulation environment that accurately reflected the real world environment it modelled and integrated contextual instructional support.

In order to determine how spatial knowledge could be transferred from a virtual representation to a corresponding real world environment, it was first necessary to examine the data gathered from the LASTS case study for evidence of spatial knowledge transfer between LASTS and the real world MGR. The simplified 12 PSR exercise performed on-board the Collins class submarine provided evidence for gauging the effectiveness of the LASTS environment in comparison to more conventional paper based training methods. This exercise was conducted by CPO Allistair Hogarth on-board HMAS Collins and involved separate performance evaluations for Group B1 and Group B2, evaluating their ability to locate a series of items within the MGR. Both groups of participants had minimal previous exposure to the MGR, with the most experienced of the participants having had two previous walk-through tours of the entire submarine only. CPO Allistair Hogarth evaluated the performance of each participant on a scale of zero to ten according to their ability to recognise items, their general submarine knowledge, and their confidence in performing the exercise. The scores assigned to each participant for each item are detailed in Table 8 below, with Figure 7 graphing the average scores for each item for Group B1 and Group B2 respectively:

Trainees	B1_1	B1_2	B1_3	B1_4	B1_5	B2_1	B2_2	B2_3	B2_4	B2_5	B1 Avg.	B2 Avg.
MGR Bilge Hatch	7	10	9	10	10	10	10	10	5	1	9.2	7.2
Halon Release Bottle	10	10	10	8	9	10	10	10	9	10	9.4	9.8
Fire Extinguishers	6	2	9	10	9	10	10	10	10	10	7.2	10
OCCABA Stowage	9	9	10	9	10	10	10	10	10	10	9.4	10
Fire Fighting Hose Reel	7	9	1	9	8	10	10	10	10	10	6.8	10
AFT Submerged Signal Ejector	9	9	8	10	10	10	10	10	-10	10	9.2	10
Emergency Pyrotechnic Locker	8	1	9	10	10	10	5	10	10	10	7.6	9
AFT Submerged Signal Ejector Controller	9	9	9	10	0	10	10	10	10	10	7.4	10
Average Score	8.13	7.38	8.13	9.5	8.25	10	9.38	10	9.25	8.88	8.28	9.5

 Table 8: Performance scores for participants performing the simplified 12 Point Safety Round as determined by CPO Allistair Hogarth.





Figure 7: Average performance scores of the simplified 12 Point Safety Round for Group B1 and Group B2 per item.

As expected, Group B1 participants performed very well, as the type of training they received before the simplified 12 PSR exercise was based in part on existing Navy training practices. However, as Figure 7 demonstrates, the average performance was better for Group B2 participants for all items except the MGR Bilge Hatch. Examining the individual performance scores from Table 8, we can see the scores for participants B2_4 and B2_5 are much lower compared to their scores for all other items, which accounts for the lower average performance

score for Group B2 for the MGR Bilge Hatch. One possible explanation for this inconsistency is the manner in which the MGR Bilge Hatch was depicted within the LASTS environment. During the LASTS training session for Group B2, the MGR Bilge Hatch was depicted as being closed, with the top of the MGR Bilge Hatch textured with the same material as the surrounding deck plate, consistent with the real world Main Generator Room. Therefore the MGR Bilge Hatch may have been less noticeable and may have appeared to blend into the floor, rendering the MGR Bilge Hatch a less distinctive spatial landmark with regards to its relative positioning, orientation, and evaluative information. Figure 8 displays the MGR Bilge Hatch in the open position, with the deck plating texture on top of the hatch.



Figure 8: MGR Bilge Hatch in the open position. The top of the hatch is textured with the same material as the deck plating, consistent with the real world MGR.

Further evidence for the superiority of LASTS trainees over their paper based counterparts can be found in the following forms:

- Group B2 participants had an average score for all items of 9.5, compared to Group B1 participants who had an average score for all items of 8.28.
- All Group B2 participants received a score of 10 for the Fire Extinguishers, OCCABA Stowage, Fire Fighting Hose Reel, AFT Submerged Signal Ejector, and AFT Submerged Signal Ejector Controller items.
- Group B2 participants B2_1 and B2_3 scored 10 for all items.

Based on the data gathered from the simplified 12 PSR exercise conducted by CPO Allistair

Hogarth, it is evident that, for this instance, those participants who received training using the LASTS environment performed the exercise more successfully than those who received conventional paper based training. With reference to CPO Allistair Hogarth's evaluation criteria, Group B2 participants collectively exhibited a greater knowledge of the submarine, possessed a greater ability to recognise items, and performed the exercise with greater confidence. Given the lack of previous experience of Group B2 participants within the real world MGR, these results support the contention that Group B2 participants were relying to some degree on the spatial representation they formed as a result of their experience within LASTS to complete the simplified 12 PSR. This indicates the presence of learning transfer between the virtual and real world MGR environments.

The disparity of the results between Group B1 and Group B2 further suggests that training within the LASTS environment was more effective in facilitating the transfer of spatial knowledge than the paper based training method. This contention is consistent with the theory of situated cognition, which submits that learning transfer is most effective between environments that share a common activity, operation or learning goal, and are similarly related in terms of context and culture. In order to determine how effective the LASTS environment was at facilitating the transfer of spatial knowledge, it is pertinent to examine the aspects of 3D game engine environments identified in the literature as supporting this process. These aspects are depicted along with the relevant evaluation criteria and data collection methods for the Simulation Learning Transfer component of the model in Table 9 below:

Aspect	Evaluation Criteria	Data Collection Method
Authenticity of the simulation environment	Accuracy with which the context and culture of the real world environment is depicted within the simulation environment	INT_A (7)
Situated tasks	Extent to which assigned tasks are situated relative to tasks within the real world environment	QU_A(11) INT_A(11)
Integrated instructional support	Degree to which instructional support is integrated into the environment	QU_A (9) QU_B2 (10) INT_AW (14)

 Table 9: Key aspects, evaluation criteria and data collection methods for the Simulation

 Learning Transfer component of the model.

4.1.1 Authenticity of the Simulation Environment

The theory of situated cognition suggests that the effectiveness of learning transfer is determined, in part, by the degree of similarity between the context and culture of the virtual

environment and that of the real world environment being represented. In order to gauge the effectiveness of the LASTS environment in this capacity, participants within Group A were asked to comment on the accuracy of the cultural and contextual depiction of the MGR within the LASTS environment. In this manner, it was hoped that the contextual and cultural accuracy of the LASTS environment could be evaluated by participants who were intimately familiar with the real world environment being depicted by the simulation. In doing so, the authenticity of the simulation environment could be determined with regard to its ability to support learning transfer. The following trends were identified from the responses given by participants within Group A:

- The LASTS environment did not represent all the detail present in the real world MGR. Some internal parts and components were missing, while others were not depicted with sufficient enough detail;
- The absence of sound within the LASTS environment was not consistent with the real world MGR. Specific reference was made to the omission of diesel motor noise as well as general ambient background noise from items such as the air conditioning unit;
- The MGR depicted within the LASTS environment appeared bereft of daily human interaction. People were not present, many day to day items, such as tools, rags, boxes and stores, were missing, and the LASTS environment was clinically clean.

The need for more detail within the LASTS environment was identified as the most prevalent trend amongst responses from participants in Group A. Several references were made to missing or insufficiently detailed internal parts and components native to the real world MGR. Three participants also made specific comments in relation to the omission of sound from the LASTS environment. These responses indicated that were inconsistencies between the context of the virtual MGR and that of the real world MGR.

A number of responses from participants in Group A also referenced a lack of evidence of a human presence in the virtual MGR. Comments from participants in Group A indicated that the virtual MGR as depicted by LASTS did not appear as it would on a daily basis as part of an operational workspace on-board a Collins class submarine. These responses suggested a disparity between the culture of the virtual MGR and that of the real world MGR.

Based on the responses from participants within Group A, it can be surmised that the authenticity of the LASTS environment with regard to its ability to support learning transfer was contextually adequate, though lacking in detail. LASTS was also identified as being considerably deficient in its cultural depiction of the typical working environment found within the real world MGR.

4.1.2 Situated Tasks

Consistent with the theories of situated cognition, simulation based learning, and constructivism,

learning transfer between virtual and real world environments can be achieved effectively via the provision of assigned tasks that are situated relative to real world learning objectives. The degree of this effectiveness is determined by the extent to which the assigned tasks within the virtual environment are situated relative to learning objectives within the real world environment.

As part of their evaluation of the LASTS environment, participants within Group A were required to follow the instructor around the virtual MGR stopping at and noting the location of each item included as part of the simplified 12 PSR exercise. The appropriateness of this task to real world

operations was then determined by the questionnaire responses provided by participants in Group A, displayed in Table 10 accordingly:

Table 10: Questionnaire responses between 0 and 10 from participants in Group A in relation tothe appropriateness of the assigned task relative to real world operations.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How appropriate to real world tasks within the MGR on-board a Collins class submarine was the exercise completed within the LASTS simulation environment?	7	8	6	8	6	-	-	7	-	7.0	2

The relative consistency exhibited amongst responses in Table 10 was also reflected during interview, where five of the seven participants within Group A noted that the assigned task within LASTS was consistent with a compartment layout or rounds type scenario within the MGR on-board a Collins class submarine. These types of operations were similar to the simplified 12 PSR carried out by participants in Group B1 and Group B2, in that they required a set list of items to be located and checked to ensure they were stored in the correct location and in proper working order.

Additional comments by a number of participants also indicated that, while the assigned task within the LASTS environment was valid for rounds or compartment layout type training, the LASTS environment itself was not capable of replicating more technical training scenarios due to a general lack of detail and insufficient interactivity in the internal components depicted

within the virtual MGR. These comments were consistent with earlier responses from a number of participants in Group A relating to the authenticity of the LASTS simulation environment which also made reference to a deficiency in detail. This suggested that the level of detail, and thus, the authenticity of the simulation environment was a factor in determining the type of training that could be successfully implemented within the LASTS environment according to participants in Group A.

4.1.3 Integrated Instructional Support

Simulation based learning theory suggests that the integration of instructional support within a simulation environment serves to support the transfer of knowledge between the simulation and real world environments. The integration of an instructional support framework into a simulation environment allows the interface of the simulation to cater to both operational and learning requirements. This integration can be supported within a 3D simulation environment via the application of scripting languages and other developmental tools commonly inherent amongst FPS game engines.

The instructional support integrated into the LASTS environment was limited to a simple scripting function that would display the name of a designated object on screen when the object was selected using the mouse. This functionality was only provided for items included as part of the simplified 12 PSR.

A number of different perspectives were sought in order to evaluate the degree to which instructional support was integrated into the LASTS environment, with participants in Group A and Group B2 asked to gauge their response via respective questionnaires, and developer Andrew Widdis asked to respond during interview. Responses from participants in Group A and Group B2 are displayed in Table 11 as follows:

 Table 11: Questionnaire responses between 0 and 10 from participants in Group A and Group

 B2 in relation to the the degree to which instructional support was integrated into the LASTS environment.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How well is the exercise integrated into the LASTS environment?	5	9	8	8	6	10	-	7	-	7.57	5
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How well is the exercise integrated into the LASTS environment?	8	8	9	10	7					8.4	3

During interview, Andrew Widdis indicated that the instructional support integrated into the LASTS environment was quite rudimentary in nature, as it was only capable of displaying the name of items relevant to the simplified 12 PSR. However, he also acknowledged that this functionality was adequate enough to provide participants using the LASTS system a visual reference as to the identity of these items when they were selected using the mouse.

Comparing the different perspectives offered by responses from Group A, Group B2, and Andrew Widdis, it is evident that there was some diversity of opinion with regard to the degree to which instructional support was integrated into the LASTS environment. While the instructional support that was embedded within LASTS was simple, it was nonetheless the only means outside of the instructor led walk-through of the virtual MGR for participants to associate items with their corresponding names. The responses of participants within Group A suggested that this functionality was of more questionable value to participants already familiar with the real world MGR, compared to participants within Group B2 who had not had such experience.

4.1.4 Validity of the Simulation Learning Transfer Component of the Model

Having analysed the LASTS environment using the evaluation criteria from the Simulation Learning Transfer component of the model, it is now pertinent to examine the same data used in this analysis to assess the validity of this component itself. The data gathered as part of the LASTS case study will now be evaluated with reference to each aspect of the Simulation Learning Transfer component identified as supporting the transfer of spatial knowledge between 3D FPS simulation environments and real world environments.

4.1.4.1 Validity of Authenticity of the Simulation Environment

The data gathered as part of the LASTS case study that was used to evaluate the authenticity of the simulation environment was provided by participants who had extensive previous experience within the real world location being represented by the LASTS environment. The participants within Group A were intimately familiar with the MGR on-board a Collins class submarine as a result of working within this environment and possessed detailed knowledge of the environment, both contextually and culturally. As such, participants within Group A were well qualified to evaluate the authenticity of the LASTS environment using the criteria established by the Simulation Learning Transfer component of the model.

Responses from participants within Group A indicated that the level of detail present in the LASTS environment was the most prevalent factor in determining its authenticity with reference to the real world MGR. The level of contextual and cultural detail, and thus the

authenticity of the LASTS environment, was found to be insufficient for LASTS to act as an effective training tool for technical tasks. However, the authenticity of the LASTS environment was found to be adequate enough to act as a familiarization tool for the purpose of learning compartment layouts and rounds based training. This suggests that the authenticity of the simulation environment is a factor in determining its ability to support learning transfer. LASTS was deemed authentic enough for the effective transfer of spatial knowledge, but not authentic enough to provide knowledge that could be transferred effectively for technical operations training. As such, any technical operations training attempted within the LASTS environment would have been largely ineffective, as the virtual MGR was not authentic enough to allow learners to obtain knowledge that could be transferred effectively to the real world MGR environment.

4.1.4.2 Validity of Situated Tasks

The assigned task proscribed within the LASTS environment required participants within Group A and Group B2 to walk around the virtual MGR while stopping and noting the location of items included in the simplified 12 PSR. This task was conducted by Andrew Widdis, who led the participants around the LASTS environment using a projector screen attached to his computer. The virtual walk-through was selected as a situated task within the LASTS environment as it was similar to the simplified 12 PSR exercise performed by participants in Group B1 and Group B2 within the real world MGR. The simplified 12 PSR required participants to locate the same series of items under observation by CPO Allistair Hogarth.

Responses from participants in Group A, who were familiar with the MGR on-board a Collins class submarine and the daily operations conducted therein, indicated that the task assigned within the LASTS environment was consistent with a compartment layout or rounds type scenario. As with the simplified 12 PSR, these operations also required knowledge of the spatial layout of the MGR, including the names and locations of relevant items. Thus, the task assigned within the LASTS environment was meaningful and situated relative to the simplified 12 PSR performed within the real world MGR.

The provision of an assigned task consistent with the simplified 12 PSR may have been a factor in determining the more effective performance of Group B2 participants compared to those in Group B1 with reference to the simplified 12 PSR exercise. Group B1 participants were not required to perform a task that was directly related to the simplified 12 PSR as part of their paper based training and were asked to merely familiarise themselves with the diagrams and photos of relevant items within the MGR. These participants were provided training that was more self-directed and less guided compared to participants in Group B2, which, with reference to the literature on simulation based learning, is less effective in supporting learning transfer.

4.1.4.3 Validity of Integrated Instructional Support

While the instructional support that was integrated into the LASTS environment was identified as being limited and rudimentary in nature, it did provide participants with the names of items included in the simplified 12 PSR. This information was required by participants in Group B2 to complete the simplified 12 PSR exercise conducted by CPO Allistair Hogarth within the real world MGR. The name of each item was mentioned only once during the instructor led walk-through for participants in Group A and Group B2, after which these participants would have had to rely on the name being displayed on the screen in order to associate the name with its corresponding item.

Limiting the display of names to items included in the simplified 12 PSR may also have assisted participants within Group B2 to focus only on the items relevant to the simplified 12 PSR. This was consistent with the paper based training received by participants in Group B1, who were provided only the names and locations of items included in the simplified 12 PSR exercise. Without the name display functionality integrated into the LASTS environment, participants within Group B2 would have had no reference outside of the instructor led walk-through as to the names of items included in the simplified 12 PSR suggested a thorough understanding of both the identity and location of each item included in this exercise. This indicates that the instructional support that was integrated into LASTS contributed to the development of knowledge regarding items in the simplified 12 PSR, and furthermore, that this knowledge was applicable to the completion of the exercise within the real world environment.

4.1.5 Summary for Simulation Learning Transfer

The theories of situated cognition, simulation based learning, and constructivism suggest that a 3D game engine environment can be used to develop a learner's spatial awareness of a real world environment via the concept of learning transfer. Spatial knowledge obtained within a virtual environment can be transferred to a corresponding real world environment, as 3D FPS simulation environments have the capacity to provide an authentic simulation utilising situated tasks and integrated instructional support in order to facilitate this process. The Simulation Learning Transfer component of the model was derived from this theoretical construct to identify the key aspects of 3D FPS simulation environments that support this process, while also providing a set of evaluation criteria for assessment purposes.

Based on the responses of participants to the evaluation criteria relevant to the Simulation Learning Transfer component of the model, the following can be surmised in relation to the LASTS environment:

- The LASTS environment provided sufficient authenticity for conducting training similar in nature to rounds or compartment layout type scenarios, but deficient in the level of detail required for more sophisticated types of training;
- The limited level of instructional support integrated into the LASTS environment was identified as being adequate for trainees not familiar with the MGR to learn the names associated with items relevant to the simplified 12 PSR exercise, but of a more questionable value to participants already familiar with these items.

Analysis of these responses provided evidence to support the validity of the Simulation Learning Transfer component of the model as an effective representation of the transfer process that is possible between a 3D FPS simulation environment and a corresponding real world environment. The presence of learning transfer between LASTS and the real world MGR was indicated via the effective performance of the simplified 12 PSR by participants within Group B2. The aspects of simulation authenticity, situated tasks, and integrated instructional support identified as being key in determining the effectiveness of this learning transfer of spatial knowledge were identified amongst the gathered data as supporting this process.

4.2 LASTS and Spatial Cognition

Question 2. What is the nature and function of spatial cognition and the subsequent formation of spatial representations?

The second research question sought to examine the role of spatial cognition in creating a mental representation of the spatial characteristics of an environment and the manner in which these spatial representations were formed. The extensive body of literature in this area indicated that this process entailed the formation of a cognitive map, where by the spatial information of an environment was encoded as a mental representation. Freedom of movement, the legibility of the environment, and the quality of the spatial information available were identified as key factors in supporting the process of spatial cognition. While the structure and subsequent formation of cognitive maps was the subject of debate within the literature, there was evidence to support the contention that 3D simulation environments could foster the development of spatial knowledge in a manner consistent with real world environments. This indicated that spatial knowledge obtained within a 3D simulation environment could be transferred effectively to real world environments.

In order to determine the effectiveness with which spatial representations formed within a virtual environment could be transferred to a real world environment, an examination of the different types of spatial representations formed with reference to the gathered data was necessary. Participants within Group B1 and Group B2 were provided with training that presented spatial information relative to the MGR in different ways, and as such, should have formed differing spatial representations of the MGR based on the information made available to them. After training, both groups of participants were required to complete the simplified 12 PSR within the real world MGR under the observation of CPO Allistair Hogarth. The observations made by CPO Allistair Hogarth that were related during interview provided some insight as to the differing spatial representations of participants in Group 1 compared to participants in Group B2.

CPO Allistair Hogarth stated during interview that there was a difference in the technique used by participants in Group B2 compared to participants in Group B1 during the simplified 12 PSR exercise. It was observed by CPO Allistair Hogarth that participants within Group B2 did not need to actually locate an item before they could confidentially identify it, unlike participants within Group B1 who did need to do this in order to complete the exercise. This difference in technique between Group B1 and Group B2 was described by CPO Allistair Hogarth as follows:

"Group B1 seemed to search the area for items, needing to actually move around looking and scanning. Group B2 displayed a greater knowledge so far as they were able to stand in one spot and describe the location of objects without having to go and touch them."

This difference between the techniques employed by participants within Group B1 and Group B2 suggests that participants within Group B2 were utilising a more effective spatial representation of the MGR environment to locate items specific to the simplified 12 PSR. This contention is further reinforced in light of additional observations made by CPO Allistair Hogarth that stated that the Group B2 participants were able to complete the exercise in approximately half the time of the Group B1 participants.

In order to gain some kind of insight as to the differing spatial representations of the MGR constructed respectively by participants in Group B1 and Group B2, the observation data can be evaluated with reference to the Landmark, Route, Survey model of spatial cognition. Using the items included as part of the simplified 12 PSR exercise as landmarks with reference to this model, it is evident that both groups possessed an adequate enough spatial representation to locate all the items included in the exercise. The technique used by Group B1 to locate items suggest a less developed spatial representation at the route level, as a more exhaustive search

was required by participants to find items, demonstrating that they were aware of the locations of items, or landmarks, but not as knowledgeable with regards to the paths between them.

This contention is justified when considering the type of training, and therefore, spatial knowledge that was made available to participants in Group B1. This group of participants was provided with an information booklet containing a plan and cross-sectional diagram detailing the location of each item included as part of the simplified 12 PSR. A photograph of each item, taken from within the MGR on-board a Collins class submarine, was also included in the information booklet. The booklet was arranged such that the diagrams and photograph for each item were displayed on separate pages. As such, it may have been difficult for participants in Group B1 to establish routes between each landmark, as this would have required constant comparative reference between multiple pages in the booklet in order to be effective. This would have also made the formation of a spatial representation at the survey level difficult, as Group B1 participants would have had a reduced capacity by which to construct a complete and overall view of the locations of items included as part of the simplified 12 PSR.

Group B2 participants, on the other hand, were able to freely move throughout the virtual MGR, and were thus unobstructed in constructing paths between landmarks within the environment as they saw fit. Furthermore, the LASTS environment also allowed participants to freely construct these paths within the confines of the virtual MGR, and thus allow them to abstract their entire experience within the LASTS environment into a single spatial representation. An indication as to this survey level of spatial knowledge being utilised by participants in Group B2 was observed during their performance of the simplified 12 PSR, whereby they did not need to rely on traversing the environment between items in order to locate them. Rather, they were able to identify the location of items from a single location without moving around. This suggests that participants within Group B2 were operating at the survey or configurational level with reference to the Landmark, Route, Survey model of spatial cognition.

Having established an indication as to the nature of the spatial representation formed by participants in Group B2, further examination of the gathered data is required in order to identify which characteristics of the LASTS environment contributed to this process. This examination will be conducted with reference to the Spatial Cognition component of the model in order to gauge the effectiveness of the LASTS environment to support the development of spatial representations that are transferable to real world environments. The determinant aspects, evaluation criteria and data collection methods for the Spatial Cognition component of the model are outlined for this purpose in Table 12 below:
Table 12: Key aspects, evaluation criteria and data collection methods for the Spatial Cognition

Aspect	Evaluation Criteria	Data Collection Method
Movement within the environment	Degree of movement permitted within the environment	QU_A (6)(a) and (b) QU_B2 (7) (a) and (b)
Legibility of the environment	Ease with which elements within the environment are recognized	QU_A (12) QU_B2 (12)
Quality of spatial information	Level of distortion between virtual environment and real environment	QU_A (13) QU_B2 (13) INT_A (12) INT_B2 (11)
- -	Quality of locational and attributional information of phenomena within the environment (3D Environment component)	QU_A (14) QU_B2 (14) INT_AW (6) INT_A (13) INT_B2 (12)

component of the model.

4.2.1 Movement Within the Environment

The process of spatial cognition entails the formation of a cognitive map of an environment that is developed using the acquisition of spatial information via the visual, tactile, olfactory, and kinaesthetic sensory modalities. While these sensory modalities collect information from the environment in different ways, they are each effective only to a certain range and under certain conditions. As such, the ability to move within the environment is essential to ensure that all possible sources of spatial information can be examined using the full gamut of senses. In order to gauge the capacity of the LAST environment to facilitate movement for the purposes of gathering spatial information, participants within Group A and Group B2 were asked to assess the degree to which they were able to move and control the viewing perspective within the virtual environment via questionnaire, the results of which are depicted in Table 13:

 Table 13: Questionnaire responses between 0 and 10 from participants in Group A and Group

 B2 in relation to the degree of movement and control of the viewing perspective within the

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How freely were you able to move within the LASTS simulation environment?	5	-	9	9	8	10	9	5	7	7.75	5
How effectively were you able to control the direction you were facing within the LASTS	8	-8	9	9	8	10	9	5	7	8.1	5

LASTS environment.

simulation environment?					-				
Group B2 participant	B_1	B_2	B_3	B_4	B_5			Avg.	Range
How freely were you able to move within the LASTS simulation environment?	10	9	8	5	7			7.8	5
How effectively were you able to control the direction you were facing within the LASTS simulation environment?	10	9	9	10	10			9.6	1

Based on these responses, there was a common consensus among participants within both groups that suggested that the LASTS environment provided adequate freedom of movement within the virtual MGR. However, both groups of participants did also indicate that they were able to control the viewing perspectively more effectively than they were able to move within the environment. Group B2 participants in particular consistently rated the control of the viewing perspective of the LASTS environment very highly.

4.2.2 Legibility of the Environment

According to the Landmark, Route, Survey model of spatial cognition, the designation of landmarks constitutes the initial stage of development in the formation of a cognitive map of an environment. Spatial information obtained via the various sensory modalities are utilised to provide both locational and evaluative information about a landmark in order to distinguish the landmark and assign it an identity. As such, there is an inherent need for an environment to be legible such that spatial information can be recognized and extracted from it. To ascertain the legibility of the LASTS environment, participants within Group A and Group B2 were asked to rate the ease with which they were able to recognize items within the virtual MGR via questionnaire, the results of which are depicted in Table 14:

Table 14: Questionnaire responses between 0 and 10 from participants in Group A and GroupB2 in relation to the ease with which items could be recognised within the LASTS environment.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How easily were you able to recognise objects within the LASTS simulation environment?	8	10	9	9	6	10	10	9	8	7.78	4
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How easily were you able to recognise objects within the LASTS simulation	9	10	9	10	9			<i><i>n</i>.</i>		9.4	1

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environment?

The responses displayed in Table 14 suggest that both groups of participants found the LASTS environment to be adequately legible with regard to the ability with which they were able to recognise items. Further indication as to the legibility of the LASTS environment is provided when considering the different perspectives provided by the responses from Group A and Group B2. Group A participants had extensive previous experience to call upon when attempting to recognise items within the LASTS environment which Group B2 did not. This suggests that the degree to which participants within Group A were able to recognise items within LASTS would have been made with some reference to the real world items with which they were familiar with. Group B2 participants, on the other hand, would have had no such reference to draw upon, and as such, would have determined the ability with which they could recognise items within the LASTS environment based on the spatial information made available to them within the virtual MGR alone.

4.2.3 Quality of Spatial Information

As with with the legibility of an environment, the quality of the spatial information available to the sensory modalities is also an important factor in determining the formation of spatial representations. Spatial representations are formed from the combination of the information provided by all senses, however, non-immersive computer-generated 3D environments are limited in this capacity as they are not capable of providing spatial information to the tactile, olfactory, or kinaesthetic sensory modalities. Given the reliance of the LASTS environment on visual cues to provide spatial information, a number of different perspectives were examined to determine the quality of spatial information contained within the LASTS environment. This examination was conducted with reference to the value of the spatial information provided by the LASTS environment while taking into account any identifiable disparities between the spatial information provided by the virtual MGR and that of the real world MGR. To this end, participants within Group A and Group B2 were required to indicate the level of distortion present between the virtual and real world MGR via questionnaire and interview, while also being asked to assess the quality of the locational and attributional information of phenomena within the LASTS environment. Andrew Widdis was also asked to evaluate the same characteristics of the LASTS environment during interview. Questionnaire responses from participants in Group A and Group B2 with reference to the distortion present between LASTS and the real world MGR are displayed in Table 15 accordingly:

Table 15: Questionnaire responses between 0 and 10 from participants in Group A and GroupB2 in relation to the level of distortion present between the virtual and real world MGR

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
What level of distortion or inaccuracy did you feel was present between the LASTS simulation and the actual MGR on-board a Collins class submarine?	7	9	8	3	6	7	5	5	7	6.34	6
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
What level of distortion or inaccuracy did you feel was present between the LASTS simulation and the actual MGR on-board a	1	7	3	1	3	· · · · · · · · · · · · · · · · · · ·				3.0	6

environments.

The responses depicted in Table 15 are understandable given the relative levels of previous experience between participants in Group A and those in Group B2 within the real world MGR. Participants familiar with the MGR environment would be expected to be more aware of inconsistencies and more readily able to identify them compared to participants who were relatively unfamiliar with the MGR environment.

Interview responses from participants in Group A indicated that the disparity in the level of detail was the most significant cause of distortion between the virtual MGR and the real world MGR. These responses were consistent with other comments made by participants in Group A with reference to the authenticity of the LASTS environment and the accuracy of the contextual and cultural depiction of the MGR. A number of interview responses from participants in Group B2 also made reference to a deficiency in detail between the virtual and real world environments at a contextual and cultural level. However, the most prevalent trend identified amongst this group of participants were references to the confines of the real world MGR environment not being represented accurately by LASTS. This distortion can be attributed, in part, to the absence of items within the virtual MGR that took up space within the real world MGR, such as boxes, stores, oil drums and other equipment as identified by participants in Group A and Group B2. Had these items been present within the virtual MGR, they would have reduced the amount of free space within the environment while also potentially limiting access to certain parts of the MGR, thus representing the confines of the real world MGR more accurately. The addition of these items to the virtual MGR may have required participants to traverse the environment differently and may have also reduced visibility across parts of the environment, thereby exhibiting the the potential to alter the quality of the spatial information available to participants and their resultant spatial representation of the environment.

To gauge the quality of the locational and attributional information of phenomena within the LASTS environment, participants within Group A and Group B2 where asked to rate the quality and detail of the surfaces of objects and architecture depicted within the virtual MGR, the questionnaire responses to which are depicted in Table 16 as follows:

 Table 16: Questionnaire responses between 0 and 10 from participants in Group A and Group

 B2 in relation to the quality of the surfaces of objects and architecture within the LASTS

 environment.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How would you rate the quality of the surfaces of objects and architecture depicted within the LASTS simulation environment?	8	8	8	8	6	6	8	4	7	7.0	4
Group B2 participant	B_1	B_2	· B_3	B_4	B_5					Avg.	Range
How would you rate the quality of the surfaces of objects and architecture depicted within the LASTS simulation	8	8	7	8	6					7.4	2

Consistent with the responses in Table 16, interview data from both groups of participants also indicated a general level of satisfaction with the quality and detail of the surfaces and objects within LASTS. However, a number of participants within Group A also commented on a lack of detail amongst certain objects and surfaces such as cabinets and control panels, though one participant did suggest that this lack of detail was less relevant to familiarization training than to more advanced levels of training at a technical or operational level.

Developer Andrew Widdis was also asked during interview to assess the quality and detail of the textures and surfaces within the LASTS environment. Andrew indicated that he felt the textures and surfaces to be of a reasonable level, but also acknowledged that these could be improved upon given more time and access to a greater volume of photographs and reference material pertaining to the MGR environment.

4.2.4 Validity of the Spatial Cognition Component of the Model

Having analysed the LASTS environment using the evaluation criteria from the Spatial Cognition component of the model, it is now pertinent to examine the same data in order to assess the validity of the the component itself. The data gathered as part of the LASTS case study will now be evaluated with reference to each aspect of the Spatial Cognition component identified as supporting the development of spatial representations in a manner consistent with real world environments.

4.2.4.1 Validity of Movement Within the Environment

Consistent with the formation of spatial representations in real world environments, the ability to move freely is necessary in order to properly access and extract spatial information from a 3D simulation environment. With regard to the evaluation of the LASTS environment, this ability was assessed according to the ability with which participants could move freely throughout the environment and control the viewing perspective, using the keyboard and mouse respectively.

Consistent with the real world MGR on-board a Collins class submarine, the virtual MGR depicted by the LASTS environment was a multi-tiered environment consisting of a lower deck level in conjunction with upper deck sections that were accessible via ladder. The list of items included as part of the simplified 12 PSR was also structured such that the items of interest were situated on both decks, requiring participants to traverse both levels in order to access them. Some of the items included as part of this list were obstructed from view from certain parts of the MGR compartment, again requiring movement or re-orientation in order to extract spatial information from the environment. The structure of the MGR environment in addition to the locations of the items included as part of the simplified 12 PSR made forming an accurate spatial representation including the location of these items near impossible without the ability to move and alter the viewing perspective within the virtual MGR. Given the successful completion of the Simplified 12 PSR exercise by Group B2, it is evident that the spatial representation of the MGR acquired by participants in Group B2 relied in part on the ability to move freely within the virtual MGR environment. This indicates that the ability to move freely is a determinant factor in the development of spatial representations in virtual environments.

4.2.4.2 Validity of Legibility of the Environment

The legibility of the LASTS environment in regard to the ability at which it supported spatial cognition was conducted with reference to the perspectives of Group A, who were familiar with the real world MGR, and that of Group B2, who were relatively unfamiliar with the real world MGR and Collins class submarines in general by comparison. Both groups of participants were asked to rate the ease with which they could identify items within the virtual MGR environment as depicted by LASTS. The extensive previous experience of participants in Group A with the real world MGR suggested that these participants had the ability to utilise their existing knowledge of items found within this environment to aid recognition of their virtual equivalents. Participants in Group B2 would not have been able to call upon such experience to

aid recognition.

Given that participants in Group B2 had no equivalent reference to real world items to call upon when attempting to recognise items within the virtual MGR, the extent to which they were able to recognise items would have been reliant on their ability to extract spatial information from the LASTS environment. This indicates that there is an inherent need for spatial information throughout the virtual environment to be legible in order for it to be recognised and interpreted meaningfully by participants. Phenomena within the environment need to have worthwhile locational and attributional information assigned to them in order for them to function as effective landmarks as part of a spatial representation. Consistent with real world environments, this suggests that the legibility of the spatial information contained within a 3D simulation environment is a determinant factor in the formation of spatial representations within that environment.

4.2.4.3 Validity of Quality of Spatial Information

Evaluating the quality of the spatial information available in the LASTS environment involved examining the distortion present between the virtual and real world MGR environments, while also evaluating the quality of the locational and attributional information contained within LASTS. Given that non-immersive 3D environments such as LASTS rely heavily on the visual sensory modalities to impart information, this evaluation focussed on the visual aspects of the LASTS environment.

A comparison of the collective performances of Group B1 and Group B2 with regard to the simplified 12 PSR indicated that Group B2 participants were more confident, more efficient, and more successful than Group B1 participants. Group B2 participants also were observed utilising a more effective technique to locate and identify items included in the simplified 12 PSR. This suggested that participants in Group B2 had a more advanced spatial representation of the MGR environment than participants in Group B1.

Group B1 participants received a booklet with a separate set of diagrams and photos for each item included as part of the simplified 12 PSR to extract spatial information from in order to develop a spatial representation of the MGR. The spatial representation developed as a result of utilising this spatial information was characterised as being reliant on exhaustive search techniques to locate and identify items, suggesting that it was operating at the landmark level of the Landmark, Route, Survey model of spatial cognition. Group B2 participants, on the other hand, received their spatial information via interaction with a computer generated three dimensional model of the MGR environment. Group B2 participants were collectively

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characterised as forming spatial representations that were more efficient, and did not require them to move around the real world MGR in order to locate and identify items as part of the simplified 12 PSR. This suggested that the spatial representations of participants in Group B2 were operating at the survey level of the Landmark, Route, Survey model of spatial cognition.

Based on the spatial representations formed by Group B1 and Group B2 with reference to the disparity between the spatial information that was available to each group respectively, it is reasonable to assume that the quality of the spatial information is a determinant factor in the development of spatial representations in 3D simulation environments. This contention can be supported via an examination of the simplified 12 PSR performance scores for each item for Group B2. Referring to Figure 7, and assuming that the LASTS environment provided better quality spatial information than the paper based booklet, it is reasonable to expect that LASTS trainees would average a higher score on all items than those participants using the paper based training method. However, this was not the case, as Group B2 averaged higher scores than Group B1 for all items except the MGR Bilge Hatch. Previous analysis has indicated that this may have occurred due to the MGR Bilge Hatch being difficult to distinguish from the surrounding deck plate when closed. This indicates that there was a lower quality of spatial information pertaining to the MGR Bilge Hatch available to participants in Group B2 which subsequently resulted in a poorer performance of the simplified 12 PSR for this item. This suggests that the quality of spatial information is a factor in determining the spatial representation of a 3D simulation environment.

4.2.5 Summary for Spatial Cognition

While there are a number of different competing theories relating to the manner in which spatial representations are characterised and encoded, it is generally well accepted amongst scholars that cognitive maps exist as a mental representation of an external environment. The Landmark, Route, Survey model of spatial cognition suggests that cognitive maps are formed around landmarks and the paths between them which can be collated into a single model of the environment at the survey or configurational level. Research into spatial cognition within computer-generated 3D environments has indicated that there is little difference in the way spatial representations are formed in virtual environments compared to real world environments. As such, computer generated 3D environments exhibit potential for fostering the effective transfer of spatial knowledge to real world environments. However, as with real world environments, the formation of an effective spatial representation is dependent on being able to move freely within a legible environment which contains quality spatial information. The Spatial Cognition component of the model was derived from this theoretical construct to identify the key aspects of 3D game engine environments that support this process while also providing a set of evaluation criteria for assessment purposes.

Based on the responses of participants to the evaluation criteria relevant to the Spatial Cognition component of the model, the following can be surmised in relation to the LASTS environment:

- The LASTS environment provided a sufficient degree of freedom of movement and control of the viewing perspective for participants to effectively gather spatial information throughout the environment;
- Participants, particularly those in Group B2, found the LASTS environment to be legible enough to facilitate the effect recognition of items within the virtual MGR;
- A general deficiency in detail and failure to represent the spatial confines of the real world MGR were identified amongst participants as being the most prevalent causes of distortion between the virtual and real world MGR;
- A general consensus amongst participants was arrived at with regard to the quality and detail of the surfaces and textures within the LASTS environment, which were regarded as being of a generally high standard, though lacking in some minor detail.

With reference to the data gathered as part of the LASTS case study, there is evidence to suggest the validity of the Spatial Cognition component of the model as an effective representation of the process of developing spatial representations within 3D game engine environments. The performance of participants in Group B2 with regard to the simplified 12 PSR indicated that the participants were using a spatial representation formed as a result of their experience in the LASTS environment to complete the exercise. The ability to move freely within the environment, in conjunction with the legibility and quality of spatial information, were identified with reference to the gathered data as supporting the development of the spatial representation of LASTS formed by participants. This was consistent with the same determinant aspects identified within the Spatial Cognition component of the model.

4.3 LASTS and 3D Environments

Question 3. What are the characteristics of 3D game engine environments in terms of their ability to support spatial cognition?

The third and final research question focussed on ascertaining which characteristics of 3D FPS simulation environments could be identified as supporting spatial cognition. Answers to the first two research questions indicated that spatial knowledge could be transferred effectively between a simulation environment and a corresponding real world environment that were contextually similar. Thus, it became necessary to determine which characteristics of non-immersive 3D simulation environments based on FPS gaming technology made them capable of representing real world environments in order to support this process.

A preliminary analysis of the gathered data indicated that the LASTS environment provided an adequate representation of the real world MGR from the perspective of both experienced and trainee submariners, as evidenced by the questionnaire responses from participants in Group and Group B2 in Table 17 below:

Table 17: Questionnaire responses between 0 and 10 from participants in Group A and GroupB2 in relation to the quality of the surfaces of objects and architecture within the LASTS

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_ 7	A_8	A_9	Avg.	Range
Your overall impression of the LASTS environment to represent the MGR of a Collins class submarine for the purposes of training?	7	9	9	- 8	4	10	10	7	8	8.0	6
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
Your overall impression of the LASTS environment to represent the MGR of a Collins class submarine for the purposes of training?	9	9	10	8	9					9.0	2

environment.

An examination of the literature relevant to the third research question revealed that computergenerated 3D environments were a valid means by which to simulate real world environments based on their ability to represent three dimensional spaces at a high visual quality while maintaining a frame rate that allowed the user fluid control of the virtual environment. These aspects of computer-generated 3D environments were used to evaluate the LASTS environment in order to determine the capability of the LASTS environment to represent the real world MGR on-board a Collins class submarine. The determinant aspects, evaluation criteria and data collection methods for the 3D environment component of the model are outlined for this purpose in Table 18 as follows:

Aspect	Evaluation Criteria	Data Collection Method
Three dimensional representation	Ability to which the environment can represent objects, architecture and landscape in three dimensions	INT_AW (24) QU_B2 (3) QU_A (2)
High visual fidelity	Quality of textures, lighting, shadows and reflections	INT_AW (21) INT_A (4) INT_B2 (3) QU_A (3) QU_B2 (4)
Immediate system response	Frame rate equal to, or exceeding, twenty frames a second	INT_AW (18)(a) and (b) QU_A (5) QU_B2 (6)
User control	Real time movement and interaction within the simulation environment (Spatial Cognition component)	QU_A (6)(a) and (b) QU_B2 (7) (a) and (b)
	Quality of collision detection	INT_AW (16) and (17) INT_A (6) INT_B2 (5) QU_A (8) QU_B2 (9)

 Table 18: Key aspects, evaluation criteria and data collection methods for the 3D environment component of the model.

4.3.1 Three Dimensional Representation

Consistent with real world spaces, computer-generated 3D environments utilise Euclidean geometry to describe the shape and position of objects within them using a set of co-ordinates operating in three dimensions. As such, 3D environments can be used to construct scale representations of real world environments that replicate the dimensions, perspectives, and relative distances between objects in a manner consistent with the real world environment being modelled. In order to evaluate the ability of the LASTS environment to represent objects and architecture native to the real world MGR on-board a Collins class submarine in three dimensions, participants from Group A and Group B2 were asked to rate this ability on a scale of 0 to 10 in their respective questionnaires. Andrew Widdis was also asked to respond to the same criteria during interview in order to provide a developer perspective. Questionnaire responses in relation to this aspect of the LASTS environment are displayed in Table 19 as follows:

 Table 19: Questionnaire responses between 0 and 10 from participants in Group A and Group

 B2 in relation to the quality of the surfaces of objects and architecture within the LASTS environment.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How well did the LASTS simulation environment three dimensionally model the objects and architecture of the MGR on-board a Collins class submarine?	7	9	9	9	7	7	9	4	8	7.7	5
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How well did the LASTS simulation environment three dimensionally model the objects and architecture of the MGR on-board a	8	8	9	10	8	·				8.6	2

The questionnaire responses depicted in Table 19 indicated a general level of satisfaction amongst both groups of participants with regard to the three dimensional depiction of objects and architecture by the LASTS environment. In support of this response, Andrew Widdis stated during interview that all of the objects and architecture within the LASTS environment had been derived from CAD (Computer Aided Design) data from the real world MGR on-board a Collins class submarine. As such, the objects and architecture within the LASTS environment would have been depicted accurately with reference to their real world counterparts, preserving the real world dimensions, perspectives and distances to scale. This is of particular relevance to the process of spatial cognition, which uses information pertaining to the distance and direction of objects within an environment in the formation of spatial representations. As such, any spatial representation formed in a virtual environment that provides a scale representation of the real world environment it represents will be able to be transferred more effectively to the real world environment.

4.3.2 High visual fidelity

Given the nature of spatial cognition, there is an inherent need for simulation environments to provide as a high a quality of spatial information as possible to the sensory modalities in order for meaningful spatial representations to be constructed. As non-immersive 3D simulation environments such as LASTS are predominantly reliant on the visual senses to impart information, it stands to reason that the visual information provided by a 3D simulation environment should be of as high a quality as possible in order to compensate for the lack of tactile, olfactory, and kinaesthetic information provided. In order to determine the ability of the

LASTS environment to act in this capacity, participants from Group A and Group B2 were asked to evaluate the quality of the textures, lighting, shadows, and reflections of the LASTS environment via respective questionnaires and interviews. Developer Andrew Widdis was also asked to respond during interview. The questionnaire responses from participants in Group A and Group B2 are displayed in Table 20 as follows:

Table 20: Questionnaire responses between 0 and 10 from participants in Group A and GroupB2 in relation to the quality of the textures, lighting, shadows, and reflections within the LASTS

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How well did the textures, lighting, shadows, and reflections within the LASTS simulation environment serve to create a high quality visual experience?	6	8	9	.9	7	4	5	3	8	6.5	6
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How well did the textures, lighting, shadows, and reflections within the LASTS simulation environment serve to create a high quality visual experience?	8	7	7	7	7		-			7.2	1

environment.

Consistent with the questionnaire data in Table 20, interview responses from participants in Group A and Group B2 indicated a general level of satisfaction with the visual elements of the LASTS environment. However, a number of discrepancies were identified amongst responses:

- Two participants within Group A made reference to a deficiency in detail in some of the textures in the virtual MGR. One of these participants illustrated that the absence of cream coloured textures to replicate the paint on most of the machinery in the real world MGR diminished the lighting in the virtual MGR, as the cream paint in the real world MGR reflected the light and thus served to better illuminate the environment;
- A discrepancy between the lighting in the virtual MGR and that of the real world MGR was also identified by a participant in Group B2;

In support of the textures, lighting, shadows, and reflections within the LASTS environment, three participants from Group B2 made references referring to their ability to successfully recognise elements of the virtual MGR during their assessment of the visual characteristics of the LASTS environment. This general level of satisfaction with the visual elements amongst participants in Group A and Group B2 was also reflected in comments made by Andrew Widdis

during interview.

4.3.3 Immediate System Response

The dynamic rendering characteristics of 3D simulation environments allow them to provide immediate visual feedback in response to user actions within the virtual environment. Combined with the 3D vector geometry environment model utilised by 3D simulation environments, keyboard and mouse input provided by the user can be responded to in a manner that creates the illusion of free movement within the virtual environment. This ability allows users to freely look and move within the virtual environment in a manner consistent with a real world three dimensional space, which is necessary for the formation of spatial representations that can be transferred effectively to real world environments. In order to assess the immediacy of LASTS to respond to user input, participants in Group A and Group B2 were asked to rate the speed with which the LASTS environment updated the display in response to their actions, the results of which are represented in Table 21. Developer Andrew Widdis was also asked to comment on the immediacy of LASTS to respond to changes in input during interview.

Table 21: Questionnaire responses betw	veen 0 and 10 from	participants in Group	A and Group
B2 in relation to the speed with which	LASTS updated the	visual display in resp	onse to user

action.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How quickly did the LASTS simulation environment update the display in response to your actions?	8	10	9	9	8	10	9	9	9	9.0	2
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How quickly did the LASTS simulation environment update the display in response to your actions?	9	9	10	10	9					9.4	1

The consensus in opinion amongst participants in Group A and Group B2 as depicted by the data in Table 21 can be explained with reference to comments made by Andrew Widdis during interview. Andrew stated that the average frame rate for the LASTS environment was between 40 and 50 frames per second. With reference to the relevant literature on computer-generated 3D environments, this frame rate is more than adequate for facilitating the illusion of movement within a 3D environment in a smooth and interactive manner.

4.3.4 User control

The ability for the user to control their experience within a 3D simulation environment is an important factor in facilitating the effective representation of real world environments. Meaningful representation requires that users be able to move throughout the virtual space while interacting with the objects within it in a manner consistent with a three dimensional real world space. To ascertain the level of user control within the LASTS environment, participants from Group A and Group B2 were asked to rate the degree of movement and control of the viewing perspective, and also evaluate the quality of the collision detection within the LASTS environment. Andrew Widdis was also asked to provide a developer perspective with regard to the quality of the collision detection within the LASTS environment.

Having previously evaluated the degree of movement and control of the viewing perspective as part of the Spatial Cognition component of the model (see Table 12), no further data collection was necessary in order to evaluate the degree of user control provided by the LASTS environment. Previous analysis of responses from participants in Group A and Group B2 indicated that the LASTS environment had provided a sufficient degree of freedom of movement and control of the viewing perspective for participants to effectively gather spatial information throughout the environment. This suggests that these participants had sufficient enough control within the LASTS environment to construct a spatial representation of the virtual MGR in a manner consistent with the construction of spatial representations within real world environments.

Collision detection was evaluated due to its influence on user control, as the ability to detect and respond to interaction between the user and the virtual space determines the manner in which the user engages with the environment, and thus, the degree of control over their experience. This aspect of the LASTS environment was determined to be adequate, with reference to the questionnaire results displayed in Table 22 below, with a more detailed response being elicited via interview.

Table 22: Questionnaire responses between 0 and 10 from participants in Group A and Group
B2 in relation to the effectiveness of the collision detection within the LASTS environment.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How effectively did the LASTS simulation environment respond to contact or collisions with objects and architecture as you were moving through the environment?	3	9	9	7	7	10	10	6	8	7.67	7
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range

How effectively did the LASTS simulation environment respond to	8	7	7	8	7	5		74	1
contact or collisions with objects and architecture as you were moving through the environment?			•						1

As part of being asked to evaluate the quality of collision detection present within LASTS during interview, participants from Group A and Group B2 were also asked to assess the ability of the LASTS environment to replicate the confines of the real world MGR. This was done in order to determine whether user control within the virtual MGR was consistent with that within the real world MGR as a product of the spatial confines of the environment.

Interview data from participants in Group A revealed a number of common trends amongst responses in relation to the quality of collision detection and accuracy to which the confines of the real world MGR were replicated within the LASTS environment:

- Three of the seven participants interviewed commented that the absence of equipment in the virtual MGR reduced the clutter and subsequently diminished the accuracy with which the confines of the real world MGR were depicted by LASTS;
- Four of the participants within Group A also made reference to the absence of tactile sensation within the virtual MGR to indicate when they had collided or rebounded off an object, with one participant suggesting that a visual cue, such as a flash of colour, could be used to indicate a collision;

A number of minor problems were also identified with the collision detection around some of the diesel engines and the ladder between deck sections by two of the participants in Group A. Similarly, two respondents from Group B2 also made reference to minor collision issues with the ladder and other objects within the virtual MGR. Collectively though, Group B2 participants indicated greater satisfaction with the quality of the collision detection and replication of the spatial confines of the real world MGR than Group A during interview. The only other issue identified by participants in Group B2 consistent with responses from Group A was that of the need for visual cues to aid in identifying collisions with objects, with one participant suggesting that a visual reference such, as a hand, may have been beneficial in this regard.

During interview, Andrew Widdis indicated that the collision detection within the LASTS environment was of a reasonable standard that was capable of being improved upon given sufficient time to perform optimization techniques. Andrew suggested that this would require the creation of a dynamic avatar object to represent the user within the virtual environment that was of a relative size and scale to the virtual MGR environment.

4.3.5 Validity of the 3D Environment Component of the Model

Having analysed the LASTS environment using the evaluation criteria from the 3D Environment component of the model, it is now pertinent to use the same gathered data to assess the validity of 3D Environment component itself. The data gathered as part of the LASTS case study will now be examined with reference to each aspect of this component identified as supporting the valid representation of real world three dimensional environments.

4.3.6 Validity of Three Dimensional Representation

Given the three dimensional nature of real world environments, it stands to reason that computer-generated 3D environments can be used to accurately represent the dimensions, perspectives, and distances contained within real world environments to scale, provided that such information is available during the development of the virtual environment.

Andrew Widdis stated during interview that detailed information, available as derived CAD data, was utilized during development to create a scale representation of the MGR. In this fashion, the same information used in the design and manufacture of the real world MGR was also applicable and able to be utilized in the construction of a virtual representation inside a three dimensional computer-generated environment. The CAD data expressed the dimensions, perspectives, and relative distances of the MGR on-board a Collins class submarine in three dimensions. These three dimensional properties of the MGR were successfully replicated by the LASTS environment according to participants in Group A and Group B2. This demonstrates that the three dimensional representation inherent in computer-generated 3D environments is a determinant factor in the valid representation of real world environments.

4.3.7 Validity of High Visual Fidelity

FPS games are typically considered to be on the cutting edge of gaming technology with regard to the quality of their visual elements. These games rely on providing the user with an immersive and engaging first person experience within the gaming environment, requiring an authentic and highly detailed visual representation in order to facilitate this process. The engines used to power these games commonly rely on the application of textures, shadows, lighting, and reflection effects in order to achieve the high quality visuals inherent in most FPS games. While the visual characteristics provided by FPS game engines make them ideal for creating engaging game environments, they also lend themselves well to the development of simulation environments with the potential to accurately represent real world environments with a high visual fidelity.

Three of the five respondents in Group B2 indicated that they were adequately able to recognise elements of the virtual MGR during their assessment of the textures, lighting, shadows, and reflections within the LASTS environment. This suggests that these participants found that the high quality visual characteristics of the LASTS environment assisted in creating a representation of the real world MGR in which the items within it, and the environment itself, were recognisable. This indicates that the high visual fidelity inherent in 3D FPS environments contributes to the valid representation of real world environments.

4.3.8 Validity of Immediate System Response

In order for a simulation environment to meaningfully represent a real world environment it must be able to respond to user input and changing conditions in a manner consistent with the real world environment it is representing. This entails replicating the ability to move, look, and interact freely within a real world environment that responds immediately to change within the confines of a simulation environment. 3D FPS simulation environments are capable in this regard, as the underlying game engines that power these environments are designed to handle the high visual demands placed upon them by FPS environments while still being responsive enough to not diminish game play.

Comments obtained during interview with Andrew Widdis revealed that the average frame rate for the LASTS environment was more than adequate for creating the illusion of movement within the virtual MGR. Information provided by participants in Group A and Group B2 also indicated that the LASTS environment was very responsive in updating the display as a result of user input. Collating these responses, it is evident that the LASTS environment was responsive enough to create the illusion of movement as provided by changes in the position and orientation of the participant within the virtual MGR. Thus, the illusion of movement provided by the LASTS environment as a result of the continuous and responsive update of the display facilitated movement within the virtual MGR in a manner consistent with the real world MGR. Participants within the LASTS environment could look and move throughout the virtual MGR and immediately observe changes to their position and orientation. This suggests that the immediacy of the system response provided by 3D FPS simulation environments is a determinant factor in the valid representation of real world environments.

4.3.9 Validity of User Control

A valid representation of a real world environment by a simulation requires that the method of interaction between individuals and the real world environment be replicated by some means

within the virtual environment. In much the same way as individuals are able to exert influence on the environment around them in the real world, so too must virtual environments replicate this ability in order to provide a valid representation. True to all FPS 3D environments, participants using the LASTS environment were given the ability to control their position and orientation within the environment using a first person viewing perspective and input from the mouse and keyboard. In this manner, the LASTS environment was able to replicate the means by which people were able to move and look within the real world MGR environment.

The degree of control afforded to participants within the LASTS environment was evaluated in terms of how well they were able to control their movement and viewing perspective with reference to interaction with the objects around them within the virtual MGR. Responses from participants indicated that the LASTS environment provided sufficient control over movement and the viewing perspective, despite the identification of some issues relating to collision detection, including the accuracy with which the spatial confines of the real MGR were represented by the LASTS environment. Having established the presence of user control within the LASTS environment is self evident. Given the three dimensional nature of real world environments, there is an inherent need for the ability to look and move freely in order to operate within, and extract meaning from, the environment. This indicates that the ability of the user to control their position and orientation within a 3D FPS simulation environment is a determinant factor in the valid representation of real world environments.

4.3.10 Summary for 3D Environments

Proponents of computer based learning contend that computer-generated 3D environments based on FPS gaming technology are a valid means by which to simulate three dimensional real world environments. Spatial cognition and simulation based learning theories suggest that the transfer of spatial representation is most effective when the disparity between the virtual and real world environment is minimised. As such, the virtual representation provided by a 3D simulation environment must be valid in order for meaningful transfer to be achieved. It has been argued that 3D environments based on FPS game engines are a valid means for simulating real world environments based on their ability to represent three dimensional spaces at a high visual quality while maintaining a frame rate that allows the user fluid control of the virtual environment. The high visual fidelity inherent in environments constructed using FPS game engines exhibits the potential to enhance realism and facilitate a sense of presence and immersion within the virtual environment. The 3D Environment component of the model was derived from this theoretical construct to identify the key aspects of 3D game engine environments that support the representation of real world three dimensional environments. Based on the responses of participants to the evaluation criteria relevant to the 3D Environment component of the model, the following can be surmised in relation to the LASTS environment:

- The LASTS environment provided an accurate, three dimensional representation of the MGR on-board a Collins class submarine that was consistent with the dimensions, perspectives, and distances of the real world environment;
- A general level of satisfaction was evident amongst participants with regard to the ability of the LASTS environment to depict the objects and architecture native to the real world MGR in three dimensions.;
- Participants collectively demonstrated a general level of satisfaction with the visual elements of the LASTS environment, although a number of issues were identified as a result of a deficiency in the detail of textures within the virtual MGR;
- The LASTS environment was deemed to be very responsive with regard to the immediacy of the feedback it provided, with participants consistently rating this attribute of the environment very highly;
- Participants indicated a general level of satisfaction with regard to the freedom of movement and control of the viewing perspective afforded by the LASTS environment. However, a number of prevalent issues were identified with the replication of the confines of the real world MGR by LASTS owing to the absence of items that altered the confines of the virtual MGR, and the absence of tactile sensation;
- Overall, participants rated the degree of control they were afforded within the LASTS environment as satisfactory, while also acknowledging that this degree of control was diminished to some degree during their interaction with objects in a manner that was not entirely consistent with that of the real world MGR.

With reference to the data gathered as part of the LASTS case study, there is evidence to suggest the veracity of the 3D Environment component of the model as an effective depiction of the valid representation of real world environments using 3D FPS simulation environments. The overall effectiveness of the LASTS environment to represent the real world MGR was indicated via the positive responses of both trainee and experienced submariner participants. The aspects of three dimensional representation, high visual fidelity, immediate system response, and user control, acknowledged as being factors in the validity of representation of real world environments by 3D FPS environments, were identified amongst the gathered data as supporting this process.

4.4 Validating the Combined Model

Having independently demonstrated the veracity of the Simulation Learning Transfer, Spatial Cognition, and 3D Environment components of the model, it is now appropriate to evaluate the validity of the combined model with reference to the data gathered as part of the LASTS case study. Recalling that the model consists of five primary principles common to all three components of the model, and four secondary principles common to two components of the model, an examination of the gathered data can be conducted with reference to the evaluation criteria identified for each principle respectively.

4.4.1 Three Dimensional Representation as a Primary Principle of the Model

Three Dimensional Representation was designated a primary principle of the model as it was identified as being a determinant factor with reference to spatial cognition, simulation based learning transfer, and the valid representation of real world spaces using virtual environments:

- The formation of spatial representations of real world environments requires extraction of spatial information pertaining to the location and orientation of phenomena in three dimensions;
- Learning transfer between virtual and real world environments requires an authentic representation to be provided by the virtual environment on a physical and function level, necessitating a three dimensional representation;
- A computer-generated 3D environment is a valid means by which to represent the three dimensional characteristics of real world environments;

With reference to the LASTS environment, the evaluation criteria and data collection methods for the Three Dimensional Representation principle of the model are outlined in Table 23 accordingly:

 Table 23: Evaluation criteria and data collection methods for the Three Dimensional

 Representation primary principle of the model.

Criterion for evaluation	Collection Method
Ability with which to determine locational information of phenomena within the environment (Spatial Cognition component)	QU_B2 (20) QU_B1 (4)
Degree to which three dimensional arrangement of elements	QU_A (1)
relative to assigned tasks in the real world are preserved within	QU_B2 (2)
the simulation environment (Simulation Learning component)	INT_A (1)
Ability to which the environment can model objects, architecture	INT_AW (24)
and landscape in three dimensions (3D Environment component)	QU_B2 (3)

4.4.1.1 Spatial Cognition Component of Three Dimensional Representation

In order to determine the ability of participants to determine locational information within the MGR environment, participants from Group B1 and Group B2 were required to mark the locations of items included as part of the simplified 12 PSR on a series of diagrams after the completion of the simplified 12 PSR exercise. To complete the map marking exercise, participants from Group B1 and Group B2 would have relied upon their respective spatial representations of the MGR environment, formed as a result of their training together with their experience in completing the simplified 12 PSR. Given that both groups of participants completed the same exercise within the real world MGR, it is reasonable to assume that the differences between their respective spatial representations after having completed the simplified 12 PSR could be attributed to the differences in training received by the two groups of participants. As such, the map marking exercise provides some indication as to determine the ability with which each group of participants were able to determine locational information of phenomena within the MGR environment.

The diagrams used during the map marking exercise were the same as those used by Group B1 as part of the paper based training they received prior to the exercise, albeit with one minor modification whereby all the top down diagrams were presented such that they detailed the lower level of the MGR. This diagram is depicted by Figure 9 accordingly:



Figure 9: Questionnaire diagram used by participants in Group B1 and Group B2 to mark the locations of items included in the simplified 12 PSR exercise.

Figures 10 through 14 represent the locations of items as marked by participants in Group B1 and Group B2 respectively for the MGR Bilge Hatch, AFT Submerged Signal Ejector, AFT Submerged Signal Ejector Controller, Emergency Pyrotechnic Locker, and Fire Fighting Equipment. For each of these figures, yellow circles represent the actual locations of items, while blue and pink crosses are used to indicate the locations marked by participants in Group B1 and Group B2 respectively. The locations depicted by the yellow circles were taken from the diagrams in the training booklet presented to Group B1 as part of their training prior to the simplified 12 PSR exercise. Note that Figures 10 through 14 do not represent instances where participants did not provide a mark to indicate the location of an item, and that multiple markings for different participants in the same location were difficult to replicate on a single diagram.





Figure 10: Collective map markings for Group B1 and Group B2 for the MGR Bilge Hatch.













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Cross-Sectional Elevation - Taken from Centre-line Looking to Port

Figure 13: Collective map markings for Group B1 and Group B2 for the Emergency Pyrotechnics Locker.

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Figure 14: Collective map markings for Group B1 and Group B2 for the Fire Fighting Equipment.

Given that participants in Group B1 were already familiar with the plan and cross-sectional diagrams of the MGR as a result of their training, it would have been reasonable to assume that these participants would have been noticeably superior in the map marking exercise compared to those in Group B2. However, results of the map marking exercise collectively suggested that:

- Participants in Group B1 and Group B2 exhibited a similar degree of accuracy in their ability to mark the locations of items included in the simplified 12 PSR;
- Participants from Group B1 had a tendency to be more accurate when marking the locations of items on the cross-sectional diagram than on the plan diagram. This tendency was also made evident during interview, whereby two of the participants made mention of a preference for the cross-sectional diagram over the plan diagram.

Group B2 participants, on the other hand, were more consistent between the cross-sectional and plan diagrams used as part of the map marking exercise. They also had no previous experience with the diagrams used as part of the map marking exercise, and as such would have been relying solely on their cognitive map of the MGR environment in order to complete the exercise. The comparable performance of the map exercise, consistency of accuracy between cross-sectional and plan diagrams, and the lack of familiarity with the diagrams themselves exhibited by Group B2 suggests

a greater spatial awareness of the MGR environment in three dimensions as a result of their experience within the LASTS environment. The map marking exercise indicates that participants in Group B2 were able to abstract the three dimensional spatial representation they formed within the LASTS environment and apply it with a comparable level of accuracy to representations of the MGR presented from differing perspectives. This suggests that the three dimensional representation provided by the LASTS environment was a determinant factor in the formation of an effective three dimensional cognitive map of the MGR environment.

4.4.1.2 Simulation Learning Component of Three Dimensional Representation

The extent to which the three dimensional arrangement of items included in the simplified 12 PSR exercise was preserved within the LASTS environment was evaluated from the perspectives of trainee and experienced submariners. Participants in Group A and Group B2 were asked to gauge the accuracy with which the locations of items included in the simplified 12 PSR were reflected within the LASTS environment on a scale of 0 to 10. Participants in Group A were also asked to respond to the degree of this accuracy during interview. Responses to the questionnaire are displayed in Table 24 accordingly: Table 24: Questionnaire responses between 0 and 10 from participants in Group A and GroupB2 in relation to the accuracy with which the locations of items included in the simplified 12PSR were reflected within the LASTS environment

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How accurately were the locations of objects used as part of the exercise on- board the Collins class submarine reflected within the LASTS simulation environment?	8	8	9	8	7	7	9	6	9	7.9	3
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How accurately were the locations of objects used as part of the exercise on- board the Collins class submarine reflected within the LASTS simulation environment?	10	9	10	10	8					9.4	2

Consistent with the data displayed in Table 24, interview responses from participants in Group A were very positive, indicating that all items included in the simplified 12 PSR were in their correct locations within the virtual MGR. These positive responses from experienced submariners, coupled with the fact that the virtual MGR was derived from the CAD data, provide strong evidence to indicate that the locations of items included in the simplified 12 PSR were represented very accurately by the LASTS environment. This accuracy is further evidenced in light of the effective completion of the simplified 12 PSR exercise by participants in Group B2. These participants were able to successfully locate and identify the series of items included in the simplified 12 PSR as a result of forming a spatial representation that included the same items in the same locations within the virtual MGR. Thus, the three dimensional representation of objects within the LASTS environment was determinant in facilitating the effect transfer of knowledge pertaining to the location of these objects in three dimensional space to the real world MGR.

4.4.1.3 3D Environment Component of Three Dimensional Representation

Having already analysed the ability with which objects and architecture are represented in three dimensions as part of the 3D environment component of the model, no further analysis is necessary in order to reaffirm that three dimensional representation is a determinant factor in the valid representation of real world environments with 3D FPS simulation environments.

4.4.1.4 Summary for Three Dimensional Representation

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that three dimensional representation is a determinant factor in spatial cognition, learning transfer, and the valid representation of real world environments using 3D simulation environments based on FPS gaming technology. This is consistent with the Three Dimensional Representation principle, which was identified as being a key aspect of the Spatial Cognition, Simulation Learning Transfer, and 3D Environment components of the model.

4.4.2 High Visual Fidelity as a Primary Principle of the Model

High visual fidelity was designated a primary principle of the model as it was identified as being a determinant factor with reference to spatial cognition, simulation based learning transfer, and the valid representation of real world spaces using virtual environments:

- Non-immersive 3D environments rely on visual elements to impart spatial information, therefore these visual elements need to be of high quality to facilitate spatial cognition;
- High visual fidelity has the potential to increase the sense of presence and immersion, thereby facilitating the transfer of knowledge;
- The high visual fidelity inherent in 3D environments based on FPS gaming technology creates the potential for the realistic depiction of real world environments.

With reference to the LASTS environment, the evaluation criteria and data collection methods for the High Visual Fidelity principle of the model are outlined in Table 25 accordingly:

Table 25: Evaluation criteria and data collection methods for the High Visual Fidelity primary
principle of the model.

Criterion for evaluation	Collection Method
Ability with which to determine attributional information of phenomena within the environment (Spatial Cognition component)	QU_B2 (1) QU_B1 (1)
Degree to which resultant presence and immersion compel undertaking of assigned tasks (Simulation Learning component)	INT_A (2) and (3) INT_B2 (1) and (2)
Quality of textures, lighting, shadows and reflections (3D Environment component)	INT_AW (21) INT_A (4) INT_B2 (3) QU_A (3) QU_B2 (4)

4.4.2.1 Spatial Cognition Component of High Visual Fidelity

Ascertaining the ability with which attributional information of phenomena could be determined within the MGR environment entailed participants in Group B1 and Group B2 providing written descriptions of the items included as part of the simplified 12 PSR as part of their respective questionnaires. Consistent with the map marking exercise, participants were asked to provide these written descriptions immediately after completing the simplified 12 PSR within the real world MGR. As such, participants from Group B1 and Group B2 would have been drawing on the spatial representations formed as a result of their respective training in conjunction with their experience in completing the simplified 12 PSR within the real world MGR. Given that both groups of participants completed the same exercise within the real world environment, differences in the written descriptions provided by each group of participants can be attributed, in part, to the differences in their respective training.

The written descriptions provided by participants in Group B1 and Group B2 were examined for the frequency of specific references to colour, shape, size, relative position, and function for the items included in the simplified 12 PSR exercise. This information is tabulated in Table 26 as follows:

 Table 26: Frequency of references to colour, shape, size, relative position, and function amongst written descriptions of items included in the simplified 12 PSR by Group B1 and Group B2.

Group	Colour	Shape	Size	Relative Position	Function
B1	14	6	6	17	8
B2	4	6	8	46	11

With reference to Table 26, a number of observations can be made with reference to the item description exercise:

- Participants in Group B1 and Group B2 provided a similar number of references to shape, size, and function in their descriptions of items included in the simplified 12 PSR;
- Group B1 participants providing more references to colour;
- Group B2 participants provided more references to relative position;

Given the superior performance of Group B2 participants in completing the simplified 12 PSR exercise, the disparity in the frequency of references to the relative position of items suggests that Group B2 participants had a better spatial awareness of the MGR environment. However, it should be noted that references to the relative position of items are locational spatial information, and not attributional.

The disparity in the frequency of references to colour between Group B1 and Group B2 may be explained in light of the fact that Group B1 participants were provided with actual photos of the real world items during training, while participants in Group B2 were instead provided with virtual representations of these items contained within the virtual MGR. During interview, all five participants in Group B1 made reference to colour being used as a source of attributional spatial information by which to locate and identify items included in the simplified 12 PSR. However, the frequency of references to shape, size, and function within the written descriptions of items by Group B1 and Group B2 were similar. This demonstrates a similar degree of ability with which to determine attributional information among participants in Group B1 and Group B2 for three of the four attributional categories observed in the written descriptions of participants. Assuming that the differences between the attributional information obtained by participants in Group B1 and Group B2 were the result, in part, of their respective types of training, it is reasonable to suggest that the photographs and virtual depictions of items provided a similar degree of attributional information to participants. This suggests that the high visual fidelity inherent within the LASTS environment was required in order to provide a comparable level of attributional information to that of a colour photograph. This demonstrates the need for high quality visual elements within 3D FPS simulation environments in order to facilitate the formation of effective spatial representations.

4.4.2.2 Simulation Learning Component of High Visual Fidelity

In order to assess the effect that the high visual fidelity had on presence, immersion, and ultimately knowledge transfer, participants from Group A and Group B2 were asked during interview whether they felt a sense of presence and immersion during their experience within the virtual MGR, and to what extent this compelled them to engage with the LASTS environment. The interview responses from these participants are summarised as follows:

- Responses from Group A in regard to a sense of presence and immersion were varied, ranging from non existent, to some level of presence and immersion, to a definite sense of presence and immersion;
- The subsequent extent to which a sense of presence motivated Group A to engage with LASTS was also varied, ranging from no degree of engagement, to some degree of engagement, to a high degree of engagement;
- The degree to which immersion compelled participants in Group A to engage with LASTS was identified as being little, to some;
- Responses from participants in Group B2 tended to be more positive, confirming some degree of presence and immersion and resultant desire to engage with the LASTS environment;

Based on the responses given by participants in Group A and Group B2, it is evident that collectively, Group B2 experienced a greater degree of presence, immersion, and desire to engage with the LASTS environment as a result, compared to Group A. Given the deficiency in graphical detail identified by participants in Group A, it is reasonable to assume that these participants may have experienced a greater sense of presence and immersion, and been subsequently more compelled to engage with the LASTS environment, had the visual elements within the virtual MGR been of higher quality. Furthermore, given the familiarity with the MGR environment of participants in Group A, the visual fidelity of the environment would have been a more determinant factor in their desire to engage compared to participants in Group B2. Participants in Group B2 were relatively unfamiliar with the MGR environment and would therefore have been more willing to engage with it in order to explore an unfamiliar space compared to participants in Group A. This suggests that the visual fidelity inherent within a 3D virtual environment is a factor in determining the willingness of users to engage with the environment. Given that engaging with the LASTS environment included the provision of the instructor led walk-through, which was intended to replicate the simplified 12 PSR in order to provide an assigned task for the purpose of learning transfer, the gather data indicates that the visual elements of the virtual environment effected the desire to engage with said task, and thus the degree of learning transfer. This suggests that the high visual fidelity inherent within 3D FPS simulation environments is a determinant factor in facilitating the transfer of knowledge between the virtual environment and the real world.

4.4.2.3 3D Environment Component of High Visual Fidelity

Having already analysed the quality of textures, lighting, shadows, and reflections as part of the 3D environment component of the model, no further analysis is necessary in order to reaffirm that high visual fidelity is a determinant factor in the valid representation of real world environments with 3D FPS simulation environments.

4.4.2.4 Summary for High Visual Fidelity

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that high visual fidelity is a determinant factor in spatial cognition, learning transfer, and the valid representation of real world environments using 3D simulation environments based on FPS gaming technology. This is consistent with the High Visual Fidelity principle, which was identified as being a key aspect of the Spatial Cognition, Simulation Learning Transfer, and 3D Environment components of the model.

4.4.3 Immediacy of Feedback as a Primary Principle of the Model

Immediacy of Feedback was designated a primary principle of the model as it was identified as being a determinant factor with reference to spatial cognition, simulation based learning transfer, and the valid representation of real world spaces using virtual environments:

- Spatial cognition requires the ability to look and move freely within an environment in order to be effective. The immediacy of feedback provided by 3D FPS simulation environments creates the illusion of movement, thus supporting this process;
- The immediacy of feedback inherent in 3D FPS simulation environments allows users to move and interact freely within the virtual environment in much the same way as they would in the real world, thus facilitating experiential based learning consistent with situated cognition and constructivist learning theories;
- Immediate system feedback is necessary in order to replicate interaction within real world environments at a functional level.

With reference to the LASTS environment, the evaluation criteria and data collection methods for the Immediacy of Feedback principle of the model are outlined in Table 27 accordingly:

 Table 27: Evaluation criteria and data collection methods for the Immediacy of Feedback

 primary principle of the model.

Criterion for evaluation	Collection Method
Extent to which system response supports free movement and control of viewing perspective within the environment (Spatial Cognition component)	QU_B2 (5) QU_A (4)
Extent to which system response supports the undertaking of assigned task (Simulation Learning component)	INT_AW (20) QU_A (4) QU_B2 (5)
Frame rate equal to, or exceeding, twenty frames a second (3D Environment component)	INT_AW (18)(a) and (b) QU_A (5) QU_B2 (6)

4.4.3.1 Spatial Cognition and Simulation Learning Components of Immediacy of Feedback

Determining the extent to which the system response of the LASTS environment supported free movement and control of the viewing perspective involved participants in Group A and Group B2 quantifying this extent on a scale of 0 to 10 in their respective questionnaires. The responses provided to this question were also used to determine the extent to which this system response supported the completion of the instructor led assigned walk-through task within the LASTS environment. These responses are displayed in Table 28 accordingly:

Table 28: Questionnaire responses between 0 and 10 from participants in Group A and GroupB2 in relation to the extent to which the system response of the LASTS environment supportedfree movement and control of the viewing perspective.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How responsive to your actions did you find the LASTS simulation environment and to what degree did this enable you to complete the exercise?	8	10	9	8	6	6	9	7	8	7.9	3
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How accurately were the locations of objects used as part of the exercise on- board the Collins class submarine reflected within the LASTS simulation environment?	8	9	10	9	8					8.8	2 .

With reference to Table 28, feedback indicated a general level of satisfaction with the responsiveness of the LASTS environment that reflected the successful performance of the assigned walk-through task within the virtual MGR by all participants. Based on the positive evaluation provided by participants, and the successful completion of the walk-through exercise within the LASTS environment, it is reasonable to conclude that the system response of the LASTS environment was sufficient enough to support the undertaking of the assigned task within the virtual MGR. Had the LASTS environment been deficient with regard to the speed with which it responded to user input, the illusion of free movement within the virtual MGR would have been compromised. This in turn would have diminished the ability with which participants were able to form spatial representations, and furthermore reduced their ability to perform the assigned walk-through task within the virtual environment. This suggests that immediate system response is required in order to create the illusion of movement necessary for forming spatial representations within a virtual environment for the purpose of supporting learning transfer.

4.4.3.2 3D Environment Component of Immediacy of Feedback

Having already analysed the frame rate criteria as part of the 3D environment component of the model, no further analysis is necessary in order to reaffirm that the immediacy of system feedback is a determinant factor in the valid representation of real world environments with 3D FPS simulation environments.

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4.4.3.3 Summary for Immediacy of Feedback

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that the immediacy of system feedback is a determinant factor in spatial cognition, learning transfer, and the valid representation of real world environments using 3D simulation environments based on FPS gaming technology. This is consistent with the Immediacy of Feedback principle, which was identified as being a key aspect of the Spatial Cognition, Simulation Learning Transfer, and 3D Environment components of the model.

4.4.5 User Control as a Primary Principle of the Model

User Control was designated a primary principle of the model as it was identified as being a determinant factor with reference to spatial cognition, simulation based learning transfer, and the valid representation of real world spaces using virtual environments:

- The ability to look and move freely is required in order to extract spatial information from an environment and subsequently form spatial representations;
- Control over interaction with the virtual environment is needed in order to replicate real world tasks with meaningful assigned tasks within the virtual environment. User control is also necessary for experiential based learning;
- The ability to exercise control over interaction within the virtual environment is necessary in order to replicate the same control inherent with experience in real world environments.

With reference to the LASTS environment, the evaluation criteria and data collection methods for the User Control principle of the model are outlined in Table 29 accordingly:

 Table 29: Evaluation criteria and data collection methods for the Immediacy of Feedback

 primary principle of the model.

Criterion for evaluation	Collection Method
Degree of movement and control of viewing perspective (Spatial Cognition component)	QU_A (6) (a) and (b) QU_B2 (7) (a) and (b)
Degree to which controls permit the execution of assigned task within the environment (Simulation Learning component)	INT_A (5) INT_B2 (4) QU_A (7) QU_B2 (8)
Quality of collision detection (3D Environment component)	INT_AW (16) and (17) INT_A (6) INT_B2 (5) QU_A (8)

4.4.5.1 Spatial Cognition Component of User Control

Having already analysed the degree of movement and control of viewing perspective as part of the Spatial Cognition component of the model, no further analysis is necessary in order to reaffirm the determinant nature of user control in the formation of spatial representations.

4.4.5.2 Simulation Learning Component of User Control

In order to determine the degree to which the controls used by the LASTS environment permitted the execution of the instructor led walk-through within the virtual MGR, participants from Group A and Group B2 were asked to gauge this degree on a scale of 0 to 10 and also provide a more detailed response during interview. Questionnaire responses for Group A and Group B2 are detailed in Table 30 as follows:

Table 30: Questionnaire responses between 0 and 10 from participants in Group A and GroupB2 in relation to effectiveness of the control schema within the LASTS environment.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How effective were the controls (the mouse and keyboard) in permitting the completion of the exercise within the LASTS environment?	7	10	9	9	6	8	10	9	9	9.0	3
Group B2 participant	R 1	DO	D 2	D A	D 5					Ava	Danga
	D _1	D_ 2	D_3	D_4	D_ 3					Avg.	Kange
How effective were the controls (the mouse and keyboard) in permitting the completion of the exercise within the	10	9	10	10	8					9.4	2

In keeping with the questionnaire responses detailed in Table 28, interview responses from participants in both Group A and Group B2 were also very positive, with no prevalent issues identified with the control schema. Based on the collective positive feedback provided by both groups of participants, as well as the successful completion of the walk-through exercise by all participants using LASTS, it is reasonable to infer that the control schema used by LASTS was adequate enough to allow the completion of the assigned task within the environment. The successful completion of the simplified 12 PSR exercise by participants in Group B2 provides evidence to suggest that the assigned task undertaken within the LASTS environment, which was identified as being consistent with a compartment layout or rounds type scenario similar to

the simplified 12 PSR by participants in Group A, facilitated the transfer of spatial knowledge to the real world MGR. Given the consistent positive response provided in relation to the degree of control afforded by the LASTS environment, it can be concluded that this degree of control exercised some degree of influence in the transfer of spatial knowledge between environments. This suggests that user control is necessary within a 3D simulation environment in order for users to undertake meaningful and appropriate assigned tasks so as to support the transfer of knowledge to the real world environment being modelled.

4.4.5.3 3D Environment Component of User Control

Having already analysed the quality of collision detection within the LASTS environment as part of the 3D Environment component of the model, no further analysis is necessary in order to reaffirm the determinant nature of user control in the valid representation of real world environments by 3D FPS simulation environments.

4.4.5.4 Summary for User Control

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that user control is a determinant factor in spatial cognition, learning transfer, and the valid representation of real world environments using 3D simulation environments based on FPS gaming technology. This is consistent with the User Control principle, which was identified as being a key aspect of the Spatial Cognition, Simulation Learning Transfer, and 3D Environment components of the model.

4.4.6 Integrated Instructional Support as a Primary Principle of the Model

Integrated Instructional Support was designated a primary principle of the model as it was identified as being a determinant factor with reference to spatial cognition, simulation based learning transfer, and the valid representation of real world spaces using virtual environments:

- The provision of assigned tasks consistent with the development of spatial awareness can be used to guide the formation of spatial representations within the virtual environment;
- Learning needs to be structured around a meaningful task that is contextually relevant to the real world environment and the knowledge that needs to be transferred;
- Integrated instructional support in the guise of assigned tasks can be integrated into 3D FPS simulation environments via the provision of the scripting languages included in FPS games.

With reference to the LASTS environment, the evaluation criteria and data collection methods for the Integrated Instructional Support principle of the model are outlined in Table 31 accordingly:

 Table 31: Evaluation criteria and data collection methods for the Integrated Instructional

 Support primary principle of the model.

Criterion for evaluation	Collection Method
Degree to which spatial information pertaining to items related to the simplified 12 PSR can be recognized and recalled (Spatial Cognition component)	INT_B2 (6) and (7) INT_B1 (1) and (2) INT_CPO (1), (2), (5), and (6) Comparison of simplified 12 PSR for B1 and B2
Degree to which instructional support is integrated into the environment (Simulation Learning component)	QU_A (9) QU_B2 (10) INT_AW (14)
Degree to which the scripting language or developmental tools support the creation of appropriate assigned tasks within the environment (3D Environment component)	INT_AW (10), (11), (12), (13) (a) - (d)

4.4.6.1 Spatial Cognition Component of Integrated Instructional Support

Evaluating the degree to which spatial information pertaining to items included in the simplified 12 PSR could be recognized and recalled entailed examining the ability with which participants in Group B1 and Group B2 responded to the simplified 12 PSR, as well as interviewing these participants and CPO Allistair Hogarth regarding their respective performances.

Previous analysis of the simplified 12 PSR exercise revealed that Group B2 participants exhibited greater knowledge of the submarine, possessed a greater ability to recognise items, and performed the simplified 12 PSR exercise with greater confidence than Group B1 participants as evaluated by CPO Allistair Hogarth. In relation to the ability with which each group was able to recognize and recall spatial information relevant to the items included in the 12 PSR, the following was elicited from comments made by CPO Allistair Hogarth during interview:

- Group B1 were somewhat slow and got confused between FWD and AFT;
- Group B2 were more efficient than Group B1 at recognizing items and possessed a greater sense of space;
- Group B1 relied on information within the photographs provided during training and did not make a good association with the items and their location. These participants instead scanned the space for the actual item that matched the photo;
- Group B2 made use of the MGR space as a whole to locate items, and then made the

comparison between the real world item and the equivalent virtual item as depicted by LASTS in order to identify it.

These responses indicate that participants in Group B1 did not possess sufficient locational spatial information of items included in the simplified 12 PSR, and instead relied on an exhaustive search to compare the attributional information provided by the photograph to items in the MGR in order to identify them. These observations were reflected in comments made by participants in Group B1 during interview, indicating a reliance on colour to identify items, which was also manifested during the item recognition exercise whereby Group B1 participants exhibited a higher frequency of responses to colour in their descriptions compared to Group B2. Interview responses from Group B1 also suggested a reliance on their memory of the photographs and diagrams provided during training in order to find items, rather than an overall spatial awareness of the environment.

In contrast to Group B1, responses from CPO Allistair Hogarth indicated that Group B2 participants utilized locational spatial information to locate items, and attributional information to identify them during the simplified 12 PSR exercise. The greater confidence observed by CPO Allistair Hogarth amongst participants in this group compared to those in Group B1 was also reflected in the comments made by Group B2 participants during interview. Group B2 indicated a collective high degree of confidence in their ability to recognise and recall locational and attributional spatial information of items included in the simplified 12 PSR.

While the instructional support provided within the LASTS environment was somewhat limited and rudimentary in nature, it did serve to provide an association between the identity of the item and its locational and attributional spatial information. This integration allowed the identity of each item and its associated locational and attributional spatial information to be presented collectively to participants using the LASTS environment. Participants in Group B2 however, were presented with the identity and associated locational and attributional spatial information of each item as separate elements on each page of the training booklet. Given that CPO Allistair Hogarth identified a deficiency in the ability of participants in Group B1 to associate the identity of items included in the simplified 12 PSR with the relevant spatial information, this suggests that the integration of the scripted naming display function into the LASTS environment served to provide a better collated and combined set of spatial information for each item included in the 12 PSR. This in turn suggests that the integration of instructional support into 3D FPS simulation environments can support the development of spatial representations provided said support is relevant to spatial cognition.

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4.4.6.2 Simulation Learning Component of Integrated Instructional Support

Having already evaluated the degree to which instructional support was integrated into the LASTS environment as part of the Simulation Learning Transfer component of the model, no further analysis is necessary in order to reaffirm the determinant nature of integrated instructional support in the facilitation of learning transfer.

4.4.6.3 3D Environment Component of Integrated Instructional Support

In order to evaluate the scripting language and development tools made available as part of the Unreal Runtime game engine, LASTS developer Andrew Widdis was asked to comment as to their ability to support the creation of assigned tasks. During interview, Andrew acknowledged that the scripting languages and development tools did support the creation of assigned tasks within the virtual environment, but the complexity and functionality of said tasks was dependent on the amount of development time available and knowledge and expertise with the scripting language and development tools. Andrew also stated that these scripts and tools could be used to to emulate some of the standard tasks performed on-board Collins class submarines, including item check-lists and emergency scenarios requiring a series of tasks to be completed in order to achieve an end result. This suggests that the scripting languages and development tools provided by FPS game engines can be utilized to create instructional support that is integrated into the virtual environment in the form of assigned tasks. Furthermore, this instructional support is capable of replicating real world tasks and scenarios, thereby exercising the potential to enhance the validity of the representation of the real world environment being depicted.

4.4.6.4 Summary for Integrated Instructional Support

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that integrated instructional support is a determinant factor in spatial cognition, learning transfer, and the valid representation of real world environments using 3D simulation environments based on FPS gaming technology. This is consistent with the Integrated Instructional Support principle, which was identified as being a key aspect of the Spatial Cognition, Simulation Learning Transfer, and 3D Environment components of the model.

4.4.7 Authenticity of the Simulation Environment as a Secondary Principle of the Model

Authenticity of the Simulation Environment was designated a secondary principle of the model as it was identified as being a determinant factor with reference to simulation based learning transfer and the valid representation of real world spaces using virtual environments:

- The degree of similarity between the context and culture of the virtual environment and that of the real world environment being represented is a factor in the effectiveness of learning transfer;
- Physical and functional authenticity is required for the valid depiction of real world environments by 3D FPS simulation environments.

With reference to the LASTS environment, the evaluation criteria and data collection methods for the Authenticity of the Simulation Environment principle of the model are outlined in Table 32 accordingly:

 Table 32: Evaluation criteria and data collection methods for the Authenticity of the Simulation

 Environment principle of the model.

Criterion for evaluation	Collection Method
Accuracy with which the context and culture of the real world environment is depicted within the simulation environment (Simulation Learning component)	INT_A (7)
Accuracy with which the simulation environment represents the real world environment at a physical and functional level (3D Environment component)	QU_A (10) (a) and (b) QU_B2 (11) (a) and (b) INT_A (8) and (9) INT_B2 (8) and (9)

4.4.7.1 Simulation Learning Component of Authenticity of the Simulation Environment

Having already evaluated the accuracy of the contextual and cultural depiction provided by the LASTS environment as part of the Simulation Learning Transfer component of the model, no further analysis is necessary in order to reaffirm the determinant nature of the authenticity of the simulation environment in the facilitation of learning transfer.

4.4.7.2 3D Environment Component of Authenticity of the Simulation Environment

In order to determine the accuracy with which LASTS represented the real world MGR on a physical level, participants in Group A and Group B2 were asked to rate the ability of the LASTS environment to represent the scale, positioning and orientation of the real world MGR on a scale of 0 to 10. The same participants were also asked to provide a response during interview as to the accuracy with which LASTS portrayed the look and feel of the real world MGR, and the degree to which this subsequently provided a realistic impression of scale, positioning, and orientation. Questionnaire responses are presented in Table 33 as follows:

 Table 33: Questionnaire responses between 0 and 10 from participants in Group A and Group

 B2 in relation to the ability with which LASTS represented the scale, positioning, and

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_ 7	A_8	A_9	Avg.	Range
How accurately does the LASTS simulation environment represent the scale, positioning, and orientation of the MGR on-board a Collins class submarine?	6	8	8	9	5	10	8	7	9	6.63	5
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
Harry a payment also do an the			,								

orientation of the real world MGR.

Consistent with the responses detailed in Table 33, interview responses from participants in Group A suggested a general level of satisfaction with the scale, positioning, and orientation in the LASTS environment with reference to the real world MGR. These responses indicated that the LASTS environment was adequately accurate in its depiction of the physical characteristics of the real world MGR, however, a number of minor issues were identified during interview:

- Two of the participants in Group A identified issues in relation to the clutter and spatial confines of the environment not being depicted accurately;
- One participant in Group B2 also made reference to the inability of the LASTS environment to reflect the confines of the real world MGR.

Evaluating the accuracy with which the LASTS environment represented the real world MGR on a functional level required participants in Group A and Group B2 to rate the ability of the LASTS environment to depict the manner in which people operated within the real world MGR on-board a Collins class submarine on a scale of 0 to 10. Participants were also asked to comment on the accuracy of the LASTS environment to depict the functional behaviour of the real world MGR, with reference to behaviour and response within the virtual MGR. Questionnaire responses from participants are depicted by Table 34 accordingly:

 Table 34: Questionnaire responses between 0 and 10 from participants in Group A and Group

 B2 in relation to the the accuracy of operations within LASTS with reference to the real world

 MGR.

Group A participant	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Avg.	Range
How accurately is operating within the MGR on-board a Collins class submarine depicted within the LASTS environment?	8	8	8	8	6	-	9	6	7	7.5	3
Group B2 participant	B_1	B_2	B_3	B_4	B_5					Avg.	Range
How accurately is operating within the MGR on-board a Collins class submarine depicted within the LASTS environment?	8	8	9	10	7	~				8.4	3

Interview responses from participants in Group A were very consistent, with all participants indicating that LASTS was more static than the real world MGR. These participants also suggested that there was little to no real functionality within the LASTS environment, save for the ability to move within the virtual MGR, which was identified as being satisfactory given the purpose of the environment. Responses from participants in Group B2 during interview were consistent with those of Group A with regard to the perceived lack of functionality and general static nature of the LASTS environment. Two of the five participants in Group B2 also indicated that the level of functionality provided by the LASTS environment was sufficient for the purpose of compartmental familiarization and locating items.

The responses from participants in Group A and Group B2 in relation to the authenticity of the LASTS environment can be summarised as follows:

- The physical characteristics of the real world MGR were represented in the virtual MGR at an adequate enough level to provide a realistic impression of scale, positioning, and orientation;
- The LASTS environment was observed to be static, offering no real functionality between the user and the environment except for the ability to traverse the environment and display the names of items included in the simplified 12 PSR on the screen as they were selected with the mouse;
- Both groups of participants tended to acknowledge that, with reference to the responses in Table 32, while there was very little functionality provided by the LASTS environment, the functionality that was provided was sufficient enough for the purpose of developing environmental awareness of the MGR environment.

Given the different perspective provided by participants in Group A and Group B2 in relation to their experience within the real world MGR, it is somewhat self evident that the authenticity of the simulation environment is a factor in determining the validity with which the simulation environment represents the real world environment it is modelling. Both groups of participants were able to make observations and evaluations regarding the LASTS environment with reference to the real world MGR, identifying discrepancies where they existed and confirming valid aspects of the virtual environment in light of their experience. This indicates that the authenticity of the simulation environment is a factor in the valid representation of real world environments.

4.4.7.3 Summary for Authenticity of the Simulation Environment

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that the authenticity of the simulation environment is a determinant factor in learning transfer, and the valid representation of real world environments using 3D simulation environments based on FPS gaming technology. This is consistent with the Authenticity of the Simulation Environment principle, which was identified as being a key aspect of the Simulation Learning Transfer, and 3D Environment components of the model.

4.4.8 Situated Tasks as a Secondary Principle of the Model

Situated Tasks were designated a secondary principle of the model as it was identified as being a determinant factor with reference to spatial cognition and simulation based learning transfer:

- Situated tasks relevant to the development of spatial awareness can be used to guide the formation of spatial representations;
- There is a need for learning to be structured around a meaningful task that is contextually relevant to the real world environment and the knowledge that needs to be transferred.

With reference to the LASTS environment, the evaluation criteria and data collection methods for the Situated Tasks principle of the model are outlined in Table 35 accordingly:

 Table 35: Evaluation criteria and data collection methods for the Situated Tasks principle of the

Criterion for evaluation	Collection Method
Degree to which situated tasks enhance spatial knowledge of the environment (Spatial Cognition component)	INT_AW (9) INT_A (10) INT_B2 (10) INT_CPO (9) and (10) Comparison of simplified 12 PSR for B1 and B2
Extent to which assigned tasks are situated relative to tasks within the real world environment (Simulation Learning component)	QU_A (11) INT_A (11)

model.

4.4.8.1 Spatial Cognition Component of Situated Tasks

Ascertaining the degree to which the instructor led walk-through of the virtual MGR enhanced the spatial awareness of the MGR environment entailed the elicitation of interview responses from participants in Group A and Group B2, as well as Andrew Widdis and CPO Allistair Hogarth in order to provide a variety of different perspectives for evaluation.

Participants in Group A were asked to provide a response as to how effective they felt the walkthrough exercise would be in developing the spatial awareness of submariners within the real world MGR environment. Feedback provided by participants in Group A collectively indicated a very positive response in relation to the effectiveness of the instructor led walk-through of the virtual MGR for new trainee submariners. Two of the participants in Group A also suggested that the effectiveness of the walk-through exercise could be increased further by subjecting new trainees to a tour of the real world MGR prior to using the LASTS environment, so as to provide a sense of contextual awareness. Collective responses to the same interview question were also very positive from participants in Group B2, who indicated that the walk-through of the virtual MGR was the next best thing to performing a walk-through in the real world MGR given the limited time available for training on an actual Collins class submarine.

Developer Andrew Widdis indicated during interview that he felt the instructor led virtual walkthrough of the LASTS environment was of great benefit in enhancing the spatial awareness of trainee submariners of the real world MGR. Andrew suggested that trainees would have a greater sense of confidence and appreciation of space within the MGR environment as a result of their experience within the LASTS environment. This contention was justified in the performance evaluation of participants in Group B2 undertaking the simplified 12 PSR by CPO Allistair Hogarth, who confirmed that Group B2 were more confident and had a better spatial understanding of the MGR environment compared to participants in Group B1. Given the collective positive response to the instructor led walk-through task within the LASTS environment as a facilitator of spatial awareness from the perspectives of trainee submariners, experienced submariners, the LASTS developer, and CPO Allistair Hogarth, it is reasonable to contend that this task would have a positive influence on the development of spatial awareness of the MGR environment. Furthermore, the superiority demonstrated by Group B2 in performing the simplified 12 PSR exercise compared to Group B1 may have been in some part the result of the provision of the virtual walk-through, as Group B1 participants had no such situated task to complete during their training. This suggests that situated tasks are a factor in the formation of spatial representations in 3D FPS simulation environments, provided that said tasks are relevant to the process of spatial cognition, which as demonstrated in previous analysis, was the case with regard to the LASTS environment.

4.4.8.2 Simulation Learning Component of Situated Tasks

Having already evaluated the extent to which the instructor led virtual walk-through was relevant to real world tasks on-board a Collins class submarine as part of the Simulation Learning component of the model, no further analysis is necessary in order to reaffirm the determinant nature of the situated tasks in the facilitation of learning transfer.

4.4.8.3 Summary for Situated Tasks

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that the provision of situated tasks are a determinant factor in spatial cognition and learning transfer. This is consistent with the Situated Tasks principle, which was identified as being a key aspect of the Spatial Cognition and Simulation Learning Transfer components of the model.

4.4.9 Legibility of the Environment as a Secondary Principle of the Model

The legibility of the simulation environment was designated a secondary principle of the model as it was identified as being a determinant factor with reference to spatial cognition and simulation based learning transfer:

- The formation of spatial representations relies upon spatial information to be legible in order to be extracted and interpreted meaningfully;
- A simulation environment needs to be legible in order for users to recognize it as the representation of a given real world environment such that effective learning transfer can occur.

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With reference to the LASTS environment, the evaluation criteria and data collection methods for the Legibility of the Environment principle of the model are outlined in Table 36 accordingly:

 Table 36: Evaluation criteria and data collection methods for the Legibility of the Environment principle of the model.

Criterion for evaluation	Collection Method
Ease with which elements within the environment are recognized (Spatial Cognition component)	QU_A (12) QU_B2 (12)
Ability at which elements included in the simplified 12 PSR can be identified and recognized (Simulation Learning component)	Comparison of simplified 12 PSR for B1 and B2

4.4.9.1 Spatial Cognition Component of Legibility of the Environment

Having already evaluated the ease with which items within the LASTS environment could be recognized, no further analysis is necessary in order to reaffirm the determinant nature of the legibility of the simulation environment in the process of spatial cognition.

4.4.9.2 Simulation Learning Component of Legibility of the Environment

Previous analysis regarding the simplified 12 PSR has demonstrated that Group B2 participants were capable in their ability to identify and recognize items included in the exercise, and that this ability was developed via their experience within the LASTS environment. This process entailed the development of a spatial representation of the virtual MGR, which was then transferred and utilized in order to complete the simplified 12 PSR within the real world MGR. In order for this to occur, the LASTS environment had to provide a legible representation such that participants in Group B2 could successfully make the association between elements in the virtual MGR and the actual equivalents in the real world MGR. This indicates the need for a simulation environment to be legible so as to support learning transfer between virtual and real world environments.

4.4.9.3 Summary for Legibility of the Environment

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that the legibility of the simulation environment is a determinant factor in spatial cognition and learning transfer. This is consistent with the Legibility of the Environment principle, which was identified as being a key aspect of the Spatial Cognition and Simulation Learning Transfer

components of the model.

4.4.10 Quality of Spatial Information as a Secondary Principle of the Model

The quality of spatial information available within a 3D FPS simulation environment was designated a secondary principle of the model as it was identified as being a determinant factor with reference to spatial cognition and the valid representation of real world spaces using virtual environments:

- The quality of spatial information is a key factor in the formation of spatial representations;
- The characteristics of 3D FPS simulation environments allow them to provide high quality spatial information to the visual sensory modalities.

With reference to the LASTS environment, the evaluation criteria and data collection methods for the Quality of Spatial Information principle of the model are outlined in Table 37 accordingly:

 Table 37: Evaluation criteria and data collection methods for the Legibility of the Environment principle of the model.

Criterion for evaluation	Collection Method
Level of distortion between virtual environment and real environment (Spatial Cognition component)	QU_A (13) QU_B2 (13) INT_A (12) INT_B2 (11)
Quality and detail of textures and surfaces (3D Environment component)	QU_A (14) QU_B2 (14) INT_AW (6) INT_A (13) INT_B2 (12)

4.4.10.1 Spatial Cognition Component of Quality of Spatial Information

Having already evaluated the level of distortion between LASTS and the real world MGR, no further analysis is necessary in order to reaffirm the determinant nature of the quality of spatial information in the process of spatial cognition.

4.4.10.2 3D Environment Component of Quality of Spatial Information

Previous analysis pertaining to the quality and detail of textures and surfaces within the LASTS environment with respect to the Spatial Cognition component of the model indicated that

participants regarded them as being of a generally high standard, though lacking in some minor detail. Given the reliance on visual elements to impart information inherent amongst 3D FPS simulation environments such as LASTS, it is evident that the quality of spatial information available to participants within the LASTS environment was of an adequate enough level to support the process of spatial cognition. The performance of the simplified 12 PSR by Group B2 provides evidence to indicate the utilization of spatial representations formed as a result of experience within the LASTS environment. These representations were formed via the extraction and interpretation of spatial information within the virtual MGR, information that was presented via the visual capabilities of the LASTS environment. This indicates that the quality of spatial information available for the formation of spatial representations is dependent on the visual capabilities of the 3D FPS simulation environment.

4.4.10.3 Summary for Quality of Spatial Information

Based on the data gathered as part of the LASTS case study, there is evidence to suggest that the quality of spatial information is a determinant factor in spatial cognition and the ability with which a 3D FPS simulation environment can support the process of spatial cognition in a manner consistent with the real world environment it represents. This is consistent with the Quality of Spatial Information principle, which was identified as being a key aspect of the Spatial Cognition and 3D Environment components of the model.

4.4.11 Combined Model Summary

The data gathered as part of the LASTS case study has provided evidence to indicate the veracity of the model proposed in relation to the third research question, which sought to determine which characteristics of 3D simulation environment based on FPS gaming technology enhanced spatial awareness in real world environments. This model proposed that a 3D FPS simulation environment could be used to enhance the spatial awareness of real world environments via the formation of a cognitive map that could be transferred and used within the real world environment being represented. The determinant principles identified by the model as supporting this process were used to derive evaluation criteria by which to assess the effectiveness of the LASTS environment, and also the validity of the principles and components that these principles, and the model itself, offer a valid representation of the key characteristics of 3D FPS simulation environments involved in the enhancement of spatial awareness in real world environments.

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5.0 Findings and Conclusion

The LASTS case study was undertaken in order to validate the model of spatial cognition in 3D FPS simulation environments proposed by this research. To this end, the LASTS environment was assessed in its ability to enhance the spatial awareness of the real world MGR in accordance with criteria derived from the model. Findings and conclusions can thus be drawn with reference to the effectiveness of the LASTS environment to act in this capacity, and the validity of the proposed model to represent the process of spatial cognition in 3D simulation environments based on FPS gaming technology.

5.1 Evaluation of the LASTS Environment

Based on analysis performed on the data gathered as part of the LASTS case study, the following findings can be stated in relation to the ability of the LASTS environment to enhance the spatial awareness of submariners in the MGR on-board a Collins class submarine:

- While both LASTS and paper based trainees performed well in the simplified 12 PSR, trainee submariners using the LASTS environment demonstrated a greater knowledge of the submarine, possessed a greater ability to recognise items, and performed the simplified 12 PSR exercise with greater confidence than those trainees who received paper based training. LASTS trainees also completed the simplified 12 PSR exercise in approximately half the time of paper based trainees.
- Observations made by CPO Allistair Hogarth during the simplified 12 PSR exercise suggested that participants who had used the LASTS environment were operating with a more developed spatial awareness of the MGR environment than those trainees who received paper based training. Analysis of these observations with reference to the Landmark, Route, Survey model of spatial cognition suggested that participants who received paper based training were operating at the lower landmark level of spatial cognition, while those trainees who used LASTS were operating at the high survey level of spatial cognition. Evidence indicating a greater spatial awareness of participants who used the LASTS environment was also made evident during the item description exercise, whereby LASTS participants provided more references to the relative positioning of items in their descriptions than non LASTS participants.
- The LASTS environment provided an accurate, three dimensional representation of the MGR on-board a Collins class submarine that was consistent with the dimensions, perspectives, and distances of the real world environment.
- LASTS provided sufficient freedom of movement and control of the viewing perspective for participants to effectively gather spatial information within the virtual

MGR environment.

- The LASTS environment was responsive enough in its ability to provide feedback to participants in response to their input to allow them to complete the walk-through exercise within the virtual MGR.
- LASTS provided sufficient authenticity for conducting training similar in nature to rounds or compartment layout type scenarios, but deficient in the level of detail required for more sophisticated types of training.
- The limited level of instructional support integrated into the LASTS environment was identified as being adequate for trainees not familiar with the MGR to learn the names associated with items relevant to the simplified 12 PSR exercise, but of a more questionable value to participants already familiar with these items.
- A general deficiency in detail and failure to represent the spatial confines of the real world MGR were identified by participants as being the two most prevalent causes of discrepancy between the virtual and real world MGR environments.
- The lack of detail perceived in the LASTS environment, particularly by participants with extensive experience on-board Collins class submarines, was found to diminish the cultural depiction of the LASTS environment, whereby any indication as to human presence within the virtual MGR was absent.
- The graphical and visual elements of the LASTS environment were satisfactory for imparting spatial information, but did not provide a great sense of presence or immersion amongst participants.
- Trainee submariner participants tended to have a more optimistic view of the LASTS environment compared to participants with extensive experience on-board a Collins class submarine, both in questionnaire and interview.

While these findings identify both positive and negative aspects of the LASTS environment, they more importantly indicate that the LASTS environment was successful in enhancing the spatial awareness of the MGR environment for participants in the study who were not familiar with the MGR on-board a Collins class submarine. Analysis of the data gathered as part of the case study provided evidence to indicate the utilization of a spatial representation developed as a result of experience in the LASTS environment. Furthermore, this spatial representation appeared to be functioning at the survey level of the Landmark, Route, Survey model of spatial cognition, and encompassed a solid understanding of the spatial characteristics of the MGR environment.

Simulation environments built upon FPS gaming technology such as LASTS exhibit great potential as spatial awareness training tools for real world environments. As evidenced by the LASTS case study, participants were successfully able to learn the spatial characteristics of an environment they had little familiarity with without needing to travel to the real world environment itself in order to do so. Furthermore, this was achieved on relatively low cost desktop computer environments using software that is adaptable from proven FPS gaming technology. In an environment such as a Collins class submarine, this type of training is invaluable given the possibility of limited access to the real world environment as a result of time constraints, deployment, or logistical considerations. While LASTS consisted only of a one room representation of a Collins class submarine, this environment can be expanded given sufficient time and resources to depict a complete Collins class submarine. This depiction could also include representation of some of the operations performed on-board a Collins class submarine using the scripting abilities inherent in FPS game engines. A complete model would allow trainees to form spatial representations that span across multiple compartments, thus providing them with the knowledge required to traverse the whole submarine efficiently and effectively.

5.2 The Model of Spatial Cognition in 3D FPS Simulation Environments

The model of spatial cognition in 3D FPS simulation environments proposed by this research was used as a foundation by which to evaluate the effectiveness of the LASTS environment to enhance the spatial awareness of the real world MGR. Analysis of the data gathered in relation to this evaluation criteria indicated that the LASTS environment exhibited all the characteristics required to support spatial learning transfer to the real world MGR to some degree. This assessment reflected the results of the simplified 12 PSR exercise performed within the real world MGR, whereby participants who had used the LASTS environment were successfully able to locate and identify a series of items as a result of the spatial representation they had formed within the virtual MGR. Thus, the model proposed by this research was validated with reference to an existing 3D FPS simulation environment that effectively enhanced spatial awareness of the real world environment it represented.

Beyond the evaluation of existing 3D FPS simulation environments, the model proposed by this research exhibits potential as an effective tool by which to inform the design of future products. In this capacity, the model could assist in the development of 3D simulation environments based on FPS gaming technology by providing a design framework consisting of the interrelated components and principles validated via the LASTS case study. In this manner, the principles of the model could function as a list of necessary features that are known to determine the ability with which the 3D FPS simulation environment is able to enhance the spatial awareness of the real world environment it is representing. As such, development of these features would be a priority; the presence and effectiveness of which could be determined using the evaluation criteria derived from the model. Thus, by implementing the model developed in accordance with this research as a tool by which to inform design, the development of future 3D FPS

simulation environments with the objective of enhancing spatial awareness of real world environments can be focussed on features that are known to contribute to the effectiveness of this outcome.

5.3 Limitations of the Study

The following limitations to this study were identified and acknowledged as having the potential to affect the results:

- LASTS did not feature any audio, and as such, participants in the study would have been unable to obtain any auditory information from the LASTS environment that may have assisted them in forming a cogent spatial representation. No conclusions may be drawn with reference to the effect of audio cues in the development of spatial representations in 3D FPS simulation environments as a result;
- The MGR was the only room that was fully detailed within the LASTS environment. Broad ranging conclusions about the effectiveness of the LASTS system for an entire Collins class submarine can not be drawn.
- The previous experience with the real world MGR environment by participants in Group B1 and Group B2 had the potential to affect results. However, given that these participants were asked during interview to detail the extent of this experience, which was subsequently identified as minimal, comparative results between Group B1 and Group B2 still remain valid as the previous experience amongst all participants in these groups was similar. Ideally, it would be preferable to use participants who had no familiarity whatsoever with the real world environment, but this was difficult given the voluntary nature of the ESP training program.
- The sample size was too small to support any detailed statistical analysis. However, trends and patterns were identified within the results that supported the validity of the model proposed by this research.
- The sample size was too small to draw any major conclusions with reference to the ability of 3D FPS simulation environments to support spatial cognition in real world environments, or the validity of the model proposed by this research.
- Of the twenty-one participants involved in this study, only one was female. No female participants were involved in the evaluation of the LASTS environment.

5.4 Further Research

A number of areas for potential future research were also identified during the course of the LASTS case study:

- The speed at which participants using the LASTS environment were able to complete the simplified 12 PSR exercise compared to participants who received the paper based training was unexpected. The time taken to complete an exercise appropriate to spatial cognition in a real world environment may provide some indication as to the nature and effectiveness of the spatial representation formed as a result of experience within a 3D FPS simulation environment;
- The inability of the LASTS environment to replicate the spatial confines of the real world MGR via the provision of tactile sensation was identified as one of the more prevalent discrepancies between the virtual and real world MGR environments. Given that non-immersive environments such as LASTS rely on the visual medium to impart information, replicating the spatial confines of a real world environment may be achievable via the provision of a visual reference to indicate collisions or proximity to objects in the virtual environment;
- Given the rudimentary nature of the instructional support that was integrated into the LASTS environment, further research is required in order to explore the extent to which the scripting languages and development tools inherent in FPS game engines can be used to support spatial cognition;
- The role of sound in a three dimensional environment as a source of spatial information and its subsequent role in the formation of spatial representations;

5.5 Conclusion

While the number of participants involved in this study were insufficient for the results to be statistically significant, the evidence provided does indicate that the LASTS environment is a suitable training tool for developing spatial awareness of the MGR on-board a Collins class submarine for trainee submariners. Trainees using the LASTS environment demonstrated an effective spatial understanding of the MGR environment as a result of their experience within the virtual MGR.

The model of spatial cognition in 3D FPS simulation environments proposed by this research that attempted to identify and represent the characteristics that support the process of spatial cognition was validated via analysis of the data gathered as part of the LASTS case study. As such, this model has the potential to aid in the design and development of future 3D simulation environments based on FPS gaming technology with the objective of enhancing spatial awareness in real world environments.

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Appendices

Appendix A – Interview Transcripts for Group A

Please note that the term 'the exercise' refers to the simplified 12 Point Safety Round.

(1) How accurately were the locations of objects used as part of the exercise on-board the Collins class submarine reflected within the LASTS simulation environment? Were these objects arranged correctly relative to other objects around them? Was everything where it was supposed to be?

A1 – Pretty close, accurate. Everything was where is was supposed to be.

A2 – Pretty accurate.

A3 – Very good. Everything that was there was where it was supposed to be, although more detail would be better. Some items are missing.

A4 – Pretty much spot on.

A5 – Placement is quite accurate. Nothing is out of order for what is there (implying that some items are missing).

A6 – Same as A5 (both stokers). Felt that some detail was missing.

A7 – Pretty good. Easy enough to find my way around. Major parts are in the right spots. Seemed OK. Looked like the MGR of a Collins class submarine.

(2) Did you feel a sense of being 'present' in the LASTS simulation environment, such that you felt as though you had a physical presence within the virtual environment? To what extent did this compel you to engage with the LASTS simulation environment?

A1 – Sort of, not overly, like playing a FPS. Some degree of engagement due to presence.

A2 - No.

A3 – No, good realism, but no real sense of presence once you have served on a boat.

A4 – To an extent, sort of realistic, can relate to being there.

A5 – You do feel a sense of presence. You feel like you're walking through. Bound to see what you want to interact with.

A6 – .

A7 – Yes, I certainly did. I wanted to find out what else I could do.

(3) Did you feel a sense of immersion within the LASTS simulation environment, such that you felt a sense of involvement or absorption within the virtual environment? To what extent did this compel you to engage with the LASTS simulation environment?

A1 - A little bit, which provided some degree of engagement.

A2 – No.

A3 – Not really in light of having served on a boat.

A4 – Sort of, can relate to being there.

A5 – Certainly to an extent.

A6 –

A7 – Not really, happy to navigate around, but that was it.

(4) How would you rate the quality of the textures, lighting, shadows, and reflections within the LASTS simulation environment?

A1 – Good. 9/10.

A2 - Good.

A3 – Good to very good.

A4 – Pretty good. Everything was nicely rendered.

A5 – Textures good. Rocker cover shapes were not right, kit missing from diesels (pipes and exhaust manifold are missing). Some textures are low grade, such as those on the keyboards and screens, which need a high degree of clarity.

A6 – .

A7 – Pretty good. Colours are slightly skewed, there is paint missing. The cream colour paint in the real MGR (missing from LASTS) creates a more illuminated space as it reflects the fixed lighting.

(5) How effective were the controls (the mouse and keyboard) in permitting the completion of the exercise within the LASTS simulation environment? Did the controls create any barriers to completing this task?

A1 – Good. Easy to use, no problems.

A2 – Seemed OK, no barriers.

A3 – Good, no problems.

A4 – Good, no problems.

A5 – Easy stuff. Anyone with any 3D games experience will find this easy.

A6 - No problems, the controls were fine.

A7 – No problems, easy enough (non gamer).

(6) How would you rate the quality of the LASTS simulation environment to detect and respond to contact or collisions between your virtual self and objects within the environment? How well did the LASTS simulation environment replicate the confines of the Main Generator Room on-board a Collins class submarine?

A1 – Didn't really have any problems. The real MGR seems more cluttered with gear lying around.

A2 – Seems OK, you don't hit your head as you would in the real MGR. Confines were not realistically replicated.

A3 – You don't bump / rebound off anything. Scale and confines were both OK.

A4 – Not too bad. When you come to a stop you could have a flash of colour when you hit your head. Confines not too bad, difficult to replicate. Couldn't get down the sides of the motors unless you crouched, which is the same as in real MGR.

A5 – Fairly good, a few hangings on diesel motors and some other areas. There was no tactile sensation. The height (of the viewing perspective) was not quite right. Adding some more pipe work would replicate the confines better.

A6 – No great problems.

A7 – Some areas were difficult to access, such as the ladders. I was able to access some areas that I would not be able to in the real MGR, such as under the SSE. Confines were OK, nothing is going to be perfect in this environment. Toolboxes were missing (in relation to confines).

(7) How accurately is the context and culture of a real world Main Generator Room onboard a Collins class submarine depicted within the LASTS simulation environment? Are there any elements present within the real world Main Generator Room that are missing that could impact on the effectiveness of training within the LASTS simulation environment?

A1 – More boxes missing, seems good.

A2 - It's not hot. There is no sound (real MGR is noisy), doesn't smell, minor bits and pieces and gauges, more detail, internals etc.

A3 – Not very similar due to access restrictions, people and contractors missing. Freedom of access is good. Lot more detail in naming displays.

A4 – Pretty good, needs sound, valves, pipes, more detail.

A5 – Add rags, day to day items, such as tools and spanners. The real MRG has buckets and boxes everywhere when seagoing (stores). There is no lived in look. No parts are lying around, not giving a day to day feel. No danger tags.

A6 – Many day to day items are missing. Needs more detail is this regard.

A7 – Need the noise of diesels, air conditioning, and the ambient noise is missing. Clinically clean, not generally a perfectly clean environment.

(8) How accurately do you feel the LASTS simulation environment represented the actual Main Generator Room on-board a Collins class submarine in terms of the look and feel of the simulation environment? How well did the look and feel of the simulation environment give a realistic impression of scale, positioning, and orientation of the real world Main Generator Room on-board a Collins class submarine?

A1 – Pretty close, fairly accurate.

A2 – All right, wandering around would be OK, but it is no substitute for real world experience. Wouldn't unleash a new sailor by themselves in the MGR after simulation.

A3 – Realism is great in light of training context. Scale etc. is good. Can't depict confines,

crawling under things etc.

A4 – Pretty good, scale etc. was very good.

A5 – No paint on rockers or other things (should be cream colour). Parts are missing, valves, pipes. Scale, positioning, and orientation are excellent.

A6 – The clutter wasn't replicated.

A7 – Yes, all good.

(9) How accurately did the LASTS simulation environment depict the functional behaviour of the real world Main Generator Room? Did objects function within the LASTS simulation environment as they do in real life? Did the LASTS simulation environment behave and respond to your actions as you would expect within the real world Main Generator Room?

A1 – LASTS was more static than the real world MGR.

A2 – Not really, pretty static.

A3 – Static. No real functionality. Walking around was OK, but no interaction with systems.

A4 – Lack of functionality.

A5 – No functionality, static. No exhaust railings.

A6 – Functionality level fine for navigating through the boat if more rooms were complete. Would be fine for initial training, but not adequate for more technical or higher level training.

A7 – No functionality. Movement functionality OK though.

(10) How effective do you feel the exercise within the LASTS simulation environment would be in assisting the development of your environmental awareness of the Main Generator Room? Do you feel that this exercise would be beneficial in developing the environmental awareness of trainees who had not yet been inside the Main Generator Room on-board a Collins class submarine?

A1 – Help them a lot, help them find items. Wouldn't need to ask questions of experienced crew.

A2 – Effective, good as a start out thing. Definitely help trainees. A good tool.

A3 – For trainees, absolutely huge benefit. Qualified submariners would not receive much benefit. Yes, better than nothing. Trainees would benefit from a guided tour of the real MGR first in terms of better developing their situational awareness.

A4 – Real effective. Good for new trainees.

A5 – In conjunction with tour of real submarine would be good for set of rounds type scenario. Need to walk through first in order to put everything in context.

A6 – .

A7 – Very, very effective. Very beneficial for initial course for those who had not been

on-board in terms of learning the locations of equipment.

(11) How appropriate do you feel the exercise within the LASTS simulation environment was in relation to actual operations on-board a Collins class submarine within the Main Generator Room?

A1 – Yes, compartment layouts.

A2 – Yes, rounds. Trainees need to find items in a trainee book, compartment layout.

A3 – Need to be linked to actual activity, much more interactive and task orientated.

A4 – Pretty good.

A5 – For rounds in the MGR, not that massive as gauges are missing etc (unable to get read out of gauges for rounds in the MGR which is required to check Halon bottle pressure etc.). Well suited to a familiarization or rounds type scenario, such as a casing sentry in harbour type situation. Not suited to engineering related tasks, as there is not enough detail such as fuel lines, injectors etc.

A6 – OK for familiarization scenario.

A7 – Yes, appropriate for non marine technician type scenarios (such as those described by A5 and A6).

(12) What distortion or inaccuracies did you feel were present between the virtual representation of the Main Generator Room and the real world one?

A1 – Couldn't really pick anything out.

A2 – It's a cartoon! Clean up minor details.

A3 – Pretty good, but separation is there between computer and real world.

A4 – None really.

A5 – Paint is missing. Some of the colours were wrong (fire extinguishers). Some items were in the wrong location. Missing components, such as Emergency Air Breathing System. Diesel detail is lacking. Cabling and pipe work is not replicated, which does not accurately represent the confines or the clutter of the MGR (sub safe tool boxes also missing).

A6 – .

A7 - It is missing a few items, which need to be added before it is ready as a real training tool.

(13) How would you rate the quality and detail of the surfaces of the objects and architecture within the LASTS simulation environment?

A1 – Good.

A2 – Some objects looked like shapes, such as the cabinets, due to a lack of detail.

A3 – Good.

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A4 - 8/10.

A5 – Deck plating textures were excellent, as were those for the Halon release. Some textures did not reflect the cream paint colour throughout the MGR. All pretty good.

A6 – .

A7 – Pretty good, more detail required on the control panels. This is not hugely important for new trainees, but an operators course would require more clarity.

(14) Given your previous experience on-board Collins class submarines, do you think that the LASTS environment could be successfully used to increase the environmental awareness of trainees prior to them getting on-board the submarine?

A1 – Help them a lot.

A2 - Yes.

A3 – Definitely.

A4 - Yes.

A5 – Casting sentry doing his rounds would find this useful, not enough detail or functionality for an engineer to do a round. Definitely useful for trainees. They would be able to find their way around more easily.

A6 – .

A7 – Definitely. There is not always a submarine available alongside for training. LASTS is a submarine alongside.

(15) What previous experience, if any, have you had with desktop computers?

A1 - Yes.

A2 - I hate them.

A3 - Yes.

A4 – Yes.

A5 – Yes.

A6 – Yes.

A7 – Some.

(16) What previous experience, if any, have you had with three dimensional computer software?

A1 – Yes, games.

A2 - A bit.

A3 – Games.

A4 – Games

A5 – Yes.

A6 – Not greatly.

A7 – Some, not really.

(17) What previous experience, if any, have you had with computer simulated training environments?

A1 – Yes, not 3D.

A2 – Yes.

A3 – Not much.

A4 – Yes, LASTS is heaps better.

A5 – Yes.

A6 – Yes.

A7 – Yes.

(18) Have you previously been on-board a Collins class submarine?

A1 – Yes.
A2 – Yes.
A3 – Yes.
A4 – Yes.
A5 – Yes.
A6 – Yes.
A7 – Yes.

(19) How familiar are you with the Main Generator Room of a Collins class submarine?

A1 – Can find my way around.

A2 – Very.

A3 - Good.

A4 – Pretty familiar.

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A5 – Yes.

A6 – Yes.

A7 – Some.

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Appendix B – Interview Transcripts for Group B1

Please note that the term 'the exercise' refers to the simplified 12 Point Safety Round.

(1) How effectively were you able to recognize and recall the locations of objects used as part of the exercise?

B1 – Visually, I could find the items well, but I could not describe them well. I needed to look around to get my bearings and familiarise myself in order to find the items.

B2 – Found it pretty easy. Recalling information was easier than recognizing. I was working from memory primarily.

B3 – Pretty good except for fire hose, which was more hidden than presented in diagrams.

B4 – Pretty good. Could recognise some items without being prompted.

B5 – Good, recall from memory easier.

(2) How effectively were you able to recognize and recall evaluative information of objects used as part of the exercise, such as their colour or shape?

B1 – Colour, association, relative size, and visual recognition to find things.

B2 – Easy. Colours of control boxes, ejector (AFT SSE) shape stood out, looked like an inverted R2D2.

B3 – Pretty good. Colour of emergency equipment stood out (bright colours, yellow or red).

B4 – Very well. Red colour fire extinguisher. Pilot air cylinder depicted two Halon bottles (this participant spotted the error).

B5 – Colour stands out in grey environment.

(3) To what degree do you feel that training you received prior to getting on-board the Collins class submarine assisted you in completing the exercise?

B1 – Needed to be longer, but it helped to form a mental image.

B2 – Training quite helpful, generally helped to assist in exercise.

B3 – Good, helpful. Easier than a computer.

B4 – Still fresh in our mind. More time would have been beneficial, but was helpful.

B5 – 30% helpful, not enough time.

(4) How well do you feel that the diagrams, photographs and descriptions of the Main Generator Room provided during training assisted you in recognizing the objects that needed to be found as part of the simplified 12 PSR on-board the Collins class submarine?

B1 – I wouldn't have found them without visual aid emphasis.

B2 - Preferred the diagrams. Photos helped in identifying unfamiliar items.

B3 – All good apart from fire hose photo of fire hose showed hose in unexpected location.

B4 – Diagrams helped, pictures helped more, which were something visual to help.

B5 – Layout was fine. One bottle picture was incorrect. The focus / highlight was on the wrong item.

(5) How effective do you feel the provided training was in developing your environmental knowledge of the Main Generator Room?

B1 – The diagrams helped me to picture where I was in the environment. I found the side on perspective diagram to be the best. Diagrams as a whole for recognition, pictures to see what the item looked like.

B2 – Fair idea of layout due to diagrams. Top down and side view both helpful to compare and develop a mental representation.

B3 – The diagrams were good. The side view diagram was the most helpful.

B4 – Very helpful. Diagrams very helpful. Understanding of environment as a result of two diagrammatic representations (top and side).

B5 – References to direction helped (arrows pointing forward and aft). Once I had a reference and knew what I was looking for, I was OK.

All participants had been on a walk through before.

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Appendix C – Interview Transcripts for Group B2

Please note that the term 'the exercise' refers to the simplified 12 Point Safety Round.

(1) Did you feel a sense of being 'present' in the LASTS simulation environment, such that you felt as though you had a physical presence within the virtual environment? To what extent did this compel you to engage with the LASTS simulation environment?

B2_1 – Present, previous experience with FPS. Standard amount of presence consistent with FPS. Compelled action within environment.

 $B2_2$ – Not to the extent that I had a physical presence, this did not effect my willingness to engage. Realism was engaging.

B2 3 -Yeh, yes.

 $B2_4$ – Just like playing a game, try and see what you can do (compelled due to presence).

B2 5 -Yeh, good, free motion made you want to look around as opposed to static.

(2) Did you feel a sense of immersion within the LASTS simulation environment, such that you felt a sense of involvement or absorption within the virtual environment? To what extent did this compel you to engage with the LASTS simulation environment?

B2_1 – Yes, standard / compatible with normal FPS game.

B2 2 - Not really, no barrier to engagement.

B2 3 -Yes, yes.

B2 4 – Not totally immersive, but good as you can wander round.

B2 5 - Not sure, always aware it was just a game. Ambient sound might be good.

(3) How would you rate the quality of the textures, lighting, shadows, and reflections within the LASTS simulation environment?

B2 $1 - \frac{8}{10}$, little bit pixelated, all very square.

B2 2 – Brilliant graphics, knew what you were looking at, realistic.

B2_3 - 7/10.

B2_4 – Quite different to real sub (refit perhaps?). Lighting biggest issue compared to real, could still work out what was what though.

 $B2_5$ – Pretty good, knew what everything was looking at. A bit sterile, too clean, not a real issue though.

(4) How effective were the controls (the mouse and keyboard) in permitting the completion of the exercise within the LASTS simulation environment? Did the controls create any barriers to completing this task?

B2 1 – Controls were good, no barriers.
B2_2 - Good, controls were easy to familiarise with, no barriers (No FPS experience).

B2_3 – Good, started floating near end ('You now feel lighter').

 $B2_4 - No$ problems.

B2_5 – Good. Mouse good for looking around. Keyboard familiar due to games. Got stuck in a few places.

(5) How would you rate the quality of the LASTS simulation environment to detect and respond to contact or collisions between your virtual self and objects within the environment? How well did the LASTS simulation environment replicate the confines of the Main Generator Room on-board a Collins class submarine?

B2 1 - 7/10, catching on objects a minor issue.

 $B2_2$ – Good, couldn't fit through spaces you would normally not be able to. Accurate depiction of where you can and can't go.

B2 3 – Good, very well replicated confines of MGR.

B2_4 – Pretty good, collision zone seemed slightly outside virtual self. No visual reference (i.e. gun, hand as in FPS).

B2 5 – Pretty good, ladder base a bit touchy.

(6) How effectively were you able to recognize and recall the locations of objects used as part of the exercise?

B2_1 – Very well, didn't have to move anywhere, rattled them all off.

B2 2 – Everything was in the same location (virtual and real), aid to memory.

B2 3 - Very easy.

B2 4 – Very well, pretty simple compartment.

B2_5 – Got them all, missed and forgot bilge hatch, otherwise easy.

(7) How effectively were you able to recognize and recall evaluative information of objects used as part of the exercise, such as their colour or shape?

B2 1 – Pretty well.

B2 2 – Pretty accurate, objects right size and colour (OCCABA).

B2 3 – Very well. Fire extinguisher at aft was red in sim, orange in real MGR.

B2 4 – Very well, I knew what I was looking for, matched virtual to real.

B2 5 – Really good, tour not as good as with a sim before hand.

(8) How accurately do you feel the LASTS simulation environment represented the actual Main Generator Room on-board a Collins class submarine in terms of the look and feel of the simulation environment? How well did the look and feel of the simulation environment give a realistic impression of scale, positioning, and orientation of the real world Main Generator Room on-board a Collins class submarine?

B2_1 – Pretty well, pretty good.

B2_2 – Sim felt roomier, no sense of objects next to you in sim. Sim didn't reflect the confines of the environment.

 $B2_3 - 8/10$, good. 7/10 or 8/10 for scale, positioning etc.

B2_4 – Accurate, very good.

B2_5 – Pretty good, more sterile. Spatially, port and starboard, forward and aft not overly evident, may be due to the symmetrical nature of the MGR.

(9) How accurately did the LASTS simulation environment depict the functional behaviour of the real world Main Generator Room? Did objects function within the LASTS simulation environment as they do in real life? Did the LASTS simulation environment behave and respond to your actions as you would expect within the real world Main Generator Room?

B2_1 – All static, not realistic. All objects within real MGR static anyway (no movement).

 $B2_2 - It$ did, not a whole lot of functionality. For what we were doing (finding objects), yes it did.

B2_3 – Sim would be better if you could open hatches, doors etc, otherwise good.

B2_4 – No real functionality, apart from click for ID of item.

 $B2_5 - Not$ much to interact with, save the ladder base. Not much functionality, but it suits it's purpose.

(10) How effective do you feel the exercise within the LASTS simulation environment would be in assisting the development of your environmental awareness of the Main Generator Room? Do you feel that this exercise would be beneficial in developing the environmental awareness of trainees who had not yet been inside the Main Generator Room on-board a Collins class submarine?

B2 1-Pretty good, unobstructed view of environment, easier. Yes, beneficial.

B2_2 – Very effective, considering limited time available on actual boat. Had good mental picture of where everything would be when I got down there.

B2 3 – Very good. Best thing you could do short of taking them into the real MGR.

B2_4 – Really good way of doing a walk through without doing a real one. Good familiarization tool. Good for pre-posting. Effective and hugely beneficial for new trainees.

 $B2_5$ – Very effective, needs to be coupled with real world training, good head start. Sim got enough info and realism for new trainees to get on-board sub and know what they were looking at.

(11) What distortion or inaccuracies did you feel were present between the virtual representation of the Main Generator Room and the real world one?

B2_1 – Size, cramped not represented. Other people and activities not represented.

B2_2 – Spatial confines of the environment. Very clean also.

B2_3 – Pretty good, no glaring oversights.

B2_4 – Fire extinguisher (wrong type), collision detection, some places you can crawl into in real life that you couldn't in sim.

B2_5 - Some smaller miscellaneous objects (oil drums, tools) not present in sim,

(12) How would you rate the quality and detail of the surfaces of the objects and architecture within the LASTS simulation environment?

 $B2_1 - Not too bad, 6/10.$

 $B2_2 - Very good.$

B2 3 - 6/10.

B2 4 – Best I've seen on a defence computer. Very good.

B2_5 – Very good, good representation.

(13) How effective do you feel training in the LASTS simulation environment was in developing your knowledge of the Main Generator Room environment on-board the Collins class submarine?

B2_1 – Pretty good.

B2 2 – Highly effective, position and orientation (forward and aft).

B2 3 – Very effective.

B2 4 - Good.

B2 5 – Very effective, spotted all items with no difficulty.

(14) What previous experience, if any, have you had with desktop computers?

B2 1 – Reasonable amount.

B2 2 -Win apps, basic.

B2 3 - A little.

B2_4 – Yes, software engineering.

B2 5 - Yes, above average.

(15) What previous experience, if any, have you had with three dimensional computer software?

B2 1-Reasonable amount.

B2 2 - No.

 $B2_3 - Not$ really.

B2_4 - Yes.

B2_5 – Yes, games.

(16) What previous experience, if any, have you had with computer simulated training environments?

 $B2_1 - Not a lot.$

B2_2 - No.

B2_3 - No.

B2_4 - Yes.

B2_5 - Yes.

(17) Have you previously been on-board a Collins class submarine?

B2_1 – Yes, once.

B2 2 – Walk around only.

B2_3 - Twice.

B2_4 - Yes.

B2_5 - Yes.

(18) How familiar are you with the Main Generator Room of a Collins class submarine?

B2_1 – Walkthrough once.

B2_2 – Brief walkthrough, no real familiarity.

 $B2_3$ – Never been there.

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B2 4 – Not overly, walkthrough only.

B2 5 - A couple of walkthroughs.

Appendix D – Questionnaire Transcripts for Group A

Please rate these following concepts on a scale of 1 to 10, with 1 being the lowest value, and 10 being the highest value:

Note that each score refers to each participant in Group A in turn, with the first score being listed for participant A1, the second for A2, and so on.

Please note that the term 'the exercise' refers to the simplified 12 Point Safety Round.

(1) How accurately were the locations of objects used as part of the exercise on-board the Collins class submarine reflected within the LASTS simulation environment?

Scores: 8 8 9 8 7 7 9 6 9 Average ~ 7.9

(2) How well did the LASTS simulation environment three dimensionally model the objects and architecture of the Main Generator Room on-board a Collins class submarine?

Scores: 7 9 9 9 7 7 9 4 8 Average ~ 7.7

(3) How well did the textures, lighting, shadows and reflections within the LASTS simulation environment serve to create a high quality visual experience?

Scores: 6 8 9 9 7 4 5 3 8 Average ~ 6.5

(4) How responsive to your actions did you find the LASTS simulation environment and to what degree did this enable you to complete the exercise?

Scores: 8 10 9 8 6 6 9 7 8 Average ~ 7.9

(5) How quickly did the LASTS simulation environment update the display in response to your actions?

Scores: 8 10 9 9 8 10 9 9 9 Average ~ 9.0

(6) (a) How freely were you able to move within the LASTS simulation environment?

Scores: 5 – 9 9 8 10 9 5 7 Average ~ 7.75

(b) How effectively were you able to control the direction you were facing within the LASTS simulation environment?

Scores: 8 8 9 9 8 10 9 5 7 Average ~ 8.1

(7) How effective were the controls (the mouse and keyboard) in permitting the completion of the exercise within the LASTS simulation environment?

Scores: 7 10 9 9 8 10 10 9 9 Average ~ 9.0

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(8) How effectively did the LASTS simulation environment respond to contact or collisions with objects and architecture as you were moving throughout the environment?

Scores: 3 9 9 7 7 10 10 6 8 Average ~ 7.67

(9) How well is the exercise integrated into the LASTS simulation environment?

Scores: 5 9 8 8 6 10 – 7 – Range: 5 Average ~

(10) (a) How accurately does the LASTS simulation environment represent the scale, positioning, and orientation of the Main Generator Room on-board a Collins class submarine?

Scores: 6 8 8 9 5 10 8 7 9 Average ~ 6.625

(b) How accurately is operating within the Main Generator Room on-board a Collins class submarine depicted within the LASTS simulation environment?

Scores: 8 8 8 8 6 – 9 6 7 Average ~ 7.5

(11) How appropriate to real world tasks within the Main Generator Room on-board a Collins class submarine was the exercise completed within the LASTS simulation environment?

Scores: 7 8 6 8 6 - - 7 -Average ~ 7.0

(12) How easily were you able to recognize objects within the LASTS simulation environment?

Scores: 8 10 9 9 6 10 10 9 8 Average ~ 8.78

(13) What level of distortion or inaccuracy did you feel was present between the LASTS simulation environment and the actual Main Generator Room on-board a Collins class submarine?

Scores: 7 9 8 3 6 7 5 5 7 Average ~ 6.34

(14) How would you rate the quality of the surfaces of objects and architecture depicted within the LASTS simulation environment?

Scores: 8 8 8 8 6 6 8 4 7 Average ~ 7.0

(15) The degree of your previous experience with desktop computers?

Scores: 10 10 9 9 4 8 10 8 8 Average ~ 8.4 (16) The degree of your previous experience with three dimensional software?

Scores: 4 10 9 8 4 6 10 4 8 Average ~ 7.0

(17) Your overall impression of the LASTS environment to represent the Main Generator Room of a Collins class submarine for the purposes of training?

Scores: 7 9 9 8 4 10 10 7 8 Average ~ 8.0

Appendix E – Questionnaire Transcripts for Group B1

(1) Please describe the following items in any terms you wish. Please be as descriptive as possible.

1. MGR Room Bilge Hatch

 $B1_1$ – Forward hatch.

B1_2 – Starboard, forward of the mmz(?)

 $B1_3$ – Metal square on floor between generator one and three opposite to pilot air cylinder.

B1_4 – See through grate hatch into the bilge room.

 $B1_5 - Access to bilge.$

2. MGR Hatch

B1_1 – Hatch in to machine room.

B1_2 - Hatch.

B1 3 – Main entrance to generator room.

B4 – Round hatch leading to the casing.

B5 – Access from casing to MGR.

3. Aft SSE

B1 1 – Outboard white round shape going into the bulkhead.

B1 2 – Cylinder looking.

B1_3 – Big white box next to SSE controller opposite MGR hatch ladder.

B1 4 – Ejector system on a 45 degree angle cylindrical in shape.

B1 5 - Fire the signals from.

4. Aft SSE Controller

B1 1 – Outboard out aft ladder bay small blue box shaped.

B1 2 - Blue box with buttons.

B1 3 – Smaller grey box next to SSE opposite MGR hatch ladder.

B1_4 – Gray box of controls adjacent to Aft SSE.

B1 5 - The signal controller.

5. Pyrotechnics Locker

B1 1 - White locker under ladder bay 3 large boxes.

B1 2 – White cabinet with two halons.

B1 3 - Large white locker next to MGR hatch ladder opposite AFT SSE controller.

B1_4 – Large rectangular box at top of the MGR walkway.

 $B1_5 - Holds$ the signals.

6. Fire fighting Equipment

B1 1 - Red in colour boxes. Occabas x 2, 2 x fire extinguishers.

B1 2 – OCABBA red boxes x 2, fire extinguishers, fire hose reel.

B1 3-All marked red, stands out from other equipment.

B1_4 – Red fire extinguishers and two red OCABBA boxes port and starboards. Black hose reel port side.

 $B1_5 - No$ response.

Please rate these following concepts on a scale of 1 to 10, with 10 being the highest value and 1 being the lowest:

Please note that the term 'the exercise' refers to the simplified 12 Point Safety Round.

(2) How effective was the training lesson you received before going on-board the Collins class submarine in preparing you to complete the exercise?

B1_1 - 7 B1_2 - 4 B1_3 - 7 B1_4 - 7 B1_5 - 5

(3) How effective do you feel the training lesson was in developing your environmental knowledge of the real world Main Generator Room on-board a Collins class submarine?

B1_1 - 7 B1_2 - 4 B1_3 - 7 B1_4 - 6 B1_5 - 7

(4) Mark the following items on the diagrams provided below See Figures 11 through 14.

Appendix F – Questionnaire Transcripts for Group B2

(1) Please describe the following items in any terms you wish. Please be as descriptive as possible.

1. MGR Room Bilge Hatch

B2_1 – Small rectangular checker plate hatch between centre and port main generators.

B2 2 – Hatch embedded in deck plates between central / stb engines.

B2 3 – Hatch allowing access to the MGR bilge. At fwd end of compartment.

B2 4 – Deck plate fwd between centre line and stbd.

B2_5 – Deck plate, silver rectangular towards fwd end of catwalk b/w diesels.

2. MGR Hatch

 $B2_1 - Aft$ access to sub.

B2 2 - Hatch leading to casing from landing where AFT SSE / controller is located.

B2_3 – Access to compartment via this hatch brings you into the aft end of the compartment.

B2 – Aft deckhead above aft SSE.

B2 - Up ladder bay AFT (port) and up to casing. White ladder bay is green and white with diagonal stripes on side.

3. Aft SSE

B2 1 – Cylindrical shaped automatic launcher.

 $B2_2$ – Signal ejection tube on upper landing with controller controlling it to the left.

B2 3 - This is just near (stbd side) of the MGR hatch ladder.

B2 4 – After part of the compartment on platform starboard side.

B2_5 – Stbd side, looks around the size of 44 gallon drum. Painted white with various valves / attachments. Connects with casing stbd side aft MGR.

4. Aft SSE Controller

B2 1 – Control panel located forward of launcher.

B2 2 -To the port side of ejection tube, small rectangular control box.

B2 3 – When facing the aft SSE this controller is on your left hand side.

B2 4 - Fwd of the SSE.

 $B2_5 - Fwd$ of the SSE panel, faces aft. Lines of circular lights / buttons. Panel grey / green.

5. Pyrotechnics Locker

 $B2_1$ – White locker.

B2 2 - Large white locker located opposite AFT SSE, lower locker of two.

B2_3 – When you come down the MGR hatch ladder this locker is directly behind you. Has a sign on it saying 'SHIP CAT'.

B2 4 – After part of the compartment on platform port side.

B2_5 – White locker under MGR hatch aft of space, rectangular with round edges. $4\frac{1}{2}$ to 5 foot high.

6. Fire fighting Equipment

B2 1 – Fire extinguishers, hose reel, Halon, OCCABAs.

B2_2 – 1 x foam ext at exit of tunnel bulkhead. 2 x OCCABA at aft end of compartment, 1 x fire hose reel at aft, port end, 1 x foam ext next to hose reel 1 x ext next to SSE.

 $B2_3$ – With the two halon release activation point and the two OCCABAs. There is also 3 fire extinguishers and a hose.

 $B2_4 - 2 \times OCCABA$ on after part of the generators, aft port side. Aft hose, dry chem ext next to pyro locker, Halon centreline aft bulkhead. Aft ext port side. Aft and stbd side fwd.

B2_5 – Extinguishers (on escape tunnel 76 bulkhead, near fire hose reel, near SSE controller panel, just below Halon release box, red panel on aft bulkhead). OCCABA stowage, hard up against diesels on aft crossdeck passage (near halon box / hose reel). Hose reel stbd side aft black reel.

Please rate these following concepts on a scale of 1 to 10, with 10 being the highest value and 1 being the lowest:

Note that each score refers to each participant in Group B2 in turn, with the first score being listed for participant B2_1, the second for B2_2, and so on.

Please note that the term 'the exercise' refers to the simplified 12 Point Safety Round.

(2) How accurately were the locations of objects used as part of the exercise on-board the Collins class submarine reflected within the LASTS simulation environment?

Scores: 10 9 10 10 8 Average: 9.4

(3) How well did the LASTS simulation environment three dimensionally model the objects and architecture of the Main Generator Room on-board a Collins class submarine?

Scores: 8 8 9 10 8 Average: 8.6 (4) How well did the textures, lighting, shadows and reflections within the LASTS simulation environment serve to create a high quality visual experience?

Scores: 8 7 7 7 7 Average: 7.2

(5) How responsive to your actions did you find the LASTS simulation environment and to what degree did this enable you to complete the exercise?

Scores: 8 9 10 9 8 Average: 8.8

(6) How quickly did the LASTS simulation environment update the display in response to your actions?

Scores: 9 9 10 10 9 Average: 9.4

(7) (a) How freely were you able to move within the LASTS simulation environment?

Scores: 10 9 8 5 7 Average: 7.8

(b) How effectively were you able to control the direction you were facing within the LASTS simulation environment?

Scores: 10 9 9 10 10 Average: 9.6

(8) How effective were the controls (the mouse and keyboard) in permitting the completion of the exercise within the LASTS simulation environment?

Scores: 10 9 10 10 8 Average: 9.4

(9) How effectively did the LASTS simulation environment respond to contact or collisions with objects and architecture as you were moving throughout the environment?

Scores: 8 7 7 8 7 Average: 7.4

(10) How well is the exercise integrated into the LASTS simulation environment?

Scores - 8 8 9 10 7 Range - 3 Average - 8.4

(11) (a) How accurately does the LASTS simulation environment represent the scale, positioning, and orientation of the Main Generator Room on-board a Collins class submarine?

Scores: 10 7 8 10 9 Average: 8.8

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(b) How accurately is operating within the Main Generator Room on-board a Collins class submarine depicted within the LASTS simulation environment?

Scores: 8 8 9 10 7 Average: 8.4

(12) How easily were you able to recognize objects within the LASTS simulation environment?

Scores: 9 10 9 10 9 Average: 9.4

(13) What level of distortion or inaccuracy did you feel was present between the LASTS simulation environment and the actual Main Generator Room on-board a Collins class submarine?

Scores: 1 7 3 1 3 Average: 3

(14) How would you rate the quality of the surfaces of objects and architecture depicted within the LASTS simulation environment?

Scores: 8 8 7 8 6 Average: 7.4

(15) How effective was the training lesson you received before going on-board the Collins class submarine in preparing you to complete the simplified 12 PSR?

Scores: 9 9 10 8 8 Average: 8.8

(16) How effective do you feel the training lesson was in developing your environmental knowledge of the real world Main Generator Room on-board a Collins class submarine?

Scores: 9 9 10 8 8 Average: 8.8

(17) Your overall impression of the LASTS environment to represent the Main Generator Room of a Collins class submarine for the purposes of training?

Scores: 9 9 10 8 9 Average: 9.0

(18) The degree of your previous experience with desktop computers?

Scores: 7 8 7 10 8 Average: 8.0

(19) The degree of your previous experience with three dimensional software?

Scores: 9 6 5 10 8 Average: 7.6

(20) Mark the following items on the diagrams provided below

1. MGR Room Bilge Hatch

2. Pilot Air Cylinder

MGR Hatch

4. Aft SSE

5. Aft SSE Controller

6. Pyrotechnics Locker

7. Fire fighting Equipment See Figures 11 through 14.

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