Exploring a Desktop Virtual Reality Application for Education: the Perspectives of Spatial Knowledge Acquisition and Information Integration

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To *Mak* and *Abah* (both my parents),
for their endless love, support and prayers.

Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

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Current practice in education encourages students to gain exposure in the real world through student visits (i.e., field trips) to sites such as process facilities (for engineering students), forests (for forestry students) and islands (for landscape architecture students), in addition to traditional textbooks and lectures. This exposure helps students to experience real world situations and integrate this experience into knowledge learned in class. This is important to students in various disciplines such as engineering, architecture and transportation.

Students, however, have limited on-site access due to issues related to safety concerns, cost and effort. In an attempt to address such issues, Virtual Reality (VR) applications have been developed and implemented. With the growth in the number of VR applications, there is currently a lack of information about the design issues of VR applications, be it from the perspective of acquiring spatial understanding of complex environments or from the perspective of integrating different types of information related to the real world. This thesis aims to bridge this gap by evaluating VR applications with respect to these issues and highlights the lessons learned from the relevant evaluations.

The results demonstrate that VR application, which links different sources of information (as developed in this thesis), promotes better learning than conventional printed materials and that students perceived it positively as a valuable complement to a physical field trip. Further findings indicate that a cut-away map (i.e., 2.5D map) is an ideal approach to assist with spatial understanding of complex environments. The design recommendations for the development of similar VR learning applications are further discussed in this thesis.

Keywords: Virtual Reality, educational software, spatial knowledge, navigation, integrated information

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Declarations

Parts of this thesis have been submitted and/or accepted for publication in advance of submission of the thesis. The publications that I have authored and co-authored are listed below, according to the year of publication:

Journal publication

- Herritsch, A., **Abdul Rahim, E.**, Fee, C.F., Morison, K.R. and Gostomski, P.A. (2013) An Interactive Virtual Tour of a Milk Powder Plant. *Chemical Engineering Education,* 47(2), 107-114 - includes part of Chapter 7.

Conference proceedings

- **Abdul Rahim, E.,** Duenser, A., Unsworth, K., McKinnon, A., Billinghurst, M., Gostomski, P., & Herritsch, A. (2013). *Visiting a Milk Factory without Gumboots: Students' Attitudes Towards a Virtual Field Trip.* Paper presented at the 2013 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE), 26-29 August 2013. Bali, Indonesia *(accepted)* – includes part of Chapter 6.

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Chapter 1
Introduction

In addition to traditional textbooks and lectures, current practice in education encourages students to gain exposure in the real world through student visits (i.e., field trips) to sites such as process facilities for engineering students (e.g., McLoughlin, 2004), forests for forestry students (e.g., Morrell, 2003) and islands for landscape architecture students (e.g., Egoz, 1999).

This exposure to, and familiarity with, real world scenarios can be related to material learned in class. The exposure also enhances students' understanding of processes in the real world (Michie, 1998) and helps them to better remember processes that occurred during the field trips (Falk & Dierking, 1997). Understanding a process may include the construction of a house or processing milk from liquid to a powder. In addition, exposure helps students gain spatial knowledge of the sites visited. Spatial knowledge allows students to develop a representation of a visited site in their minds and, therefore, makes them aware of the position and layout of the components in the site. Integrating classroom content with real world scenarios and acquiring spatial knowledge are important to students in various disciplines such as:

- *Engineering:* Students gain insights into real-time processes occurring in the real world. Spatial knowledge gained during the trip helps them with their design skills that require them to know the position of, and connections between, each piece of equipment.
- *Architecture:* Looking at designs of different buildings helps students gain insight into their scale. In addition, spatial knowledge enhances their design skills.
- *Transportation:* Looking at the different elements in a city, such as different paths, houses and buildings, helps students to plan and organise transport facilities (e.g., streets, highways, public transport).

Apart from students, spatial knowledge acquisition is also important for training in disciplines such as:

- *Fire fighting:* to assist strategy development to put out the fire and to identify the escape routes.
- *Plant operations:* the operators need both spatial knowledge and process understanding to assist with trouble shooting particular equipment in a specific location of a process plant.

Though exposure to the real world is important, students have limited opportunities for this. Gaining on-site access can be difficult because of safety concerns (Abe et al., 2005; Klemm & Tuthill, 2003), weather (Lesley & Michael, 2005), time constraints (Abe et al., 2005), and cost and effort (Lesley & Michael, 2005; Lewis, 2008). Even if access is possible, often it is a restricted, one-off trip that does not allow touring the site at the students' own pace. Therefore, students may not be able to gain sufficient insight, which may make it more difficult for them to understand the concepts learned in class and to apply that learning to real-world scenarios. In addition to this, students with impaired mobility (e.g., wheelchair bound, hearing impaired) may find it difficult to participate in a site visit, although they may have the opportunity to attend one.

In an attempt to address such issues, Virtual Reality (VR) applications have been developed and implemented. VR applications create opportunities to 'bring the environment to the users' through interactive 3D environments to enhance the learning experience (Ausburn & Ausburn, 2004).

However, with the growth of VR applications, there is currently a lack of information about the design issues of VR applications, be it from the perspective of integrating different types of information related to the real world or from the perspective of acquiring spatial knowledge in complex buildings, for example multilevel buildings with large equipment that does not fit within a single level. This thesis aims to bridge this gap by evaluating VR applications related to these issues and highlighting the lessons learned from the relevant studies.

1.1 Research motivation

Over recent decades, research related to using VR applications a) as a medium to acquire spatial knowledge and b) to relate classroom learning to a virtual environment (e.g., virtual field trip, educational software) has been conducted separately. The reason is that the literature on spatial knowledge acquisition suggests that the applications developed for spatial knowledge acquisition need to minimise the possibility of causing excess cognitive overload on the users (Haik, Barker, Sapsford, & Trainis, 2002; Witmer, Sadowski, & Finkelstein, 2002), which therefore means only the necessary components are included in the applications. Conversely, applications developed for classroom learning with the inclusion of virtual environments contain various types of information to assist students with their learning.

Given the separate literature related to spatial knowledge and learning applications, the motivation for the research related to these two is now discussed separately.

1.1.1 Spatial knowledge acquisition

The initial development of VR applications related to spatial knowledge acquisition focused on the military and aviation industries. The applications were used for simulation training, where the trainees were trained in a safe, simulated environment. The training that focused on gaining spatial knowledge was important for military and aviation trainees because they had to be aware of their surroundings as part of the job. Most studies focussed on a single-level environment, such as a large sea (Darken, Allard, & Achille, 1998) or a top-down view of a geographical area for aircraft landing (Hutchinson, 1994).

Currently, research on spatial knowledge acquisition no longer focuses on military and aviation needs but has expanded to investigate how members of the public develop their spatial knowledge using different types of aid. This is because spatial knowledge is important to the public for reasons such as evacuation planning (Mol, Jorge, & Couto, 2008), locating specific areas during an emergency (e.g., emergency room in a hospital) or understanding the structure and layout of a building for design purposes. These studies focus more on the interior of buildings commonly navigated by the public.

The studies initially focused on single level buildings (e.g., Darken & Cevik, 1999; Haik et al., 2002; Stoakley, Conway, & Pausch, 1995). However, the lack of studies for multilevel buildings motivated Chittaro and Venkataraman (2006) to conduct a similar study on a multilevel building that was to be used for evacuation training. Since then, there has been an increase in studies related to spatial knowledge acquisition in virtual multilevel buildings (Bacim, Trombetta, Rieder, & Pinho, 2008; Luo, Duh, Chen, & Luo, 2009; Luo, Luo, Chen, Jiao, & Duh, 2010).

Although several studies have been conducted on single and multilevel buildings, these studies may not be relevant to all types of building. With other building features and purposes, many of today's buildings are not confined within single and multilevel forms but go beyond that; for example, multilevel buildings with different floor layouts and different area sizes. The current increase in the number of complex buildings raises the need to have more research to aid occupants when evacuating a building in an emergency (Oosterom, Zlatanova, Fendel, Pu, & Zlatanova, 2005). The need to focus on navigation in different types of building is also supported by Phan and Choo (2010) who highlight the failure of fire fighters to put out a fire in a traditional Korean building because of their lack of knowledge of the structure of the building. In their research, they develop an Augmented Reality (AR) application to train fire fighters to navigate such buildings. In education, students, particularly engineering and architecture students, often visit buildings that are complex, such as multilevel buildings with large equipment that occupies more than one level (e.g., automobile manufacturing companies, milk processing plants, oil refineries, aluminium smelters) or modern multilevel condominiums with unique structure and layout. This further supports the need to explore the acquisition of spatial knowledge of complex, multilevel buildings.

A further motivation for this research relates not only to the type of building, but also to navigation aids used to assist the acquisition of spatial knowledge. As navigation in a virtual environment lacks sensory cues (Bowman, Davis, Hodges, & Badre, 1999), current literature focuses on evaluating different types of navigation aids such as signs, maps (Chittaro, Gatla, & Venkataraman, 2005) and cues (Steiner & Voruganti, 2004). Of all the aids, maps are common, comprehensively studied aids (Cliburn & Heino, 2009). One reason is the flexibility in developing computer-based maps that allows them to be interactive, such as being able to rotate them (Chittaro, Ranon, & Leronutti, 2009) or even use them as a direct navigation tool (moving from one location to another in the virtual environment). Regardless of the different types of map, the use of maps as a direct navigation tool is still under-explored, as many studies focus on using map as a medium to provide an overview in a virtual environment. This further motivates the exploration of using a map as a navigation aid for acquiring spatial knowledge in a complex, multilevel building.

1.1.2 VR applications as learning and teaching resources

In recent decades, there has been a revolution in the development of VR applications in education. Early developments focussed only on the inclusion of visual presentations with little additional information. With the growth of technology, current applications can make use of different information formats (e.g., 3D models, animations, videos and diagrams), including information that is not available in the real world such as looking inside a working machine (Bell & Fogler, 2004; Cameron et al., 2008; Norton et al., 2008). Combinations of information in different formats provide students with greater insights into real-world scenarios (Ausburn & Ausburn, 2004). In addition, there has been growth in open source (e.g., PanoSalado[1]) and VR application development software (e.g., Tourweaver[2], Voyager[3]), making it easier to develop applications, with less time and effort required by developers.

The simplicity of developing VR applications, alongside the ability to include various types of information, demonstrates the advantages of VR applications with respect to conventional learning resources such as paper-based learning materials (e.g., textbooks, lecture notes), where these materials have restrictions in terms of displaying interactive and integrated information.

The current state of the literature demonstrates that most VR applications use different locations (not within the same screen) to display information. This can be seen in the Virtual Chemical Reaction Module (Vicher) (Bell & Fogler, 2004), Virtual Reality Interactive Learning Environment (ViRILE) (Schofield, 2010), BP Refinery application (Cameron et al., 2008) and Virtual Trillium Trails (VTT) (Harrington, 2011), which all use multiple locations to display information.

An issue when using different locations (not within the same screen) to display information (particularly in word and picture formats) is the lack of integration between information, which may cause the students to have limited understanding compared with both words (e.g., in printed text or narration form) and pictures (e.g., illustrations or animation) being presented together (Mayer, 1997). This thesis investigates this issue by studying a VR application that places emphasis on information integration. Subsequent to the development of the application, it is evaluated in terms of its usability and learning

[1] http://www.panosalado.com/
[2] http://www.easypano.com/Virtual-tour-software.html
[3] http://www.voyager360.com/

effectiveness, given that it is crucial for an educational application to be evaluated in terms of usability and learning (Squires & Preece, 1996). A usable application allows it to be used as expected with little or no hesitation (Rubin & Chisnell, 2008). With regard to learning, it is expected that the application would improve students' learning compared with conventional resources, such as paper-based learning materials.

In addition, this thesis discusses the evaluation of a VR application when used as a medium for a virtual field trip (VFT). Given that a significant reason for developing the VR application is limited access to industrial sites, it is important to evaluate its use as a VFT. VFTs are not new, having been studied by Lewis (2008), Spicer & Stratford (2001) and Stumpf, Douglass & Dorn (2008). However, despite the number of related studies, VFTs were often conducted by replicating scenarios that happened on physical field trips (PFTs), such as looking at the same items and walking along the same paths. This meant that students were exposed to similar scenarios in the PFT and VFT without utilising the capabilities of the technology to develop a more enriched VR application (e.g., provide integration between learning content and the virtual environment) to be used as a medium for a VFT. Under-utilising the capability of the technology has been highlighted as a negative aspect of VFTs, given that the technology allows one to do more (Spicer & Stratford, 2001). This thesis aims to add knowledge to the area by further exploring students' attitudes towards VFTs and PFTs when the learning content and the virtual environment are integrated, where this scenario is not available in the PFT.

To summarise, one aspect noted in the literature is the advantage of VR applications compared with traditional learning resources (e.g., paper-based notes), where the application can include different formats of information, as demonstrated in many existing studies. However, one under-explored aspect in these studies is the integration of information. This absence initiated the motivation to explore the aspect, with the aim of evaluating it against conventional learning approaches (e.g., paper-based notes and physical field trips).

1.2 Research problem

The research motivation above leads to the identification of the research problems as stated below:

i. The absence of studies related to the acquisition of spatial knowledge of multilevel buildings with large equipment that does not fit within a single level. An extension of this is that there are not many studies related to using a map as a direct navigation tool (moving from one location to the other location) compared with just using it to provide an overview of the virtual environment.

ii. Educational VR applications often have different types of information that are not well integrated and linked. Since not much is known about integrating different types of information, the issue is further investigated in this thesis.

1.2.1 Addressing the problems

User studies were conducted to address the research problems. Problem (i) is addressed through the question:

> *How do different types of map affect the acquisition of spatial knowledge in a virtual complex multilevel building?*

The complex multilevel building term refers to multilevel buildings that feature, for example, large equipment that does not fit within a single level - i.e., it occupies more than one level. This question aims to investigate the differences that occur in the spatial knowledge acquired by the users of different types of map. The user study is discussed in Chapter 4 (User Study 1: Spatial knowledge acquisition in a complex large scale virtual environment).

For problem (ii), a VR application focusing on integration between different information formats was evaluated in user studies related to VFTs and students' learning achievements. Before that, a usability study of the application was. All these aim to bring together lessons learned from the evaluations that could provide insights for the future development of similar applications. These user studies are:

- Usability study - Chapter 5 (A usability study of the milk processing VR application).
- Comparison of students' attitudes towards physical and virtual field trips - Chapter 6 (User study 2: Students' attitudes towards virtual field trips).
- Comparison of students' learning achievements from the VR application and paper-based materials - Chapter 7 (User study 3: The learning assessment comparing the VR application to paper-based learning material).

1.3 Research contributions

The contributions of the thesis are as follows:

i. The thesis demonstrates the effects of different types of map in assisting in the acquisition of spatial knowledge when using a VR application in a complex multilevel building.
ii. The thesis provides valuable insights that are useful for developing educational VR applications that integrate different types of information.
iii. The thesis highlights lessons learned for designing and organising a virtual field trip.

1.4 Research background

In an attempt to address the issue of limited on-site access to industrial plants, the "Immersive Learning through Virtual Reality" project was initiated as a collaboration between the HIT Lab New Zealand and the Chemical and Process Engineering Department (CAPE) at the University of Canterbury. The broad objective of this project was to develop a Virtual Reality (VR) application to provide students with a resource that offers exposure to a process facility and integrates the related learning content.

The development of this VR application was based on a multilevel milk processing plant with integration of the learning content (e.g., Process Flow Diagram (PFD), videos, 3D models). This provides a suitable platform to address the issues raised in this thesis. The project is used as a case study to research the gaps raised.

1.5 Thesis structure

This thesis is presented as follows: **Chapter 2** reviews the literature related to VR applications for spatial knowledge acquisition and education and training. Definitions of the terms used in this thesis are also included in this chapter. **Chapter 3** describes a user study conducted using a VR application simulating an oil refinery. This application was chosen because it has similar content and purpose to the milk processing plant application developed in this thesis. Therefore, this provides useful insights for the design of the milk processing plant application. **Chapter 4** describes the user study carried out to investigate the differences in spatial knowledge acquired (in a large-scale multilevel virtual environment of a milk processing plant) by users when using different maps. **Chapter 5** describes a usability study carried out with the milk processing plant VR application to determine the value of aspects of its design and how well the problems found with the oil refinery application are addressed. **Chapter 6** attempts to determine the value of virtual field trips compared with traditional physical field trips from the students' perspective. **Chapter 7** compares the learning effects of using the VR application as a learning resource for class assessments compared with conventional printed notes and **Chapter 8** concludes with a discussion of the findings, the research contributions and suggestions for further research.

Chapter 2

Literature review

The previous chapter provides an overview of the state of the literature related to the use of Virtual Reality (VR) applications as a medium for acquiring spatial knowledge and as a medium for integrating classroom learning with the virtual environment. This chapter extends the previous chapter by reviewing the literature relevant to both areas. It begins by defining VR and discussing its general use in education and training (Section 2.1). Next, the review focuses on two aspects: first, on spatial knowledge (Section 2.2) and then on the design of existing VR applications in education (Section 2.3). The chapter ends with a summary of the literature (Section 2.4).

2.1 Virtual Reality

Virtual Reality (VR) is defined as *"the combination of systems comprising computer processing (PC-based or higher), a building platform for creating three-dimensional environments, and peripherals such as visual display and interaction devices that are used to create and maintain virtual environments";* where a *virtual environment (VE)* is a three-dimensional environment that allows users to interact with the objects within the environment in real time (Cobb & Fraser, 2005, p. 525). Therefore VR provides an interactive, three-dimensional environment where users can manipulate and explore the environment (Sherman & Craig, 2003).

The degree of VR varies from non-immersive to immersive, based on the level of the immersion provided (Vince, 2004). *Immersive VR* usually includes apparatus such as a Head Mounted Display (HMD), data gloves or Cave Automatic Virtual Environment (CAVE) that increases the user's sense of immersion in the VE. *Non-immersive VR*, on the other hand, runs on a standard desktop computer. Although this results in a decreased sense of immersion, no significant differences are evident in the learning outcomes between the *immersive* and *non-immersive VR* (Moreno & Mayer, 2002). The ability to use *non-immersive VR* on a standard desktop computer, without any additional apparatus, makes it a cheaper and more flexible option than *immersive VR,* and therefore makes it an adequate tool for training and education.

2.1.1 VR in education and training

VR applications were initially developed and implemented in the military and the aviation industries for simulation training. However, as the technology became more robust and accessible, applications have been developed for other purposes such as education and training.

In education, VR applications have been used to showcase physical sites (e.g., manufacturing plants (Cameron, Crosthwaite, Donaldson, Samsudi, & Fry, 2005), geological sites (Stumpf et al., 2008), forestry (Abe et al., 2005)), which are becoming difficult to access for reasons such as safety, cost and confidentiality. These applications help students to be exposed to the materials learned in the class, which is useful to enhance their understanding. The exposure also helps students to gain spatial knowledge of the visited site, providing them with an awareness of the position and layout of the components in the site, which is useful particularly for engineering and architecture students.

2.2 Spatial knowledge

Spatial knowledge can be acquired through navigation. Navigation is defined as moving from one point to another (Hunt & Waller, 1999) and is a combination of *way finding* (cognitive element) and *travel* (motoric element) (Sherman & Craig, 2003). Sebok, Nystad & Helgar (2004) added that navigation also includes *orientation*, which is the ability to know one's current location and view point. *Way finding* does not involve any movement but only strategies that lead to movement. *Travel* describes the act of moving through the environment (Bowman et al., 1999; Sherman & Craig, 2003). In a VE, there are different ways to *travel*, such as relative motion, which requires users to move in a continuous form from one location to the other (similar to walking technique in the physical world); or absolute motion, which involves pointing to a location on a map to move to that location (Stuart, 2001).

Navigation is a common daily routine for individuals in the physical world. This may include going to school, commuting to the office or brisk walking in the evening. These navigation activities result in the individuals identifying different elements of the environment such as the buildings, roads and areas within the city and more. Although different cities have different structures, the individuals seem to identify similar elements that form the construction of the city, regardless of the differences (Lynch, 1960). These similarities were recognised by Lynch (1960), who compared the descriptions provided by the residents from three cities (Boston, Jersey City and Los Angeles) in their identification of the elements in the respective city. Lynch shows that the individuals identified common elements from each city:

- Paths : Routes where people travel (e.g., streets, footpaths and trails).
- Edges : Elements that are not considered paths (e.g., edges of walls and the shoreline).
- Districts : Sections of the city.
- Nodes : Points in the city where a person could enter (e.g., junctions, crossing of a path).
- Landmarks : Objects that serve as external reference points for navigation.

To put the elements into context, imagine a small neighbourhood as an example. This small neighbourhood *(district)* is part of a big city. There are a few houses and a school *(landmarks)* and these houses and the school are connected by roads *(path).* Along the roads, there are junctions *(nodes)* that allow individuals to choose the direction of travel. In addition, there are walking paths alongside the road *(edges)* that also provide spaces between the houses and the roads.

The perception of the above elements however, may differ from the perspective of individuals who travel in the city. For example, a person who travels by road would see the road as the routes and the walking paths as the edges, but a person who walks (instead of travelling by car) would see the opposite, i.e., walking paths are the routes and the roads are the edges.

The above provides an example of how individuals see things when navigating. Individuals may see similar elements of the city, but the perception of each element varies. A similar situation can be applied in different places and scenarios, e.g., navigation in closed buildings such as shopping malls, manufacturing plants and schools. Individuals navigating a shopping mall would identify escalators, shops, food courts and car parks but the perception of these elements may differ among them as some may refer to the escalators as a landmark and others may refer to it as a path.

2.2.1 The importance of spatial knowledge

Spatial knowledge is useful for various reasons: for example, workers in a manufacturing building need to have an understanding of the building's layout to assist them when looking for a piece of equipment to be fixed; the occupants of a building need it to evacuate during an emergency; the public needs it for daily activities such as shopping, looking for a specific room in a hospital or hotel. When a person knows the location of the respective places s(he) can avoid being stressed and confused when locating a specific location in a particular area (Dogu & Erkip, 2000). This could happen to hospital visitors and outpatients when they are unable to find their way to a specific location, particularly during emergencies (Ulrich et al., 2008). A similar situation may also occur in operating plants where the workers cannot locate specific equipment when it needs to be repaired or fixed. For students, spatial knowledge is useful especially in helping them with design skills, e.g., engineering and architecture students.

2.2.2 Landmark, route and survey knowledge

When individuals navigate, they first gain *landmark knowledge,* which is the identification of the available landmarks in the environment. A landmark is an object in the environment that serves as a reference point (Lynch, 1960) and may be a 'start' or 'end' point when people move in the environment (Siegel & White, 1975).

Once landmarks are identified, people start to develop *route knowledge* (also known as procedural knowledge) which describes the path(s) between the landmarks (Siegel & White, 1975). Route knowledge is an egocentric perspective (first person view) and is usually gained by personal exploration of the environment. At this stage, the person would travel using only known routes (Satalich, 1995).

As *route knowledge* expands, people finally develop *survey knowledge,* which is also known as configuration knowledge (Darken & Peterson, 2001; Sebrechts et al., 2000). Survey knowledge is an exocentric perspective (bird's eye view) and having this knowledge allows people to build a 'picture' of the environment in their mind, which is also known as a mental map, cognitive map or spatial representation. The mental map may not only include the landmarks but also other elements that may be used as a reference point as well.

The above demonstrates how the *landmark, route* and *survey knowledge* is acquired through a person's direct experience in the environment, e.g., walking in a mall, navigating a new neighbourhood. This is known as 'primary' *survey knowledge*. 'Primary' *survey knowledge* is developed in a sequential manner, comprising *landmark, route* and *survey knowledge* (Darken, 1996; Siegel & White, 1975).

Another way of acquiring *survey knowledge* is through other resources such as maps or photographs, where a person does not need to be directly exposed to the environment. This is known as 'secondary' *survey knowledge* (Thorndyke & Hayes-Roth, 1982). In 'secondary' *survey knowledge*, a person can gain immediate *survey knowledge* without the need to first acquire *landmark* and *route* knowledge. For example, a map of a neighbourhood displays the representation of the playground, houses, streets, etc., which are available in the neighbourhood. By looking at the map, a person would gain an immediate bird's eye view of the neighbourhood (*survey knowledge*), and at the same time able to identify the houses and playgrounds (*landmark knowledge*) and the available streets that connect the houses and playgrounds (*route knowledge*). 'Secondary' *survey knowledge*, however, is inferior to 'primary' in terms of orientation issues (Darken & Peterson, 2001) because it tends to be orientation-specific compared with knowledge gained from direct experience in the world (Thorndyke & Hayes-Roth, 1982).

2.2.3 A map as a navigation aid in the VE

Navigation in a VE is different from the physical one because of a lack of cues for distance, motion and direction (Bowman et al., 1999), making it more difficult to navigate compared with the physical environment (Vinson, 1999). Therefore, navigation in a VE is often assisted with aids such as maps, arrows, signs and other cues. Navigation with aids is more efficient than navigation without aids (Luo et al., 2009; Wu, Zhang, Hu, & Zhang, 2007; Zuo, Xu, Yuan, & Feng, 2009).

Although there is a wide range of navigation aids that could be used to assist navigation in a VE, providing users with many navigation aids at once could result in cognitive overload as users need to look at multiple aids while navigating the VE (Haik et al., 2002; Witmer et al., 2002).

Among these navigation aids, maps are most commonly used and have been the subject of a number of studies (Sherman & Craig, 2003), particularly for a large-scale VE environment (Cliburn & Heino, 2009; Ruddle, Payne, & Jones, 1999). Cliburn and Heino (2009) undertook a study comparing the performance of a map and signs in assisting users to search for the target locations in a VE. The results indicate that, with signs, users managed to locate the target faster and in less distance than with a map. A subsequent study (Heino, Cliburn, Rilea, Cooper, & Tachkov, 2010), found that the same did not happen when the number of targets increased, suggesting that an increased number of targets caused users to have difficulty in processing the knowledge using the signs compared with the map that provided immediate survey knowledge of the environment. This suggests that navigation in a large scale VE with many elements is best assisted by the use of a map. This is consistent with a study by Ruddle et al. (1999). A large scale VE refers to a VE where not all objects can be seen in detail from a single viewpoint (Kuipers, 1978). This applies to most desktop VEs because of the limited screen size that makes it impossible to view a large VE from a single viewpoint.

The strength of maps compared with other navigation aids (e.g., signs, arrows) relies on their capability to provide an exocentric view of the environment that consequently provides users with an immediate representation of the environment. This agrees with the definition of a map, which is *"...an abstraction of physical space*" (Darken, 1996, p. 52) or *"a graphic representation that shows spatial relationships*" (Tyner, 2010, pp. 6-7). A map is also commonly used when navigating a physical environment and, therefore, this provides familiarity to users when using it as a navigation aid in a VE. Although the map may assist users to acquire immediate survey knowledge ('secondary' survey knowledge), the content of the exocentric view should be carefully designed to improve the acquisition of survey knowledge (Luo et al., 2009).

Apart from being used as a navigation aid, a map can also be used as a direct travelling aid, where users can move to a specific location by selecting specific points on the map that correspond to the relevant locations of the VE (Sherman & Craig, 2003). An example of this is shown in Figure 2-1, where users can move to a specific location in a VE, comprising 360^{o} panoramas, by selecting specific nodes on the map.

This approach could be described as point-to-point navigation because the users' movements in the VE are restricted to the nodes available on the map. Travelling directly in the map allows users to focus on tasks (e.g., searching for a specific object) instead of navigation (Haik et al., 2002). This is because the users can move directly to the specific location of an object instead of having to move according to a particular path until they reach the location.

[Copyright clearance to reproduce image not obtained]

Figure 2-1 Users can move to specific locations in the VE (left) by selecting the orange nodes on the map (right) (University of California, 2012).

This approach, however, may result in users having limited route and survey knowledge of the VE (Chittaro & Venkataraman, 2006), because users may have limited knowledge about the surroundings between the initial and target positions (Bowman, Koller, & Hodges, 1997).

The efficacy of maps in assisting users with navigation, in addition to their flexibility, has motivated researchers to explore the different characteristics of maps as navigation aids, as discussed in the next section.

2.2.3.1 Orientation issues

One of the issues of using a map as a navigation aid is that the survey knowledge gained from the map tends to be orientation specific (Richardson, Montello, & Hegarty, 1999). For example, when a map remains static, regardless of how the user is orientated in the VE, the user’s acquisition of spatial knowledge may be influenced by the orientation of the map.

In a physical environment, the orientation issue can be addressed by rotating the physical map so that it aligns with the user’s viewpoint in the physical environment. In a VE, a more dynamic approach can be taken where the map can be developed in a dynamic way such as auto rotating to the user’s orientation and adding an indicator of the user’s orientation and position. Providing an indicator showing the orientation of the user is important because the lack of such indication causes the user to have problems when navigating the VE, as found in Cameron et al. (2008) and Villanueva, Moore & Wong (2004). Having an orientation aid would also allow users to concentrate more on the task (e.g., searching for things, paying attention to the surroundings) rather than the orientation itself (Haik et al., 2002).

An approach to minimise the orientation issue is to either rotate the map according to the user's navigation view ('forward-up' map) or include an indicator showing the direction in which the users are looking ('north-up' map). Darken and Cevik (1999) compare the performance of 'forward-up' and 'north-up' maps when performing different search tasks (Figure 2-2). Each map is provided with a You-Are-Here (Y-A-H) marker, a symbol indicating the user's position in the VE.

The 'forward-up map' (Figure 2-2, left) would always be oriented in the direction in which the users are facing in the VE, and the Y-A-H marker is presented as a sphere. In the 'north up map' (Figure 2-2, right) the north (or the top) of the map would always be at the top regardless of the user's orientation in the environment; the Y-A-H marker is presented as a cone pointing to the direction in which the user is facing in the VE. Therefore, the map remains static throughout the navigation. An evaluation of both types of map revealed that different types of search required different presentation of maps; a 'target search'[4] is performed better using the 'forward-up map' and a 'prime search'[5] is performed better using the 'north-up map'.

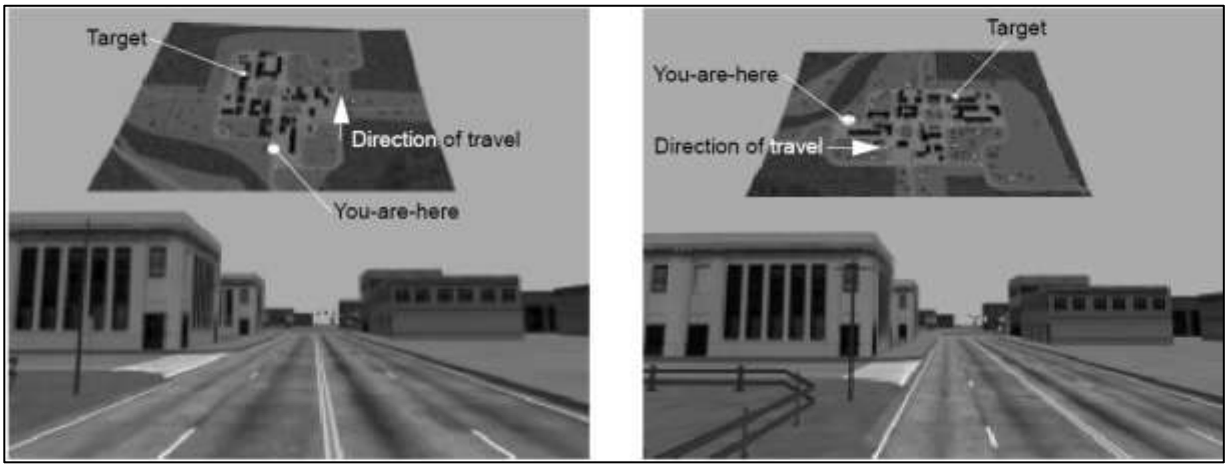

Figure 2-2 The 'forward-up' map (left) and the 'north-up' map (right) (Darken & Cevik, 1999).

[4] A searching task in which the target is shown on the map.

[5] A searching task in which the location of the target is known, but the target does not appear on the map. The search is presumed to be non-exhaustive.

2.2.3.2 Map designs

The flexibility of a computer-based map allows the inclusion of various features such as auto rotation of the map according to the user's orientation, updating the user's location in real time or providing users with interaction such as the ability to zoom in/out of the map, all of which are not available in a physical map. However, a careful approach needs to be taken when designing and developing the maps to ensure that they provide users with the required survey knowledge instead of confusing users. A well-developed map is useful for navigation and also spatial knowledge acquisition, which is crucial in many scenarios such as evacuation planning or looking for a particular location in a building (Li & Giudice, 2012). Adding unnecessary aids results in users having cognitive overload (Haik et al., 2002). Unnecessary aids could include adding a map and arrow, when the map is already sufficient to aid the users with the navigation.

An early approach to developing a map for a large scale VE is the 2D map, was based on the map principles of Darken and Sibert (1996). They suggest:

- Dividing the large scale VE into smaller parts that are shown on the map together with all the elements of the environment such as the paths, landmarks, etc.
- Showing the user's position on the map.
- Orienting the map with respect to the direction in which the user is facing in the VE.

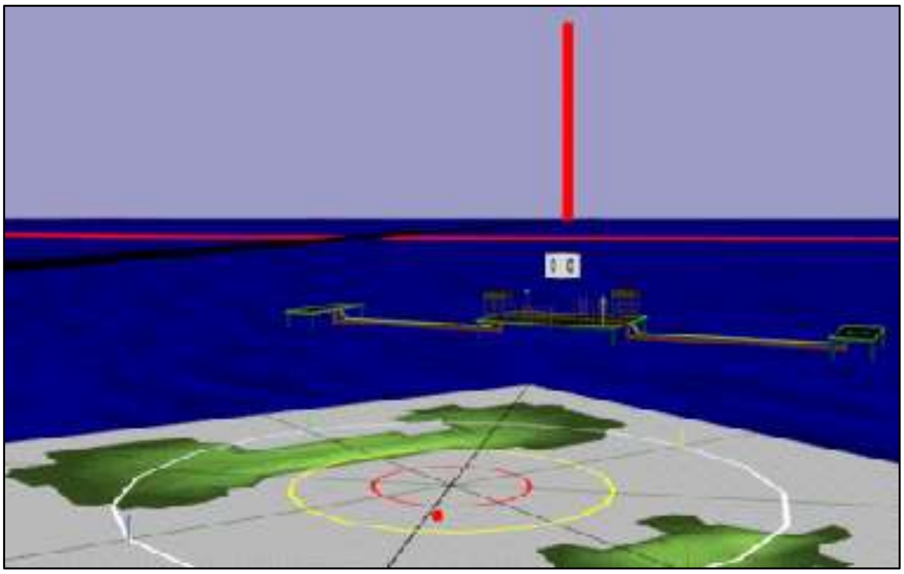

Figure 2-3 The combination of a grid and map (Darken & Sibert, 1996).

The first point, dividing the large scale VE into smaller parts, was done using a grid placed on the map (Figure 2-3). The results of the study demonstrate that this approach helps users to gain more accurate survey knowledge than using the map without any grid. The last point, orienting the map with respect to the user's direction, could be substituted by using a cue that shows the orientation of the user rather than orienting the map, as suggested in a more recent study by Darken and Peterson (2001). This was also supported by the fact that users were not keen to rotate the map (although given an option to do so) when the map is provided with an indicator showing the direction in which the user is looking (Chittaro & Venkataraman, 2006).

A more interactive map was developed by Stoakley, Conway & Pausch (1995). Known as 'World in Miniature' (WIM), this interactive, immersive 3D map replicates a life-sized VE. The user's interaction with the WIM is done using a tennis ball installed with buttons for interaction (e.g., moving an object) while the other hand holds a clipboard where the user can control the display of the WIM. For example, if the clipboard is raised, the WIM in the screen also rises. Any interaction in the WIM (e.g., moving an object) corresponds to the movement in the VE. The users view of the WIM through the Head Mounted Display (HMD).

A drawback of WIM is that it displays the entire VE in a single map, which causes a problem for a large scale VE, because all details are cramped into the single map. This drawback was overcome by adding a scale and scrolling function to the WIM, allowing a detailed view of the environment (Wingrave, Haciahmetoglu, & Bowman, 2006). Using the scrolling function, (similar to a zoom in/out function) to allow a detailed view of a map also aligned with the suggestion by Haik et al. (2002). The zooming function of a map was preferred by the users who felt it supported the navigation (Hornb, Bederson, & Plaisant, 2002).

Another approach that could be used to overcome the crowded large scale VE is to divide the large scale VE into smaller parts, as suggested in the map principles (Darken & Sibert, 1996) discussed earlier. However, dividing a large scale into a small VE may not meet the objective of the WIM, which is intended to display the whole VE at once.

The early development of maps was more focused on a single level space, be it an open space such as a large sea or closed space such as building. Little is known about studies related to navigation in multilevel buildings. Navigation in multilevel buildings is often a problem since people have a tendency to lose their orientation when moving to a different floor (vertical movement) and assume the layout of each level in the building is similar (Soeda, Kushiyama, & Ohno, 1997). This navigation is more complex because it requires both horizontal and vertical knowledge of the environment; therefore, presentation of a map needs to consider both horizontal and vertical aspects.

The lack of studies related to maps for multilevel buildings has been pointed out by Chittaro and Venkataraman (2006), who developed an interactive 3D Break Away Map (I3BAM), which was intended for multilevel buildings (Chittaro et al., 2005). The I3BAM was based on WIM, with some modifications made to suit multilevel buildings.

In I3BAM, users can only travel in the VE and the user's current position and orientation in the VE are updated correspondingly on the map using an indicator (a sphere with an inverted triangle), similar to the suggestions made by Darken and Peterson (2001). The map only shows the floor where the user currently is (Figure 2-4 (a)).

Apart from using it while navigating the VE, the user could also use I3BAM to examine the layout of a building, by selecting the respective floors the user wishes to view. In WIM, displaying more than a single floor may block the view of other floors, particularly floors below the current view. In I3BAM, a user can select the floor s(he) wishes to view and the other floors are slid away, as shown in Figure 2-4 (b). A preliminary study using the I3BAM as a means to examine a physical building shows promising results, where the users were able to navigate in the real building based on the information presented in I3BAM.

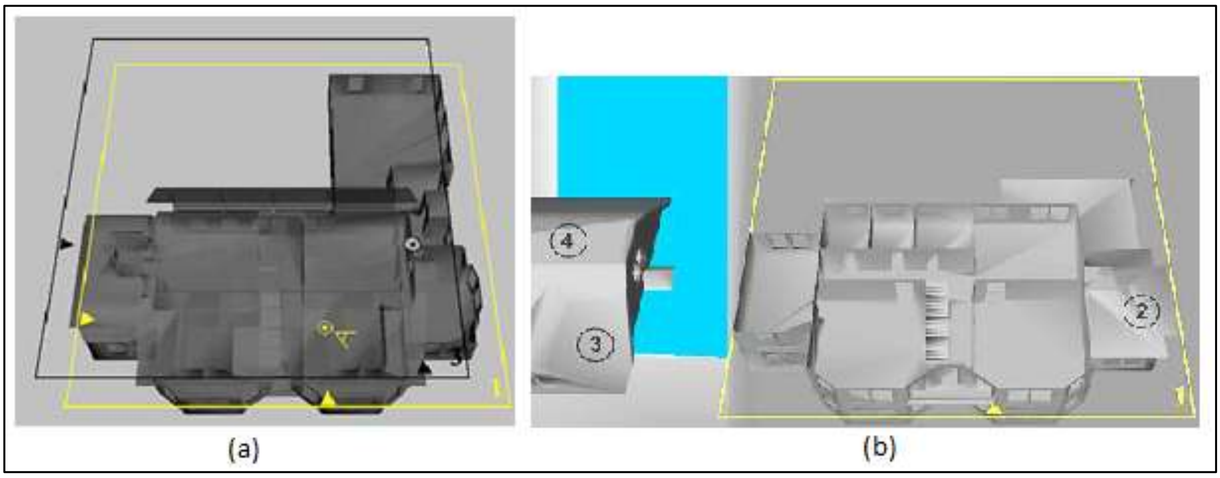

Figure 2-4 The map with an indicator showing the user's location and position at the current floor (a). The map is showing level 2, where levels 3 and 4 are slid to the left (b). The blue coloured zone, as in (b), has no significant value (Chittaro et al., 2005)

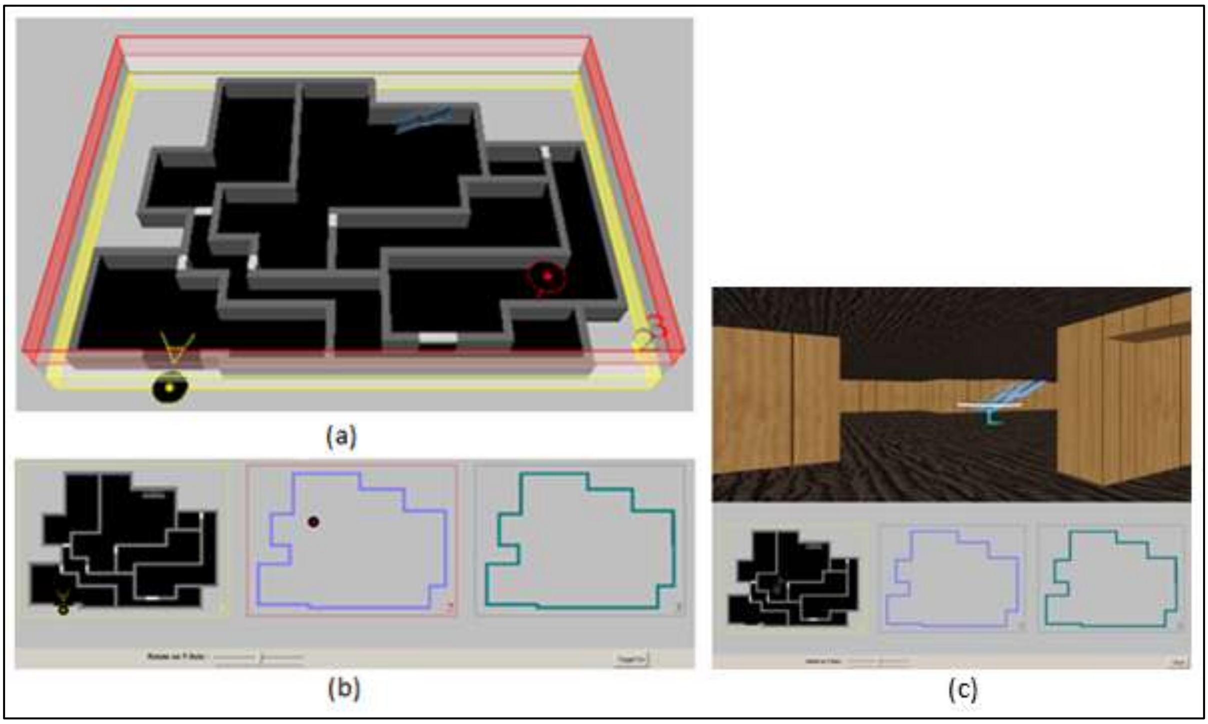

Figure 2-5 The 3D map (a) and the 2D map (b) of a multilevel buiding. The 2D map and the corresponding VE in a multilevel building (c) (Chittaro & Venkataraman, 2006).

In a more recent study, Chittaro and Venkataraman (2006) compare the effectiveness of the I3BAM by simplifying it into a 2D (Figure 2-5 (b)) and a 3D map (Figure 2-5 (a)). The 2D and 3D maps have common features in that both maps display all three levels of the building including the stairs where users can move between levels. Similar to the I3BAM, travelling can only be done in the VE, and the position and direction of the user in the VE is updated correspondingly on the map. Only the map with the user's current position is displayed in detail whereas the remaining floors have only their respective borders outlined. Sliders are provided for the maps, where the 2D map could be rotated about the axis normal to the panel and the 3D map could be rotated around the horizontal and vertical axes.

Testing tasks included a way-finding task and a direct estimation task (pointing to an object in the VE from a predetermined location). The results of the study indicate that the 2D map assists users in performing the way-finding task efficiently (looking for different objects in the VE). No significant differences were found in terms of the acquisition of spatial vertical and horizontal knowledge.

Another study using a map as a navigation aid in a multilevel building is by Luo, Luo, Wickens and Chen (2010) who compare different conditions of an exocentric view: '3D floor map', '3D building map' and 'transparent condition'. Similar to the study by Chittaro and

Venkataraman (2006), users can only travel within the VE and the map updates each user's position accordingly. Movement between floors is done using the elevator. The conditions in the user study are shown in Figure 2-6.

In the 3D floor map, only the floor where the user is currently located is displayed, similar to the 3D map by Chittaro and Venkataraman (2006). In the 3D building map, a view of all floors is displayed at the same time with a transparent floor, which allows the user to view all floors regardless of which floor the user is currently on. In the transparent condition, no map is made available. However, the walls are transparent so that when the users move from one floor to another through the elevator, they gain an exocentric view of each floor (through the transparent wall) before they walk out of the elevator. Therefore, the users gain a larger overview from an exocentric perspective of each floor than that shown on the 3D floor map or 3D building map.

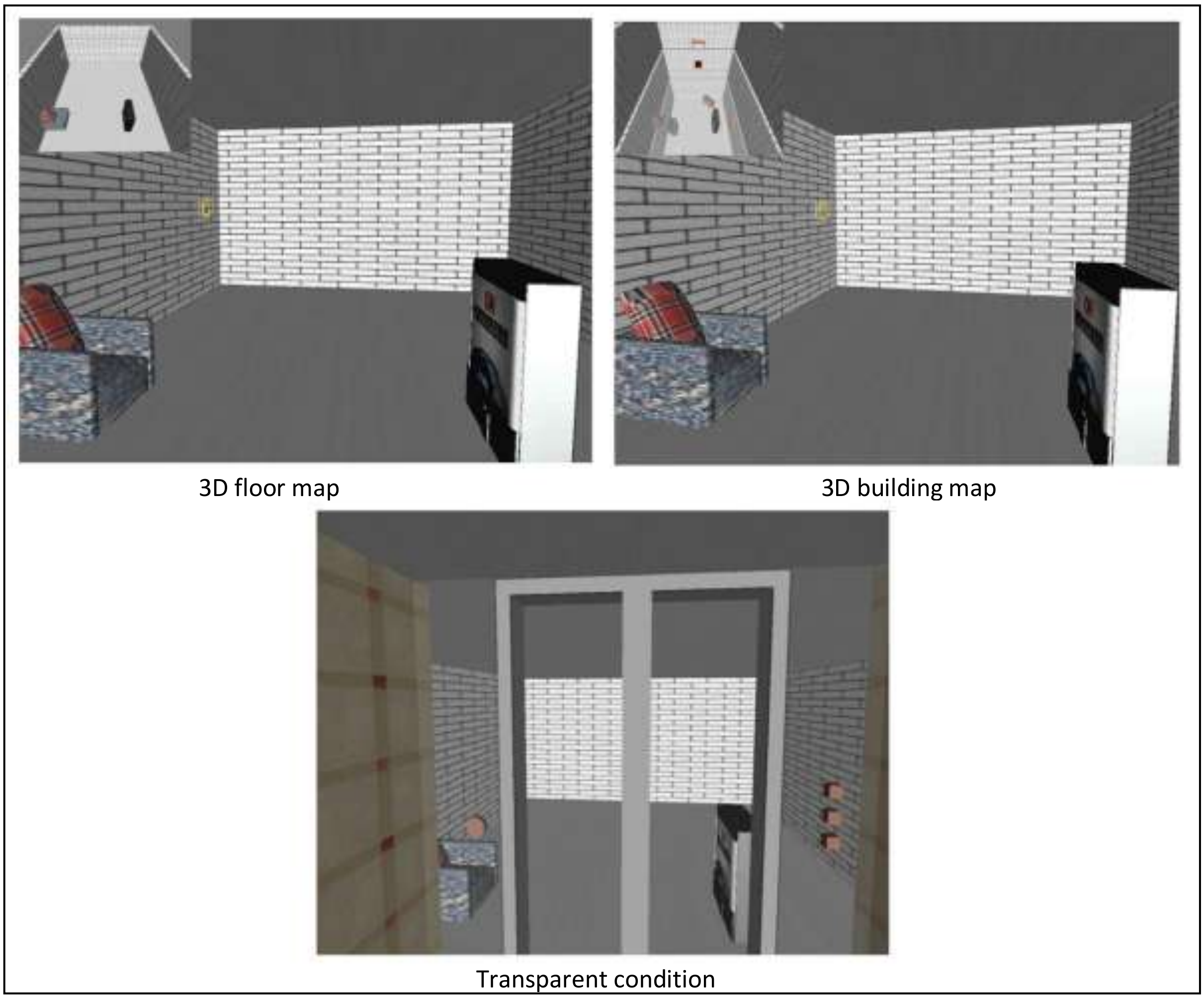

Figure 2-6 The 3D floor map, 3D building map and the transparent condition of a multilevel building (Luo, Luo, Wickens, et al., 2010).

Figure 2-7 The The cut-away map according to the user's viewing direction in the VE (Andujar et al., 2010).

The study included the judgement of relative direction, where the users need to point to an object in the VE from a given imaginary position and orientation. The results indicate that, in general, users of the 3D building map (where all levels of the building are displayed concurrently with transparent floors) achieve the most accurate direction judgement. The 3D building map is better in conveying vertical information (vertical relations between the building levels) compared to the 3D floor map.

Another study on multilevel buildings was conducted in a more immersive environment. Andujar, Argelaguet and Trueba (2010) developed an interactive cut-away map, an extension of WIM, to allow users to view objects that have been blocked by other objects (e.g., a wall), as shown in Figure 2-7. The results demonstrate that this map assists users with performing a search task more efficiently (searching for an object in one location and moving it to another location).

2.2.4 Discussion

Many studies examine single level buildings; however, only a few studies are concerned with multilevel buildings. None of these studies focuses on complex, multilevel buildings with large equipment that does not fit within a single level. This is a common feature of manufacturing plants or factories with large equipment. With the growth of complex, multilevel buildings, particularly in the engineering and industrial sectors, there is a need for a medium for workers and visitors (e.g., students, trainees) that provides clear and intuitive spatial information in these environments. Developing spatial knowledge of such buildings is important for various reasons such as training, evacuation planning, designing a plant and locating specific equipment to troubleshoot. Expanding research into complex multilevel buildings is also suggested by other authors (e.g., Luo et al., 2010).

There is also a lack of studies taking an in-depth look at navigation in multilevel buildings. Among the few studies available, only Chittaro and Venkataraman (2006) and Luo et al. (2010) studied the use of maps in a desktop VR environment. Although the maps for that study were developed for multilevel buildings, they have not been used as a navigation aid in a complex, multilevel building as investigated in this thesis. These maps also have advantages and disadvantages when used in the complex multilevel building described in this study, as discussed next.

First, the 2D map of Chittaro and Venkataraman (2006) presents each level of the building separately in a top-down view. Only the level where the user is currently located is displayed; the remaining levels are not displayed. Although this map could provide clear horizontal distances between the objects, the top-down view does not preserve the shape of each object, which may cause confusion to the users in identifying the objects on the map. This, in turn, may lead to confusion in identifying the vertical position of the objects because users would have difficulties in identifying the top and bottom of the objects.

Next is the 3D map used in the study by Chittaro and Venkataraman (2006) and the 3D floor map in the study by Luo et al. (2010). These maps are reviewed together because both were developed similarly; the maps display only the level where the user is currently located. Like the 2D map, this approach allows identification of the horizontal positions of objects. However, when used to cater for the complex, multilevel building considered in this thesis, presenting one level at a time may cause difficulties since objects on the map that represent equipment on more than one level, break into parts. Therefore, users see only part of the object at one time. However, this map has an advantage over the 2D map in that it allows users to have a small reference to identify the objects (although only small parts are shown at each level). The display of the small parts of the objects may also help to identify the vertical position of the objects.

The 3D building map, as in Luo, Luo, Wickens, et al. (2010) displays all levels of the building at once and provides users with better vertical positions of the objects compared to the 3D floor map. Displaying all vertical levels exposes users with vertical positions, compared to a 2D map (Montello & Fontaine, 2001). A 3D map also preserves the shapes and structures of the objects on the map, allowing users to easily identify the objects. However, objects displayed in a 3D map may block other objects. This may cause difficulty in identifying horizontal positions due to a blocked view. The blocking of objects could be minimised using a cut-away approach, as proposed by Andujar et al. (2010). The advantages and disadvantages of each map are summarised in Table 1, in the summary section (Section 2.2.5).

In addition, much of the literature has focused on using maps to provide an overview of the virtual environment, instead of using them as a direct travelling aid (point-to-point navigation). Though the study by Haik et al. (2002) used a point-to-point map, it was used for a single level building and that leaves the research using such a map for a multilevel building under-explored.

Why a point-to-point navigation map needs to be considered. The VR applications with a point-to-point navigation technique have advantages for both developers and end users. It provides a simple means for developing VR applications since developers work only with images of the selected point of interest. The developers can save time, especially when it involves a large scale VE, since they can concentrate on developing the VR with only intended images of the locations required by the content provided, instead of series of images. Hence, less time and effort is required to edit and program these images. Furthermore, the 'point-to-point' approach is also available in some VR application development software such as Tourweaver[6], Voyager[7] and Virtualtourengine[8] and also some open source applications such as PanoSalado[9], which, therefore, provide the developer with less development work. A similar benefit also applies to end users since they can immediately go to the respective locations in the VE instead of wandering around the VE through a series of unnecessary steps.

[6] http://www.easypano.com/Virtual-tour-software.html
[7] http://www.voyager360.com/
[8] http://www.virtualtourengine.com
[9] http://www.panosalado.com/

2.2.5 Section summary

The current state of the literature suggests that only few navigation studies focus on multilevel buildings or use point-to-point map as a direct travelling aid. Apart from that, the literature also provides valuable insights for designing maps intended for large scale VE. In general, here are the key components:

- An orientation aid needs to be provided (both the user's current position and orientation).
- An organisational principle should be integrated – divide the map into smaller components.
- Allow a detailed view of the map, a zoom in/out and map resizing function should be included (Section 2.2.3.2).

The reviewed literature also provides useful suggestions as a basis for the development of maps in complex, multilevel buildings (i.e., buildings with large equipment that does not fit within a single level), as shown in Table 1.

Table 1 The advantages and disadvantages of the different type of maps.

	Description	For multilevel building	
		Advantages	Disadvantages
2D map (Chittaro & Venkataraman, 2006).	The map presents each level of the building separately in a top-down view.	It provides a clear view of the horizontal distances between the objects.	The top-down view does not preserve the shape of the objects.
3D map (Chittaro & Venkataraman, 2006). 3D floor map (Luo, Luo, Wickens, et al., 2010).	The map displays only the level where the user is currently located. Other levels are not displayed.	Provides the horizontal position of the objects. It allows users to view part of the objects since they are presented in a cut-away form.	May lead to confusion because objects are broken into parts and users see only part of the objects at one time.
3D building map (Luo, Luo, Wickens, et al., 2010).	The map displays all levels of the building at once with transparent floors.	Preserves the shapes and structure of the objects on the map.	May cause blocking of other objects.

2.3 VR applications as learning or teaching resources

VR applications have been widely used in various education disciplines such as engineering (Cameron et al., 2005), forestry (Abe et al., 2005), astronomy (Chih Hung, Jie Chi, Shen, & Ming Chang, 2007), geology (Lewis, 2008) and audiology (Duenser, Heitz, & Moran, 2010). There are different types of VR application such as simulation-based applications, virtual characters and applications representing a physical environment. Simulation-based applications refer to applications that allow users to perform lab work, experiments or simulation activities. Examples of this application are 'technology-assisted problem solving' (TAPs) (Sidhu & Singh, 2008) where users can interact with a robotic arm, and a VR application for simulating the unit operations of a distillation process (Rafael, Bernardo, Ferreira, Rasteiro, & Teixeira, 2007), as shown in Figure 2-8 and Figure 2-9.

VR applications with virtual characters refer to visual representations of a character (e.g., humans) that are able to speak, move and interact with the users. An example of this application is a virtual patient used for training audiology students (Figure 2-10), where students can perform assessments of the virtual patient and it would provide responses related to the assessments.

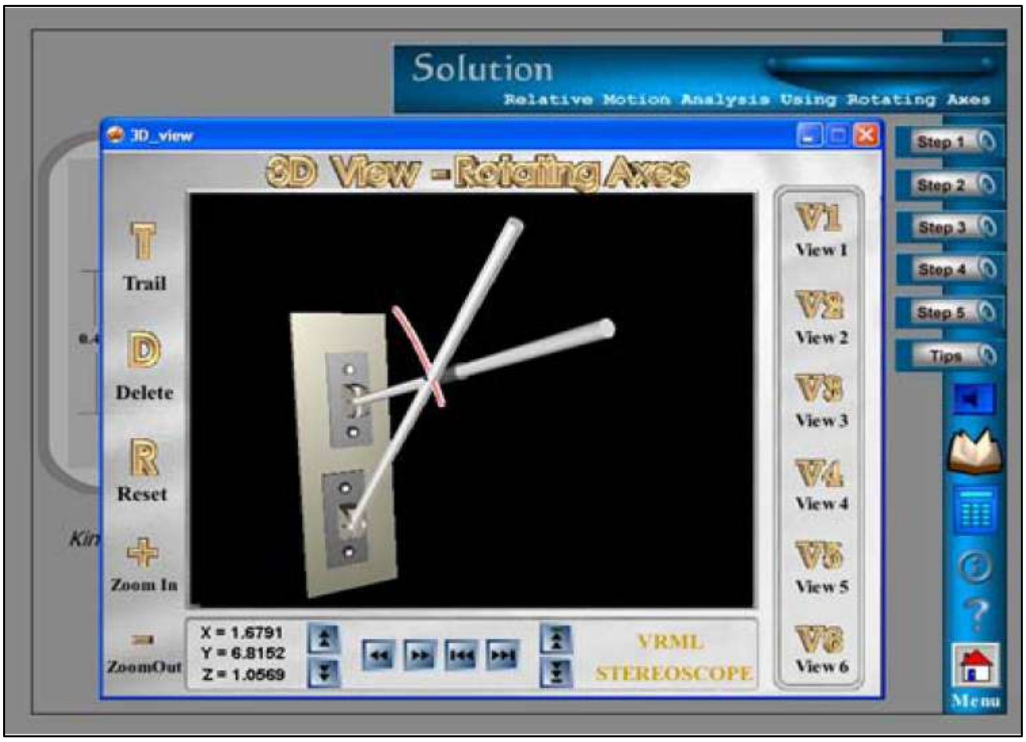

Figure 2-8 The technology-assisted problem solving application (Sidhu & Singh, 2008). Reprint by permission of the publisher- IGI Global, Copyright © 2010.

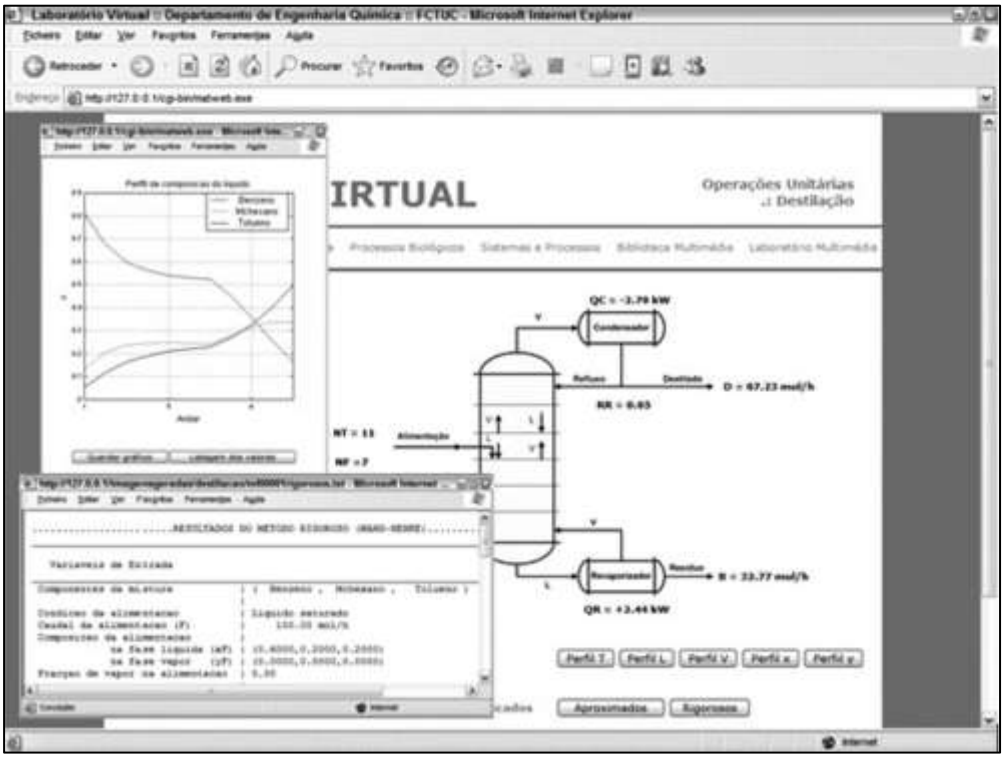

Figure 2-9 The distillation simulation package (Rafael et al., 2007).

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Figure 2-10 A virtual patient used for training audiology students (Duenser, Heitz, & Moran, 2010).

A VR application representing a physical environment involves the inclusion of panoramas or computer graphical representations (CG). This is intended to expose students to actual processes or scenarios that occur in a physical environment that would be difficult to access for various reasons such as safety concerns, weather and time constraints. Using a CG format to display the VE may result in limited visual details (Ruddle, Payne, & Jones, 1997). More VR applications have been developed using panoramas of realistic photos. Panorama-based applications are easier to develop than using CG format because they involve taking a series of pictures (Chang, Lin, & Hsiao, 2009) compared to CG format, which requires more development and modelling effort. An example of a VR application with panoramas of realistic photos is the BP VR application (Cameron et al., 2008), as shown in Figure 2-11. A map is in included at the bottom of the application, indicating the user's current position in the environment.

Since this thesis focuses on the use of a VR application with panoramas, as an alternative to exposing users to a physical environment (e.g., a field trip), the literature review focuses on applications using CG or panoramas.

[Copyright clearance to reproduce image not obtained]

Figure 2-11 One section of the panorama potrayed in the BP VR application (Cameron et al., 2008).

2.3.1 The use of VR applications

VR applications can be used as a medium for a virtual field trip and also as a learning resource.

Virtual field trips. To distinguish between a virtual field trip (VFT) and a non-VFT (which refers to a conventional field trip where students physically visit the related places), the non-VFT is refer to as a physical field trip (PFT).

A PFT can be defined as a trip arranged *"for educational purposes in which students go to a place where the materials of instruction may be observed and studied directly in their functional settings; for example, a trip to a factory, a city waterworks, a library, a museum, etc."* (Krepel & DuVall, 1981, p. 8). PFTs are conducted in different disciplines such as earth science, geology, engineering, architecture and farm management. The trips are intended to assist students to relate what they learn in class to the physical world and are an effective and enjoyable learning form (Kent, Gilbertson, & Hunt, 1997). They help to develop critical thinking about subjects related to the trip (Chanson, 2003) and increase students' positive attitudes towards science (Consult Jem, 2007). Exposure to, and familiarity with, real-world experiences have been shown to be useful to engineering graduates (Chanson, 2003). In addition, field trips help students to understand concepts to an extent which is difficult to achieve via lectures and lab work (Lei, 2010).

Exposure to the sites of field trips is becoming more difficult for reasons such as safety concerns (Abe et al., 2005; Klemm & Tuthill, 2003), weather (Lesley & Michael, 2005), time constraints (Abe et al., 2005), large numbers of students resulting in organisational difficulties (Bergin et al., 2007; Lesley & Michael, 2005) and cost and effort (Lesley & Michael, 2005; Lewis, 2008). An alternative is to employ virtual field trips (VFTs) (Bergin et al., 2007). A VFT is defined as *"a journey taken without actually making a trip to the site"* (Woerner, 1999, p. 5). VFTs have been conducted in disciplines such as earth science, (Lin, Tutwiler, & Chang, 2011), geology (Lewis, 2008) and geography (Stumpf et al., 2008). A VFT uses a VR application to show the physical environment, presented using panoramas that presenting the physical environment. The quality of the images is important in order to portray the detailed aspects of the physical environment (Kolivras, Luebbering, & Resler, 2012), since low quality images cause difficulties when attempting to identify small objects (Abe et al., 2005). A high level of realism helps students maintain interest in the VFT (Poland, Baggott la Velle, & Nichol, 2003). In addition, Woerner (1999) suggests that the VFT needs to be linked and integrated with the curriculum to promote better learning.

A VFT could be conducted in an 'instructor directed' or 'student directed' mode (Çaliskan, 2011; Lin et al., 2011). 'Instructor directed' refers to students not having any interaction with the medium used for the VFT (e.g., software, websites) and only watching and listening to the instructor's explanation while using the application. 'Student directed' refers to students interacting with the application during the VFT; either by themselves or with assistance or guidance from the instructor (e.g., the instructor may guide the class and provide explanations at the same time as the students are using the application).

The VFT can provide more flexibility than the PFT because it can be conducted on an individual basis (Spaulding & Ranney, 2008) or in groups, at any time and place (Çaliskan, 2011; Qiu & Hubble, 2002) and at the students' learning pace (Ku, Goh, & Ahfock, 2011). Therefore issues related to time, weather, safety and health are not a concern in a VFT.

However, the VFT also has limitations that include the absence of sensory experiences - such as smell and touch (Çaliskan, 2011; Hurst, 1998; Qiu & Hubble, 2002), the absence of direct experience with the physical environment such as measuring the temperature of a river, weighing the different sizes of pebbles. Lesley and Michael (2005) add that although a VFT could not provide the real experience of a PFT, it does provide a replication of the real experience in a compromised manner.

Learning resource. Learning is *"a natural process that leads to changes in what we know, what we can do and how we behave"* (Gagné, 2005, p. 1). According to Bloom's taxonomy of educational objectives, learning can be categorised into three types: cognitive, affective and psychomotor (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). Cognitive learning involves knowledge and the development of intellectual skills such as recall or recognition of specific facts, procedural patterns and concepts. Affective knowledge includes the manner in which people deal with things emotionally, such as feelings, values, appreciation and motivation. The psychomotor domain includes physical movement, coordination and the use of the motor-skill areas. In many studies of educational software, cognitive learning is measured by assessing students' understanding of the content information presented in the software.

VR applications can provide students with a wider exposure to learning content than conventional learning methods such as lecture notes, textbooks and other printed materials.

Conventional learning resources may not be able to deliver all required information to students in some subjects (Bell & Fogler, 2004). For example, a description of a pump could only be presented via text and figures in a conventional learning resource (i.e., paper-based notes), but in a VR application it could be explained through the use of videos, animations and panoramas.

Computer-based applications provide a flexibility to develop different types of learning applications in general, including VR applications. Regardless how the VR applications are developed, each component in the application must be carefully designed, developed and evaluated to promote better learning among the users (Schofield, 2012). Evaluation is one of the issues related to computer-based learning application as most of the applications are not thoroughly evaluated in terms of educational effectiveness (Youngblut, 1998).

2.3.2 VR applications for education

This section reviews existing VR applications with a focus on the design and evaluations conducted using the applications.

2.3.2.1 Virtual Chemical Reaction Module (Vicher)

Early VR applications were mostly developed based on graphical representations of physical environments. One example is the Virtual Chemical Reaction Module (Vicher) (Bell & Fogler, 2004) where users explore reactor rooms in a virtual plant and are exposed to simulated accidents (Figure 2-12).

Figure 2-12 Left: interaction of vapour, right: simulation of an accident in the virtual plant. Both are presented in graphical representations format instead of photrealistic (Bell & Fogler, 2004).

The learning assessments include writing an essay related to the evaluation of the hazards and safety features of the physical and virtual chemical plant. The results reveal no significant differences between the assessments (Bell & Fogler, 1998).

2.3.2.2 BP refinery application

This application was developed based on the Crude Distillation Unit 2 (CDU2) at the BP Oil Refinery (Bulwer Island), Brisbane (Cameron et al., 2005). It comprises 19 different nodes, each corresponding to a different location in the refinery. Each node is linked to a 360^{o} panorama using images taken at the respective locations. At each node, users are allowed to rotate, zoom in/out and pan/tilt.

The user's current location is indicated by a 'red figure' on a map. A compass is placed at the base of each node. The user needs to tilt down to see it. The user can move from one node to another by selecting nodes on the map or via a green, transparent arrow that is available on the panoramas when the cursor hovers over the corresponding node or when the 'show hotspots' button is clicked, as shown in Figure 2-13.

The user can also go to a specific node using the search engine (Figure 2-14). The search engine displays the result of a search and, by clicking on the name of the pieces of equipment, will direct users to the appropriate node.

[Copyright clearance to reproduce image not obtained]

Figure 2-13 The BP Oil Refinery VR application (adapted from (Norton et al., 2007)).

[Copyright clearance to reproduce image not obtained]

Figure 2-14 Results generated by the BP Oil Refinery VR application search engine (adapted from (Cameron et al., 2008)).

[Copyright clearance to reproduce image not obtained]

Figure 2-15 A hotspot in the BP Oil Refinery VR application (where the specific equipment is highlighted in red). When the hotspot is clicked, a list of available items is displayed in a pop-up menu (adapted from Cameron et al., (2008).

[Copyright clearance to reproduce image not obtained]

Figure 2-16 Examples of the process flow diagram (left) and animation of the distillation phase behaviour (right) in the BP Oil Refinery VR application (Cameron et al., 2008).

Hotspots or highlighted areas of interest refer to specific areas or pieces of equipment in the panoramas. These are highlighted when the user clicks on the 'Show hotspots' button or when the cursor hovers over the specific equipment. When the hotspot is clicked, a pop-up window with a list of additional information relevant to that equipment appears, as shown in Figure 2-15.

The list of items in the pop-up window contains links to additional information related to the piece of equipment, such as the Process Flow Diagram (PFD), or a process animation (Figure 2-16). When a user clicks on an item in the pop-up window, the user is directed to the respective pages (e.g., animation of the related process, process flow diagram).

[Copyright clearance to reproduce image not obtained]

Figure 2-17 Piping and instrumentation diagram to the VE reference (left). Animation video of the processes in the plant (right) (Cameron et al., 2008).

[Copyright clearance to reproduce image not obtained]

Figure 2-18 Pump isolation procedures (left) (Cameron et al., 2008) and choosing personal protective equipment (right) in the BP Oil Refinery VR application (Cameron et al., 2005).

Certain process flow diagrams (PFDs) are accompanied by piping and instrumentation diagrams (P&IDs). By selecting a piece of equipment in a P&ID, the user is directed to the part of the VE where the equipment is located (Figure 2-17).

Other information included in the application is an induction video on health and safety issues in the refinery, a video of a self-guided tour of the virtual plant and animation videos of the processes in the plant. An example of the animation video is shown in Figure 2-17.

Several interactive features are also included, such as an interactive page for pump isolation procedures (where users need to perform a pump shutdown) (Figure 2-18), choosing personal protective equipment (where users select personal protective equipment to enter the plant safely) and equipment search (where users search for a specific piece of equipment).

The BP Refinery VR application was evaluated with undergraduate process engineering students and, based on the survey responses gathered by Birtwistle and Barnes (2006) (as reported in Cameron et al. (2008)), some issues were identified such as disorientation and uninteresting narration used in the application. In addition, the 3rd, 4th and 5th year students found that some activities (e.g., shutting down the pump) were not challenging for them. The same paper also offer a suggestion to resolve the disorientation issue, which was to include a compass that would rotate based upon the direction in which the users were facing. The issues of uninteresting narration and activities could be solved by the inclusion of more interactive activities and by a variety of tones in the narration. Aside from these criticisms, students found that the high-level, interactive activities in the application made them more motivated and engaged when using the application.

Another three subsequent VR applications developed by the same team - the Coogee Energy Plant (Shallcross, Lukey, et al., 2010) (Figure 2-19), the City West Water facility (Shallcross et al., 2011) and the Pacific Terminals Australia (PTA) - are described in Maynard et al. (2011). All applications have a similar layout and functionality as the BP application, including panoramas, hotspots with links to diagrams, other information associated with related equipment, and a map with nodes of the locations to which users can move.

In addition to the layout and functionalities described above, the City West Water facility and the Pacific Terminals Australia (PTA) VR applications include panoramas taken during construction and in the operation period and therefore allow the user to view the construction process of the plant from start to completion, as shown in Figure 2-20. This exposes the users to a wider area of engineering such as learning how engineers from different disciplines work on the key issues of the design and understanding how different engineering disciplines and stakeholders work together (Shallcross, Cameron, et al., 2010). The inclusion of the construction panoramas within the existing panoramas is referred as 4D learning application by the authors of the above study.

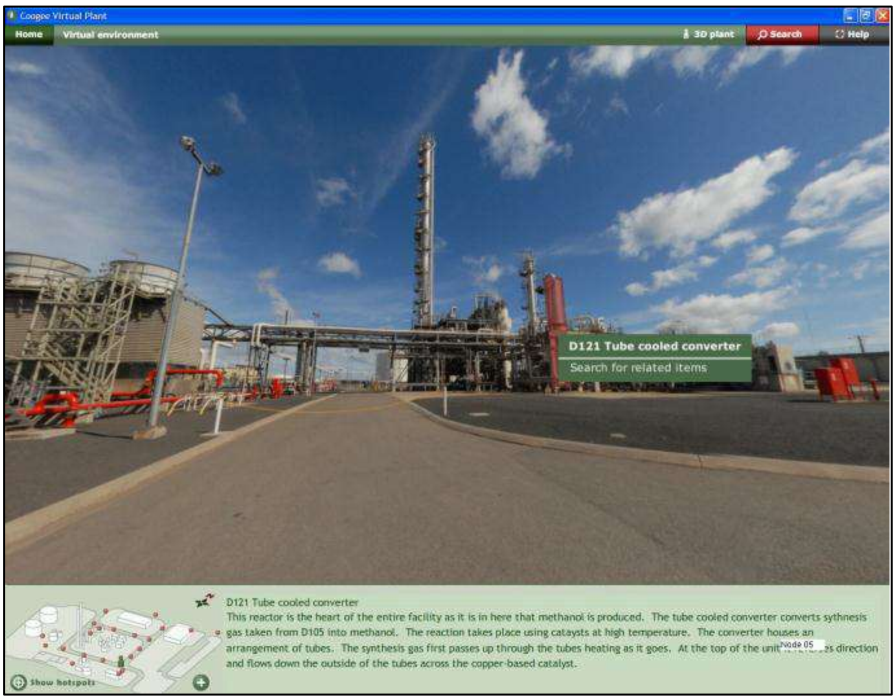


Figure 2-19 The Coogee Energy Plant VR application (Maynard et al., 2011).

Figure 2-20 The VR appllication showing the sequence of construction at Pacific Terminals Australia (PTA), starting from the top left image to the bottom right image (Maynard et al., 2011).

A more recent 4D learning application has been developed – the BP Northpoint Weighbridge and Boya Quarry WA application, as reported in Maynard et al. (2012). The same paper also discusses the learning assessment of the VR application. The evaluation was conducted with only the BP VR application, where students need to identify the hazards related to piece of equipment by using a P&ID only. The same test was repeated later using the VE of the BP VR application. The results indicate a significant difference between the students' understanding and identifications of hazards when using the P&ID and the VE, which suggests that the VE portrayed in the VR application is able to expose students to the connection between the pieces of equipment in the physical world (through the panoramas), and connect the students' knowledge between the theory and practical.

The results also indicate that the students had positive attitudes towards the application in terms of its usefulness in enhancing their knowledge. The links between the panoramas and the diagrams (as shown in Figure 2-17) were found to be useful.

2.3.2.3 Virtual Reality Interactive Learning Environment (ViRILE)

The Virtual Reality Interactive Learning Environment (ViRILE) (Schofield, 2010) contains two parts: ‘laboratory’ experiments and ‘real’ industry processes. The ‘laboratory’ experiments (see Figure 2-21) were developed as a dual frame, one containing the panoramas and the other detailed information related to it in text and image format. The application simulates the configuration and operation of a polymerization plant, allowing students to understand complex materials and interact with a detailed processing simulation.

The ‘real’ industries’ processes (see Figure 2-22) consist of data that provides the simulation of the real world processes. This enables students to gain insights into the constraints faced by engineers in the real world. The evaluations focused on the students’ ability to understand how the changes made to the simulation model affect the objects’ behaviour in the virtual process plant. The results indicate that the application helps students with retention and deep understanding of the content. The linking between the information helps the students to better understand the connections between the individual elements of the materials being studied (Schofield, 2012).

[Copyright clearance to reproduce image not obtained]

Figure 2-21 The ‘laboratory’ experiments (Schofield, 2010).

[Copyright clearance to reproduce image not obtained]

Figure 2-22 The'real' industries' processes (Schofield, 2010).

2.3.2.4 Virtual Forest

An interactive VR application with panoramas of a forest was developed for forestry education (Abe et al., 2005) (see Figure 2-23, left). The application is presented in four panels and allows students to perform quiz and sketch functions in addition to navigating the virtual forest.

The quiz is done in the information panel and the sketch function is done in a newly-opened window (see Figure 2-23, right). The quiz and sketch functions were completed as part of the educational evaluation, which is discussed later.

The information window also allows students to exchange drawings (made using tablets) with other students by clicking on the names of students listed in the window. When exchanging drawings, the drawing by the other students will be shown and the position of where the drawing was made in the virtual forest is shown in the 2D map.

The user study conducted with the application was related to assessing the educational value and the enjoyment the students had while using the application.

[Copyright clearance to reproduce image not obtained]

Figure 2-23 The main page of the application (left) and the sketch function (right) of a forestry VR application (Abe et al., 2005).

Examples of questions included a quiz related to specific objects in the virtual forest (e.g., a Japanese garden) and sketching a leaf of the objects appearing in the photo (see Figure 2-23, right). The quiz assessed the students' understanding of the information presented in the application and the sketch assessed how carefully the students had observed the tree leaves.

The results indicate that the application has educational value and that the students enjoyed using it. They would also like to visit the physical forest portrayed in the panoramas. Negative comments received related to the low quality of the panoramas which resulted in the students being unable to see small objects such as mushrooms and insects. The majority of the students also agreed that their interest in visiting the physical forest portrayed in the application increased after using the application. No questions on students' preferences over the PFT were asked.

2.3.2.5 Grand Coulee panoramas

A simple application developed by Lewis (2008) was intended to be used as a medium for a VFT. In the study, all students attended a five-day classroom session with explanations and laboratory experiments (e.g., to show the students the process of well-sorted sediment layers) related to two sites (Grand Coulee and Camas Prairie) to expose them to creations of nature such as a waveform. They were then divided into the PFT and VFT groups. Students in the PFT group visited the same two sites for 10 hours with a gap of four days between each site. Students in the VFT group 'visited' the same two sites in one day, where each visit took 45 minutes with a 15 minute gap in between.

[Copyright clearance to reproduce image not obtained]

Figure 2-24 A panorama showing the layers deposited at the bottom of the glaciers (Lewis, 2008).

Both the PFT and the VFT groups had the same guide. The VFT session was conducted by projecting 8 feet x 6 feet panoramas of the sites on a screen with the ability to zoom-in to specific areas, if necessary. No additional information was included in the panoramas (Figure 2-24).

Students in both the PFT and VFT stopped at the same locations in each site and the same materials were discussed. After the field trips, students in both groups were given assessments that included writing an essay on the formation of the dam in the visited sites, to assess their understanding about the trip. The results indicated no significant differences between the scores the students obtained for their essays, whether PFT or VFT students. Lewis added however that although there was no significant difference, both trips still differ in terms of senses (e.g., smell, touch). It is also difficult for the VFT to provide a sense of the real size of the elements in the PFT, such as a volcano or a tornado.

2.3.2.6 Indian River Lagoon

Garner (2004) conducted a similar study, where the students were given an explanation about the visited sites before the PFT and VFT. The students attended four consecutive lectures two weeks before the trips. Both the VFT and PFT sessions were held in Indian River Lagoon on the same day and each trip lasted for two hours. The students in the PFT group went to the site in the morning for two hours. During the PFT, students observed the mangrove zonation, sea grass habitat, water movement, etc.

The VFT was held in the afternoon in a computer lab for two hours, where each student used the software. The session was conducted by the same guide who conducted the PFT. The guide began with an introduction about how to use the software, including an overview of the Living Lagoon via an introductory video clip.

In addition, this study measured whether the VFT or PFT exposure affected the attitudes of non-science major students towards environmental science. Therefore, the students recruited for this study were non-science major students enrolled in a physical science subject as their elective. No images or detailed descriptions of the VR application were given by the author of this study. Efforts were made to ensure the students were exposed to the same features during the PFT. The VFT students were given the same materials as the PFT students and were advised by the guide to focus on certain areas covered by the PFT students. In addition, the guide provided assistance and answered questions when needed.

The students then completed a test assessing their knowledge in estuarine ecology three days later. The results indicated no significant difference between the students in the VFT and PFT in their scores in the assessments and their attitudes towards science.

2.3.2.7 Tempe Butte VR application

Instead of splitting the students into VFT and PFT groups, Stumpf et al. (2008) compared three different conditions where students were split into VFT, PFT and both VFT and PFT groups. The VFT was conducted using the Tempe Butte VR application[10], comprising a series of static panoramas (Figure 2-25 left), similar to the views that students see in the PFT. These panoramas were linked to pages that provided detailed information, close-up pictures, videos and detailed graphical models of the features (Figure 2-25 right) that allow the students to relate the VFT to the content learned during lectures before the VFT.

Students in both the PFT and VFT visited the respective areas of interest in the sites in the same sequence. The study's authors admitted that they were biased towards the PFT and therefore the guides were more enthusiastic in the PFT. The assessments included geomorphology questions related to Tempe Butte. In addition, the students were also asked to write an essay about their personal connection to Tempe Butte in terms of its physical geography.

The results suggested that both the VFT and PFT are equally effective for teaching basic knowledge in introductory physical geography classes. However, Stumpf et al. (2008) believe that the equal effectiveness of both VFT and PFT is valid only for an introductory course and a PFT may be required for advanced and more difficult course.

[10] http://alliance.la.asu.edu/gph111/VirtualTempeButte/intro/overview.html

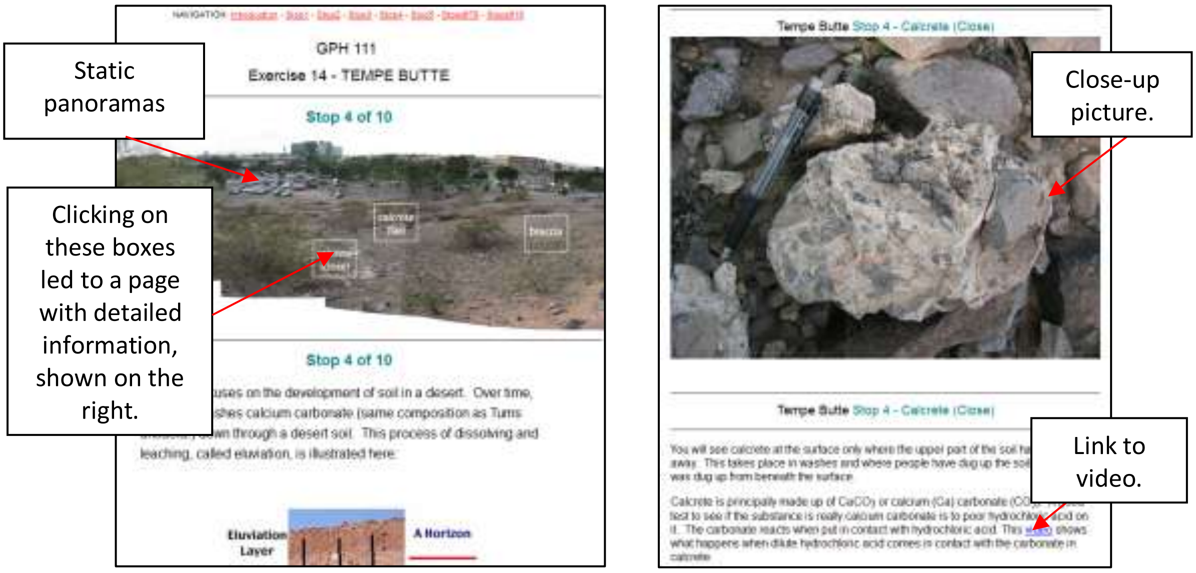


Figure 2-25 Static panoramas (left) and the linked page that provides detailed information (right) in the Tempe Butte VR application (Stumpf et al., 2008).

Essay responses however reveal that the students who attended the PFT had a better appreciation of the natural landform, which could be caused by the instructor's passion and enthusiasm.

2.3.2.8 Virtual Trillium

A Virtual Trillium Trail (Figure 2-26) (Harrington, 2011) was developed for elementary school students, where each student attended both a PFT and a VFT. The VFT included a scientific visualisation of the biological plot study data, the activities performed during the PFT, educational content, fact cards used in the PFT and the footpath of the PFT; all of which provided similar navigational experiences as in the PFT. The fact cards were accessed by moving the cursor on the card.

Each 1.5 hour session of the PFT and VFT was carefully coordinated so that the sessions were similar. The same guide was used in both sessions; the guide provided explanations and answered questions. The VFT was conducted in a 'student directed' manner where each student was given a PC to explore the software. It was observed that students explored the software more by themselves than through listening to the guide's explanation.

Although care was taken to ensure both the PFT and VFT were similar, there was a difference in the PFT in terms of the sensory experiences and also the element of surprise such as the sighting of a mother turkey and a salamander, experiences that were not available in the VFT because it focused only on plants.

Figure 2-26 The Virtual Trillium Trail and a fact card (Harrington, 2009b).

On the other hand, although the content of the PFT and VFT was similar, students in the VFT had more flexible navigation. They were allowed to "fly" to have an exocentric view of the panoramas, and were able to explore the software independently.

Since the application was developed for elementary school students, the assessments include naming the trees and plants; and writing a story and drawing a picture of the related flowers. The results indicate no significant difference between the PFT and VFT. However, further interviews with the students revealed that the PFT is superior for learning that requires connecting complex concepts and contexts. When learning is just about applying curriculum materials, both the PFT and VFT provide similar educational efficacy. This aligns with the perception by Stumpf et al. (2008) regarding the VFT and PFT, as described earlier.

2.3.2.9 Eastern Mediterranean Island

Poland et al. (2003) conducted a VFT (student directed with teachers' assistance when needed) using a website development based on an Eastern Mediterranean Island. The students are able to perform simulated activities such as taking samples of sand compaction (Figure 2-27). Students submitted a report based on the data collected and were subsequently interviewed about their experience. The marks for the reports were compared with the marks of reports submitted for a PFT to the Scilly Isles.

Figure 2-27 Eastern Mediterranean website (Poland et al., 2003).

All except two students had been to the Scilly Isles, which are more accessible, and had the same elements as the Eastern Mediterranean Island. The results showed no significant difference in the marks for the PFT and VFT. The results of the observations and interviews found that most students enjoyed the VFT, felt motivated and felt it developed interest in learning. In addition, all students felt that the VFT should not replace the PFT, as they emphasised the need for 'hands-on' with the materials (e.g., sand compaction) during sampling.

2.3.2.10 Tidepools VR application

A study related to a zoology VFT was conducted by Spicer and Stratford (2001) using an application called Tidepools, which teaches coastal biology. During the VFT, second-year students explored the application themselves for 2-3 hours before completing a questionnaire asking their opinion regarding the VFT. The explorations were related to the tide pool animals' responses to low oxygen. After about 8.5 months, the same students attended a PFT, which was conducted at a different site but with the same problem-based approach as in Tidepools. Six weeks after the PFT, the students completed a questionnaire related to the PFT. The time gaps between the VFT, PFT and the questionnaires were due to a semester break.

No details were provided about the PFT sites. In addition, the link provided to the Tidepools website is no longer available. The results indicate that most students agreed that the VFT should not be used to replace the PFT and their agreement was strengthened after attending the PFT. In addition, most students were positive and enthusiastic about the educational value of Tidepools. The negative comments received were the application did not utilise the ability of the technology to do more, and not having enough time to explore the application themselves.

2.3.2.11 Geological field trip

Chang et al. (2009) used a combination of graphical images and a panorama framework for a VR application that also included a streaming video server, instant messenger server, auto-grading and feedback system; all of which allowed interactivity among the students (Figure 2-28 and Figure 2-29).

No details on the assessments were discussed in the paper, except that the application was used as a teaching supplement and preparation for a PFT. The assessments of the VR application indicate that most students felt the application was useful in learning geological concepts. In addition, after completing the VFT, the students felt as though they had been on a PFT.

Figure 2-28 Graphical images for a geological virtual field trip (Chang et al., 2009).

Figure 2-29 Panoramas for a geological virtual field trip (Chang et al., 2009).

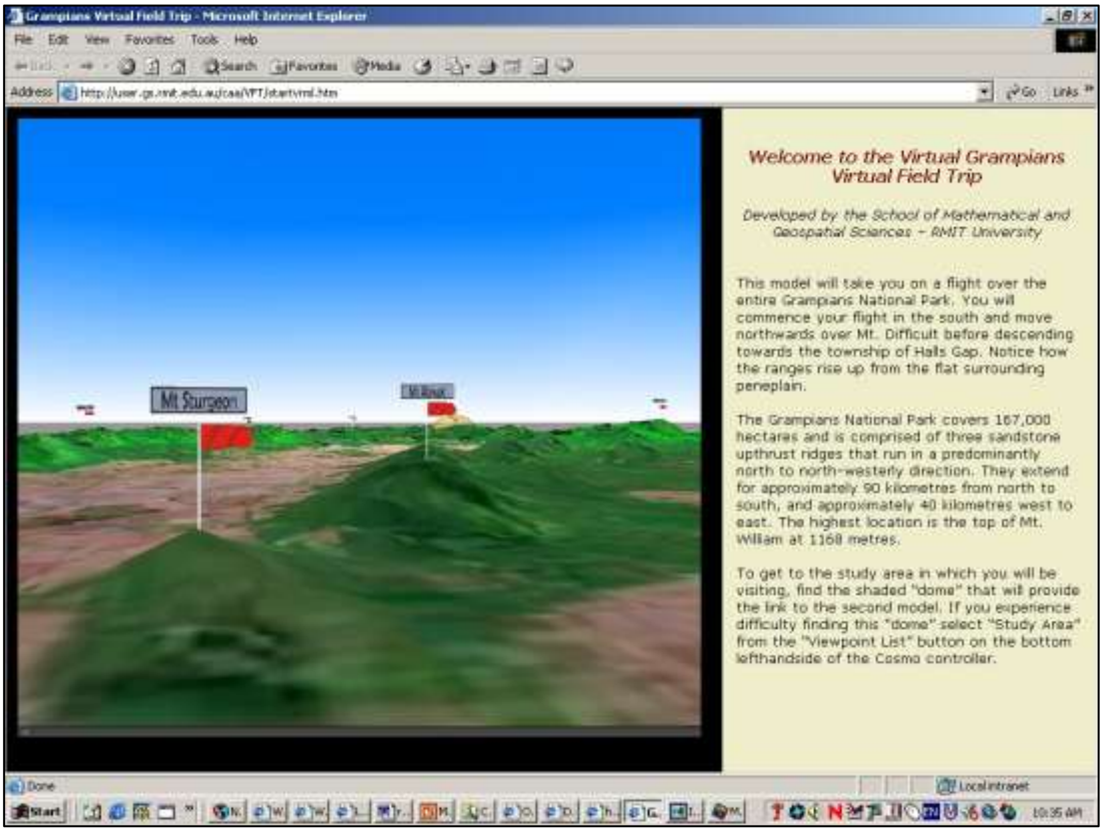


Figure 2-30 The Grampians National Park VR application (Arrowsmith et al., 2005).

2.3.2.12 Grampians National Park VR application

Arrowsmith et al. (2005) developed a VR application comprising topographic maps, photos of important locations and study points of the Grampians National Park (Figure 2-30).

A preliminary study was conducted with 17 postgraduate students. The VFT was used in a self-directed manner, where all students navigated the virtual site using their own computer without any instructor. Since this was a preliminary study, comparisons of the VFT and PFT were based on the students' existing experiences of a PFT; without specifically noting the activities that occurred during the PFT.

Ten students had been on a PFT in the Grampians National Park, five had been on a PFT to another site and the remaining two had never been on a PFT. All but one student felt more comfortable about going on a PFT to Grampians National Park after going through the VFT and most disagreed that the VFT should replace the PFT. No specific reasons were given for the disagreement but the students identified the absence of sensory experiences such as touch and smell as the disadvantage associated with using the VFT.

2.3.3 Discussion

The VR applications, in terms of their layout and purpose are summarised in Table 2. The 'purpose' column indicates how VR applications are being used. The purpose 'learning resource' refers to studies that did not compare the use of the VR application as a VFT and PFT. The purpose 'virtual field trip' indicates that the application was used as a VFT.

Two main issues are identified based on the reviewed VR applications. One relates to the design and the other relates to using the VR application as a medium for a virtual field trip (VFT).

Table 2 A comparative summary of VR applications.

VR application	Purpose	Layout
• Virtual Chemical Reaction Module (Vicher) (Bell & Fogler, 2004)	Learning resource	• Single panel display. • Graphical presentation.
• BP Oil Refinery (Bulwer Island), Brisbane (Cameron et al., 2005) • Coogee Energy Plant (Shallcross, Lukey, et al., 2010) • City West Water facility (Shallcross et al., 2011) • Pacific Terminals Australia (PTA) (described in Maynard et al. (2011))	Learning resource	• All these applications are developed based on the same platform. • Single panel view. • Integration of information is done using multiple locations.
• Virtual Reality Interactive Learning Environment (ViRILE) (Schofield, 2010)	Learning resource	• Dual panel: One contains the VE and the other frame contains the detailed information of the components in the VE.
• Virtual forest (Abe et al., 2005)	Learning resource	• Four panels, allowing users to view sketches by other users.
• Grand Coulee panoramas (Lewis, 2008)	Virtual field trip	• A single panel of panoramas only without additional information
• Indian River Lagoon (Garner, 2004)	Virtual field trip	• N/A (No images or detailed description of the VR application given in the paper.)
• Tempe Butte VR application (Stumpf et al., 2008)	Virtual field trip	• Single panel view with static panoramas. • Integration of information (detailed information, close-up pictures, videos and detailed graphical models of the features) is done using multiple locations.
• Virtual Trillium (Harrington, 2011).	Virtual field trip	• Single panel display.
• Eastern Mediterranean Island (Poland et al., 2003).	Virtual field trip	• Single panel display.
• Tidepools (Spicer & Stratford, 2001)	Virtual field trip	• N/A (No descriptions are available).
• Geological field trip (Chang et al., 2009)	Virtual field trip	• Single panel display.
• Grampians National Park (Arrowsmith et al., 2005)	Virtual field trip	• Single panel display. • Integration of information is done using multiple locations.

2.3.3.1 *Design of educational VR applications*

One of the challenges in developing educational software is to ensure that the applications are easy to use and simultaneously enhance learning. A well-documented instructional design principle for educational software is the theory of multimedia learning (Mayer, 1997, 2003, 2008), which states that learning takes place better when explanations are presented using a combination of both words and pictures instead of either words or pictures only. Words can either be spoken (e.g., narration) or printed (e.g., text).

The theory of multimedia learning was developed based on the Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2003), which demonstrates how learners learn from information presented in both words and pictures (Figure 2-31).

This theory is based on three assumptions:

- Dual-channel assumption:
  Learners use two separate channels for processing audio and visual information representation.
- Limited capacity assumption:
  Only limited information can be processed in one channel at the same time.
- Active learning:
  Learning occurs when the learner is engaged in the cognitive processes of multimedia learning, which are selecting, organising and integrating words and images.

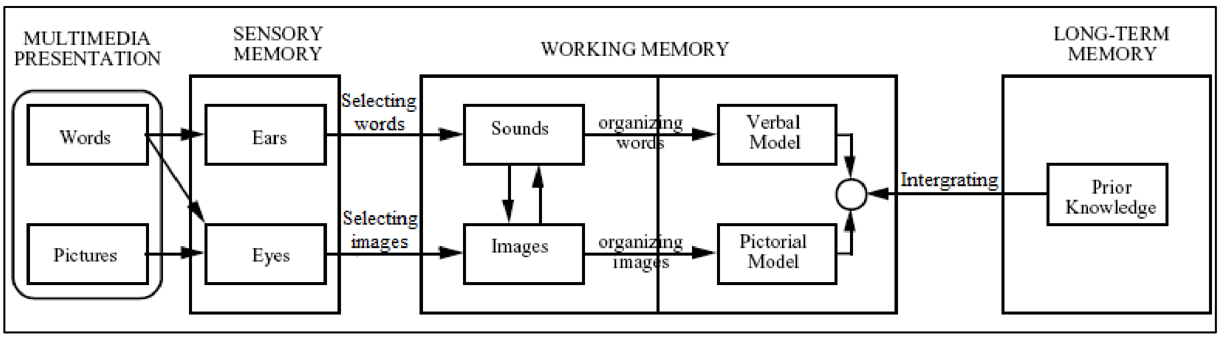


Figure 2-31 The framework of the cognitive theory of multimedia learning (Mayer, 2003).

Table 3 The principles of multimedia learning (Mayer, 2005).

Principles of Multimedia Learning	Definition
Multimedia principle	Learners learn better when information is presented in words and pictures instead of words alone.
Spatial contiguity principle	Learners learn better when the text is placed near the corresponding pictures instead of far from each other.
Temporal contiguity principle	Learners learn better when words and pictures are presented simultaneously instead of sequentially.
Coherence principle	Learners learn better when extraneous words and pictures are excluded rather than included.
Modality principle	Learners learn better when words are presented in the narrative instead of on-screen text.
Redundancy principle	Learners learn better from animation and narration instead of animation, narration and on-screen text. The visual channel will be overloaded as animations and on-screen text are presented in 'visual based' format.
Individual difference principle	Learning has higher effects in learners with low prior knowledge rather than high prior knowledge; and high spatial learners rather than low spatial learners.

The overall cognitive process is not linear and learners may move from one process to another in any way. The theory suggests that learners have limited capability to process channels of both words and pictures. Therefore this suggests that by simply adding both words and pictures into a multimedia application does not help learning. The combination of words and pictures needs to be presented in a manner where it enhances learning without causing cognitive overload. As a guideline to the presentation, a series of multimedia learning principles (Table 3) have been developed based on the results of various multimedia learning tests.

A common feature of most of the reviewed VR applications, regardless of whether they are used as a learning resource or as a VFT, is the use of multiple pages to display linked information. Although these applications still apply the multimedia principle (learners learn better when information is presented in words and pictures instead of words alone), the use of different locations (not within the same display) to link related information may cause a lack of integration of linked information.

In engineering, for example, the Process Flow Diagram (PFD) is important because it represents a chemical process at a conceptual level (Becker, Haase, Westfechtel, & Wilhelms, 2002). The link between the panoramas and the diagrams has also been found to be useful (Maynard et al., 2012). When the PFD is not made available and integrated with other information, it may cause difficulties for users to connect the ideas understand the related information.

For instance, the BP VR application uses two panels to display the map and the panoramas. When the users view the PFD or other information linked to some equipment in a panorama, users are directed to a new page without any display of the panoramas or the map. This may cause difficulties for users when linking related information to the physical environment. When the information is presented sequentially (in this case, on a different location), the user's cognitive load is likely to increase as the user needs to hold the information presented in the previous page until they reach the next related page (Mayer & Moreno, 2002).

Although other applications such as the Tempe Butte VR application (Stumpf et al., 2008), the Grampians National Park application (Arrowsmith et al., 2005) and ViRILE (Schofield, 2010) use two-panel displays, where one presents the panoramas and another provides the explanation related to the panorama, there are no comprehensive links between the information presented in the application. The virtual forest (Abe et al., 2005), on the other hand, has a four-panel layout. However, these panels are mainly used for sharing information among users of the application instead of integrating related information.

Thus a key issue of the applications under review is the lack of integration of information. The large amount of different forms of information (e.g., diagrams, text, photos, videos, etc.) and the connections between related information leads to the motivation of developing and evaluating an application that integrates the information so that it is easy to use while providing a meaningful learning resource for students. Linking the information helps the students to have a better understanding of the individual elements of the materials being studied (Schofield, 2012).

2.3.3.2 Virtual field trip (VFT)

A summary of the VFT studies conducted with the VR applications that have been reviewed is presented in Table 4 (on page 70 and 71).

Table 4 A summary of the virtual field trips evaluations.

Related studies	Procedure	Assessments	
		Learning	Attitude
Grand Coulee panoramas (Lewis, 2008)	• Two groups: students attended either the VFT or PFT. • Before the trips, all students attended a session with explanations related to the sites. • In the VFT session, the students were shown panoramas projected on a large screen with explanations given by the instructor.	No significant difference between the PFT and VFT.	No significant difference (*towards liking or not liking science better)* between the students attending the VFT or PFT.
Indian River Lagoon (estuarine ecology) (Garner, 2004)	• Two groups: students attended either the VFT or PFT. • Two weeks before the trips, all students attended a session with explanations related to general ecology, aquatic science and estuaries. • During the PFT, students worked in groups - some took measurements of dissolved oxygen values. • The VFT began with an introductory video with an instructor. Each student then explored the VR application on their own. They were allowed to ask questions of the instructor. Efforts were taken to ensure the same exposure obtained during the PFT was explored by the VFT students using the VR application.	No significant difference between the PFT and VFT.	No significant difference between the PFT and VFT.
Tempe Butte VR application (Stumpf et al., 2008).	• Three groups: students attended either the VFT, PFT, or both. • Students in both the PFT and VFT visited the respective areas of interest at the sites in the same sequence. • For the VFT, students explored the VR application on their own or in a group. The demonstrator showed how to use the VR application and occasionally explained information presented in the VR application.	No significant difference between the PFT and VFT.	Students who attended the PFT had a better appreciation of the natural landform.

Related studies	Procedure	Assessments	
		Learning	Attitude
Virtual Trillium (Harrington, 2011)	• 12 Students attended both the PFT and VFT. • The content of the VFT was similar to the PFT. However, some items could not be anticipated, such as seeing the salamander or hen in the PFT, and therefore could not be replicated in the VFT. • Students had individual access to use the VR application during the VFT with assistance from the guide.	No significant difference between the PFT and VFT. However, PFT is superior for understanding more complex concepts.	-
Eastern Mediterranean Island (Poland et al., 2003)	• Students attended both the PFT and VFT. • The PFT and VFT were conducted at different sites but with a similar activity. Both involved activity such as taking sample compaction data, but in the VFT it was conducted as a simulation activity. • In the VFT, students were able to explore the VR application by themselves with explanations from the instructor.	No significant difference between the PFT and VFT.	Majority enjoyed the VFT.
Tidepools (Spicer & Stratford, 2001)	• Students attended both the PFT and VFT. • The PFT and VFT were conducted at different sites but with a similar problem-based approach.	-	Majority felt that the VFT was useful and enjoyable.
Geological field trip (Chang et al., 2009)	• Students attended only the VFT. No comparison between the VFT and PFT.	-	Majority found it useful and felt as if they had visited the physical site.
Grampians National Park (Arrowsmith et al., 2005)	• A preliminary study with postgraduate students. • Comparisons based on the students' experience in any PFT, either to the same site portrayed in the VR application or a similar site. • Students interacted with the application individually.	-	All found the VFT useful and would prepare them for the PFT.

The advantages of the VFT over the PFT (except for the limitations of the sensory experiences) have sparked debates as to whether a VFT could be used as a replacement for a PFT. This has encouraged research (e.g., (Harrington, 2011; Spicer & Stratford, 2001; Stumpf et al., 2008) to compare the effectiveness of student learning and attitudes towards the VFT and PFT.

Although students had positive attitudes towards the VFT, in general, they felt that the VFT should not be used as a replacement for a PFT (due to aspects that involve senses such as touch and smell (Arrowsmith et al., 2005; Lewis, 2008)), but could be used as a complementary resource (e.g., a preparation resource for a PFT) (Arrowsmith et al., 2005; Poland et al., 2003; Spicer & Stratford, 2001). The suggestion of having the VFT as pre-PFT and post-PFT tool is consistent with Klemm and Gail's (2003) study. The results of the studies by Harrington (2009) and Poland (2003) suggest that VFTs could be used when PFTs are not available but VFTs should not be used to replace the PFTs if they are available. This contrasts with Garner (2004) who states that both VFT and PFT equally prepared students for achievement exams and therefore when both are available the educators may opt for VFT, which is less expensive. All these studies are related to visits to nature sites such as a lagoon and a national park. Lewis (2008) adds that choosing between a PFT and a VFT depends on the objectives of the visit. If the objective is to expose students to the visited site, then a VFT may be suitable. However, if the objective is to help students understand the big size of a coulee and the surroundings, then a PFT would be a better option.

Most studies above found similar results in terms of the students' learning effectiveness from both the VFT and PFT and also students' attitudes towards the VFT. Though the results are similar, a closer look into these studies identifies that comparisons between the PFTs and VFTs mainly focus on replicating scenarios at the field sites. Examples of these include studies by Garner (2004), Lewis (2008) and Stumpf et al. (2008).

The following were stated in Garner (2004) and Harrington (2011):

> *"Efforts were made to ensure that students on each field trip were exposed to exactly the same features. Certain experiences were guaranteed. For example, both*

physical and virtual field trips exposed students to vegetational zonation" (Garner, 2004, p. 66).

"The field trip activities were carefully controlled to be the same, except that the Real was in the real outdoor location and the Virtual occurred through the VTT software run in a computer lab … However, the Virtual did allow for the students to fly, travel off-trail, and freely explore the entire space independently" (Harrington, 2011, p. 178).

Some of the activities in the VFT included asking students to stop at the same place as in the PFT (Garner, 2004; Stumpf et al., 2008) or providing a similar explanation in both trips (Lewis, 2008). Garner took a step further by ensuring that students in both the VFT and PFT spent the same amount of time on each trip, although it is arguable if this was necessary since the PFT required physical effort to move from one place to another, which required more time than the movement in the VFT, which was mostly done via mouse clicks.

The studies by Arrowsmith et al. (2005), Poland (2003) and Spicer and Stratford (2001) did not stress the similarity of the VFT and PFT. In fact, the sites visited for the PFT differed from the VFT, although both sites exposed the students to the same learning concepts. In these studies, no details of the PFT were included. Therefore there is no clear indicator regarding the similarities or the differences between the procedures for the VFT and PFT.

Simply replicating the exact procedures and materials of the PFT in the VFT caused underutilisation of the VR application. This approach does not make use of the flexibility of the VFT, as it can be a more powerful tool allowing greater integration of information and showing items that cannot be observed in the PFT. The issue of not utilising the capabilities of a computer-based application was highlighted as a negative aspect by students in the VFT study conducted by Spicer and Stratford (2001).

In addition to not utilising the flexibility and capability of a computer-based application, replicating the procedures of a PFT means students are not exposed to areas that are not accessible during a PFT, particularly at sites with strict access due to safety and hygiene reasons. Examples of these situations are:

- Engineering field trips to manufacturing sites where safety and hygiene is a major concern and therefore students have restricted access to some areas.
- Architecture students visiting a building under construction where limited access was given to them due to safety issues.
- Zoology students visiting wild animals at a national park that limits the physical approach distance to animals.

Exposure to inaccessible areas may not be an issue for the VFTs reviewed in this chapter because most are related to environmental studies, therefore most visits were conducted to a nature site that did not involve real-time working machines such as grinding machines and pumps, which cause noise. Therefore, the field trip organisers could take their time when guiding the tour to minimise noise. This was demonstrated when Lewis (2008) waited for students to gather and be quiet before giving information, and provided the students with ample time when they arrived to take notes. This was done to avoid issues related to difficulties listening to speakers while simultaneously observing the environment and making notes, which was identified as an issue by Gail and Klemm (2002). Though this can be avoided in geology PFTs, the situation cannot be avoided in other PFTs such as to an engineering process plant, because the machines keep on running, which increases the noise level, or the requirement to use a respirator in certain areas, which could make it even more difficult to understand the guide.

The scenario described above raises the need to conduct a study comparing a VFT and PFT when a VFT is conducted to expose students to more than they gained on the PFT. The focus of the VFT is more on the integration of information between the learning content and the VE. The integration of information allows students to connect what they learned in class to the related processes that take place in the process plant. Previous studies suggest that the combination of the VE with the data produced greater understanding of information (Moore and Gerard, 2002, as cited in (Arrowsmith et al., 2005)).

Since the VFT can provide more integrated information than the PFT, a drawback of a comparison is the inability to assess the learning effectiveness of both trips, since the VFT may have advantages over the PFT. VFTs are limited in terms of their sensory experiences (e.g., touch, smell, etc.), therefore the term ‘advantages over the PFT’ refers to the information included in the VR application compared with the information gained verbally or through written materials during the PFT. Due to this drawback, the study conducted in this thesis concentrates only on the attitudes towards both the PFT and the VFT. In addition to this, the reasons stated in the literatures regarding the students' preferences for PFTs are mainly related to physical experiences (e.g., Arrowsmith et al., 2005; Lewis, 2008). The present study intends to expand this knowledge by exploring further reasons pertaining to the PFT preferences.

2.3.4 Section summary

The review of the literature related to VR applications in education has revealed that educational VR applications often have different types of information that are not well integrated and linked. Furthermore, when it is used as a medium for VFT, the applications are often a replication of a PFT without the information integration that could provide students with the ability to connect what they learned in class to the related processes that take place in the physical environment.

2.4 Chapter summary

This chapter begins with the definitions and an overview of virtual reality and continues with the issues related to spatial knowledge acquisition, design, development and evaluation of VR applications in the contexts of classroom learning and field trips.

2.4.1 Spatial knowledge acquisition

The use of maps as navigation aids has been studied in VEs of single-level buildings and multilevel buildings. However, little research has been conducted on using point-to-point maps as navigation aids in complex, multilevel VEs, particularly for large-scale VEs. Complex multilevel buildings refer to buildings with large equipment that does not fit within a single level and therefore stretch over multiple levels. The structure of these buildings and their equipment is common in manufacturing (e.g., automobile manufacturing companies and fertiliser factories). This study intends to add knowledge to the existing research related to using maps as navigation aids in complex, multilevel buildings.

2.4.2 VR applications as learning or teaching resources

This thesis focuses on using a VR application with panoramas as an alternative to exposing users to a physical environment (e.g., a field trip). Therefore, the literature review focuses on VR applications with the inclusion of panoramas or computer graphical representations of a physical environment. These VR applications have been widely used in education, however less is known about integrating different sources of information, where the information is interconnected.

Therefore, the proposal is to address this by using multiple panels to display simultaneously integrated and connected information. This is based on the research by Mayer and Moreno (2002) that demonstrates that users learn better when information is presented simultaneously, because they can relate all information at once without causing cognitive overload. This is also known as the contiguity principle (learners learn better when the text is placed near the corresponding pictures instead of far from each other). However, caution is needed to ensure that unnecessary presentations such as sounds or extra information are not included, in order to avoid cognitive overload in students (Mayer & Moreno, 2002).

The issues addressed in this thesis therefore are:

i. Studying point-to-point maps for spatial knowledge acquisition of complex, multilevel buildings, i.e., those with large equipment that does not fit within a single level.

ii. Studying a VR application featuring information integration, that is used for classroom learning and VFT.

For this, two VR applications of a milk powder processing plant were developed. The production plant is a five-level building with equipment that extends beyond a single level. In addition to this, the complexity of the milk powder processes resulted in the inclusion of various sources of information integrated with one another. These two conditions (layout of the plant and amount of information) provide a platform to address the issues raised. This approach is then evaluated as a classroom learning resource and as a medium for field trips.

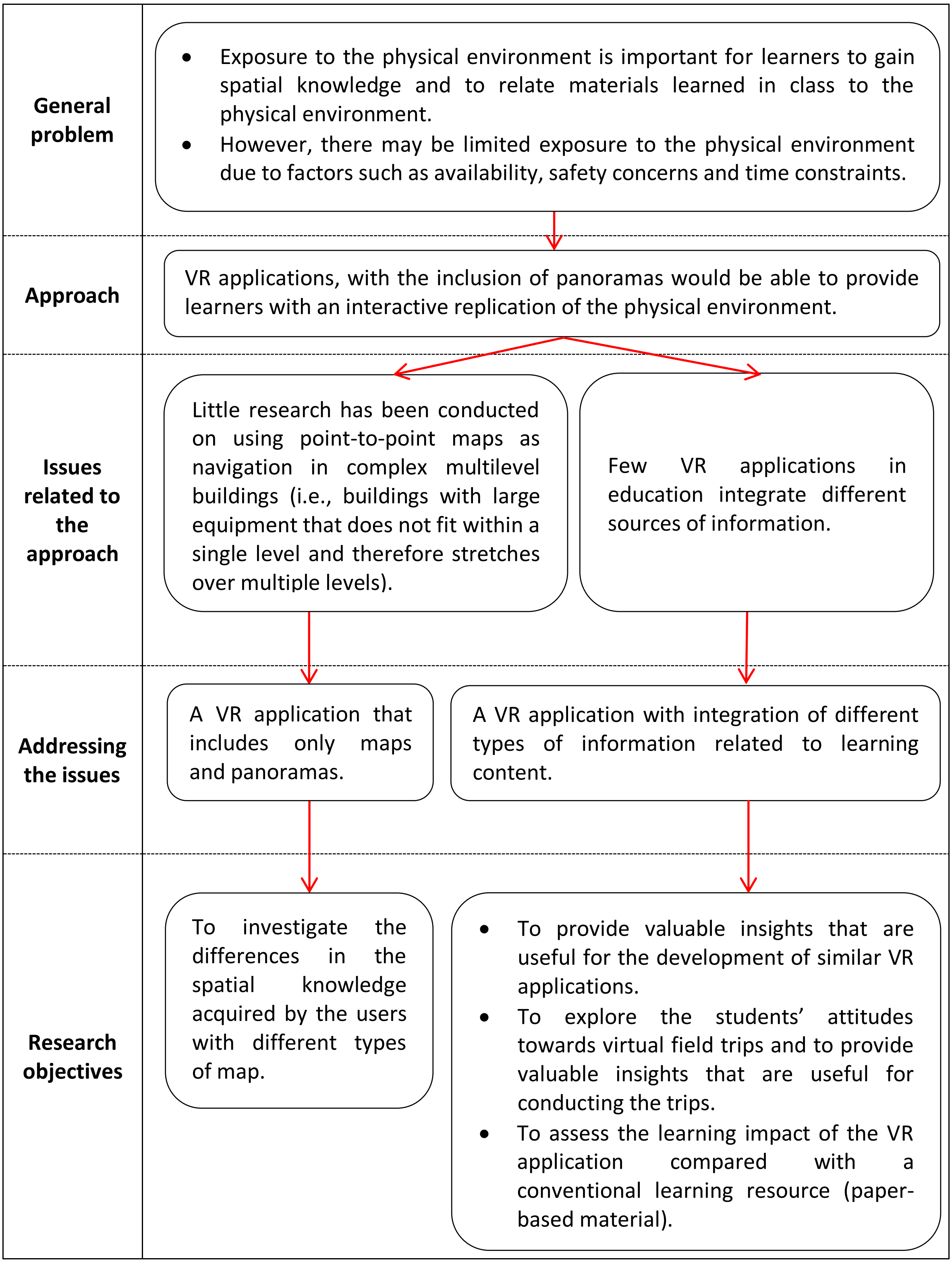


Figure 2-32 Summary of the research motivations and approaches.

The reason for developing two VR applications was due to the different focus of the studies. The first issue (i) was related to spatial knowledge acquisition which is concerned with the use of maps as an aid for navigation. Therefore it is suggested that unnecessary information should be avoided to avoid additional cognitive load for the users (Haik et al., 2002). Hence, the VR application developed to cater for this only contained the map and the panoramas. The second issue (ii) was related to an application that integrates different information as a medium for a virtual field trip and learning resource. Therefore, the VR application contains various formats of learning content. The first VR application was developed by the author and the second application was developed by CAPE and HIT Lab NZ as part of the "Immersive Learning through Virtual Reality" project. The issues, approaches and objectives are shown in Figure 2-32.

Chapter 3
A usability study of the BP VR application

To seek further input related to VR applications, a usability study was conducted with lecturers and students of Department of Chemical and Process Engineering (CAPE), University of Canterbury, using the BP Refinery VR application (Cameron et al., 2008) described in Section 2.3.2.2. The usability study was conducted as an initial step to gain insights about a similar VR application and to identify issues (if any) related to the application.

The rationale for using the BP VR application was because the application uses a point-to-point map and also contains similar types of information (e.g., PFD, P&ID, videos) to those included in the milk powder production VR application. Therefore the BP VR application provides a comparable testing scenario. In addition, full access to the BP VR application was available as a result of project collaboration.

Although the BP VR application was evaluated previously (Cameron et al., 2008), that evaluation covered only issues faced by students and, therefore, conducting another evaluation for both students and lecturers in this research would provide more information regarding the application from the perspective of users who will be using the VR application as teaching material (lecturers) and learning material (students). Since the lecturers would also be the content providers for the milk powder production application, the evaluation was considered vital. Part of the results of the usability study has been discussed in Abdul Rahim et al. (2010).

The chapter begins with the objectives of the usability study (Section 3.1), followed by the method (Section 3.2), the results (Section 3.3) the discussion (Section 3.4) and the chapter summary (Section 3.5). The user study was approved by Lincoln University Human Ethics Committee.

3.1 Objectives

The objectives of the user study were:

i. To identify issues related to the VR application (which may corroborate the findings of the literature review).

ii. To assess the lecturers' opinions of the BP VR application and how it could be used as a teaching and learning resource.

3.2 Method

3.2.1 Participants

An email was sent asking for students and lecturers to volunteer as participants for the user study. Eight lecturers and seven students from CAPE volunteered to participate. For the lecturers, the user study was conducted in their offices using a laptop, and for the students it was conducted using a desktop computer in a computer laboratory. The study was conducted using the 'think aloud' method[11], a questionnaire and a short interview.

The sessions for the first three lecturers were recorded using CAMTASIA[12] but the remaining lecturers and students were only video-recorded as CAMTASIA slowed down the VR application and caused frustration for the participants. The screens were video-recorded to provide details of the navigation style performed by the participants.

3.2.2 Procedure

The procedure for the user study was as follows:

i. Participants completed a consent form containing written information concerning the objectives of the user study.

ii. Participants completed a general information form.
The form for the lecturers sought information regarding their experience with the BP VR application and the associated teaching materials (e.g., lecture notes, slide presentations) (see Appendix A.1). For the students, the form asked questions related to their year of study, exposure to any physical process plant and their experience using any VR software (see Appendix A.2).

iii. Participants were given an overview of the BP Refinery application.

[11] To say out loud what they were thinking while performing the task.
[12] An audio and screen video record software (http://www.techsmith.com/camtasia/)

For the lecturers this included a brief showing of the induction video, the self-guided process tour video and an interactive page for choosing personal protective equipment. Although these features were not included in the prescribed navigation tasks, they were shown briefly because they were part of the content-related items in the VR application and the lecturers needed to rate the degree of importance of these items in the questionnaire. These features were excluded from the students' user study because they were not the content provider for the milk powder production VR application.

iv. Participants were then provided with a brief demonstration of how to navigate the VR application (e.g., moving from one node to another, displaying the hotspots).

v. Participants were permitted to practise using the application until they were familiar with it. There was no time limit for the practice sessions.

vi. The participants performed the navigation tasks such as:
   - Finding specific equipment and,
   - Going to a specific node and facing a specific direction.

   In addition, the lecturers were asked to perform a pump shutdown activity, to expose them to possible content that could be included in the intended VR application.

   The instructions for the tasks are given in Appendix A.3 (lecturers) and A.5 (students).

vii. Participants answered a questionnaire (given in Appendix A.4 (lecturers) and A.6 (students)) that asked them to:
   - State their level of agreement with the statements related to their experience using the application, on a Likert-scale ranging from 1 = Completely Disagree to 6 = Completely Agree.
   - Participants were required to state their level of agreement with the statements on a Likert scale ranging from 1 = Extremely Unimportant to 6 = Extremely Important.

As this questionnaire intended to seek participants' opinion regarding the application, an even scale was used to allow positive and negative responses to be obtained by the participants.

viii. A short interview with regard to the participants' opinions, in general, about the application, was conducted at the end of each session.

3.3 Results

During the analysis, the external hard disk containing the students' videos was corrupted. Therefore, Sections 3.3.3 and 3.3.4 provide only the observations of the lecturers and comments made by them.

3.3.1 Participants' backgrounds

Of the eight lecturers, two had not seen or used the BP VR application before. The remaining six had previously seen it but only three had actually used it; for 1 day, 1 week and 12 months respectively, as a preparation for teaching. One lecturer had used it once during the lecture. Other medium used during the lectures include Power Point slides, static images, animated images and videos. Some also used white boards and overheads during class.

The students were 1st, 2nd and 3rd Professional students[13]. They had experience of process plants ranging from 1 day to 6 months. This had taken place on field trips, work, internships and job interviews. One had seen and used the BP VR application for one day but the remaining students had no experience with any VR software.

3.3.2 Participants' agreement with statements in the questionnaire

All except one completed the pump shutdown task. The VR application was running slowly because CAMTASIA was running concurrently and the lecturer decided not to carry out the task. This particular lecturer had used the BP VR application before and had previous experience using the pump shutdown interactive page. Therefore, s(he) was still able to answer the questionnaire.

[13] 1st Professional are students in their first year of chemical engineering (after completing the foundation studies of engineering), 2nd Professional are second year students and 3rd Professional are final year students.

3.3.2.1 The questionnaire related to participants' experiences using the VR application.

Figure 3-1 shows the participants' agreement with the statements related to the experience using the BP VR application (on a scale of 1 = Completely Disagree to 6 = Completely Agree). For statements 11 and 12, only seven of the eight lecturers answered the questions, hence the median (for the lecturers) is based on the seven who answered.

Two-thirds of the statements were in agreement. For statements 8 and 10, the responses from both the lecturers and students tend towards disagreement suggesting that the feelings of being lost and dizziness in the virtual plant were felt by only a few participants. Split responses for statement 9 were received from the lecturers, suggesting that the sense of 'not knowing the direction' was experienced by half of them.

For statement 11, the students' responses inclined towards disagreement compared with the lecturers. This shows that the lecturers used the help button quite often whereas the students did not use it while navigating the VR application, as observed during the user study.

With regard to statement 1, although participants' levels of agreement about using the compass were high, it was observed that the compass was used only when they performed a task that specifically asked them to face in a particular direction. Other than that, none used the compass during navigation.

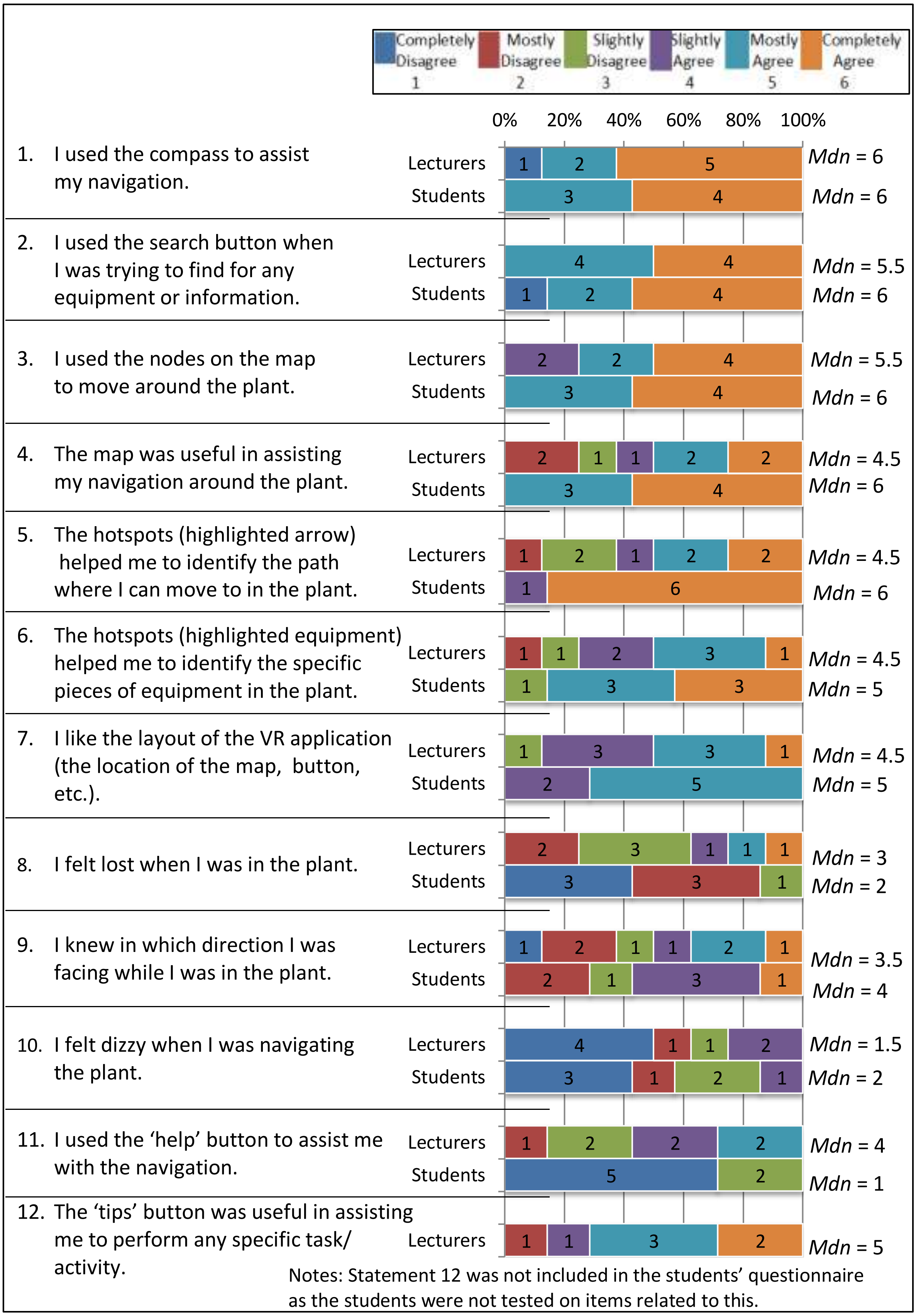


Figure 3-1 Participants' level of agreement with the statements related to the experience using the BP VR application. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

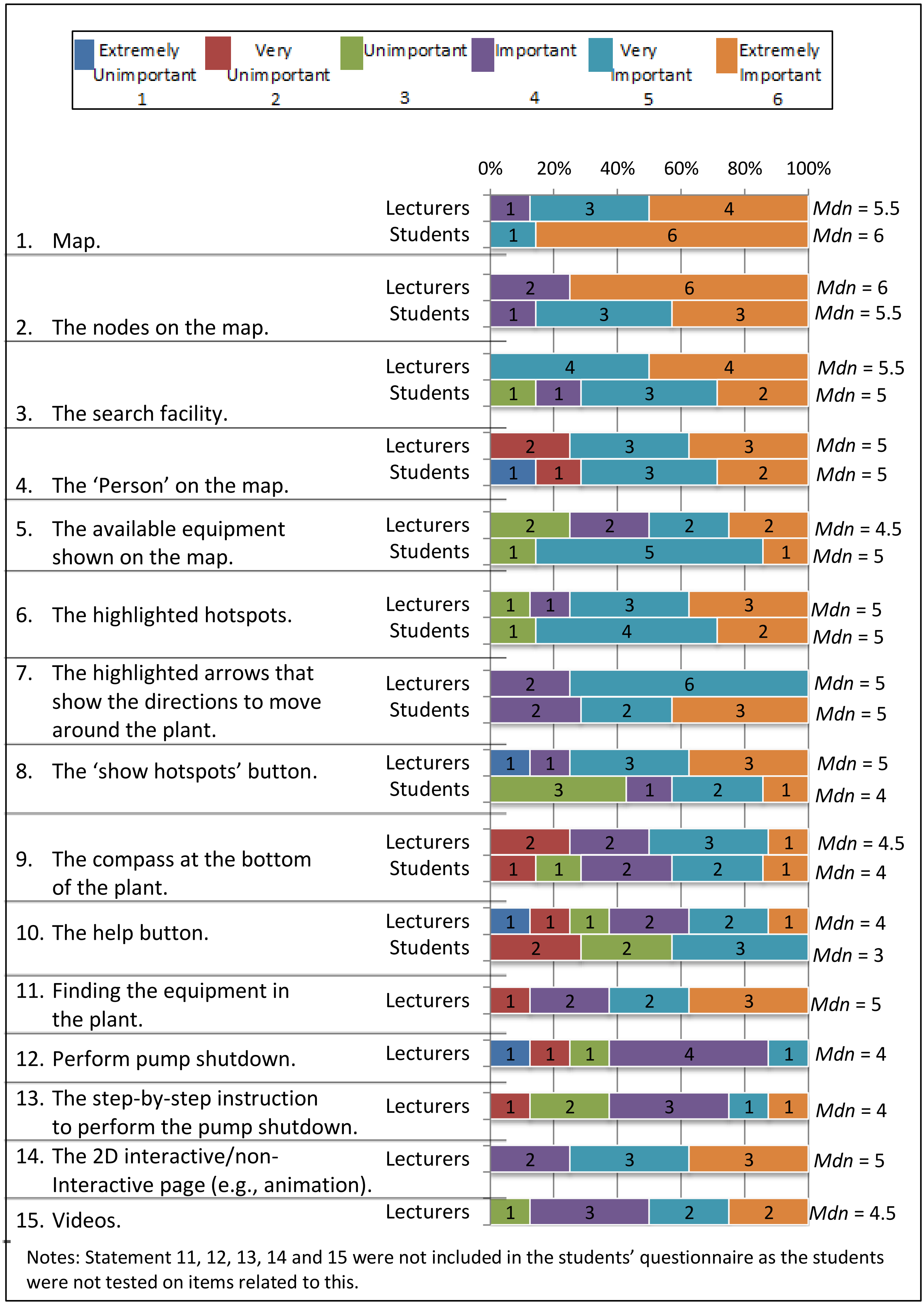


Figure 3-2 Participants' levels of agreement with the statements about the VR application. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

3.3.2.2 Questionnaire related to the importance of the features in the BP Refinery application

Figure 3-2 shows the participants' agreements with the importance of different features in the application (on a scale of 1 = Extremely Unimportant to 6 = Extremely Important). Statements 11 to 15 are only in the lecturers' questionnaire.

The responses from majority of the participants on all components tend towards important, except for the help button where most of the lecturers' responses tend towards important and most of the students' responses tend towards unimportant. This agrees with their responses to the statement *'I used the 'help' button to assist me with the navigation'* in the earlier part of the questionnaire (Figure 3-1) where, during their navigation, the lecturers used the help button quite often compared to the students.

3.3.3 Observation of the task completion

As stated earlier, the external hard disk containing the students' video was corrupted and therefore the analysis for this section provides the comments and observations only of the lecturers. However, it was noted that most students managed to perform the tasks and most comments received were regarding the colour of the hotspots, which the students claimed were hard to see.

Table 5 shows the list of the tasks. Except for tasks 1, 2 and 7 where some needed hints to help them, most lecturers managed to complete the tasks without assistance.

Table 5 The tasks lecturers were required to perform.

No	Task
1	Enter the plant. Look for equipment numbered 802-B and go to the nearest node to the equipment.
2	From this position, look for the available hotspots.
3	From the highlighted hotspots, identify equipment 802-B.
4	Show how you can display the available menu associated with the specified equipment. Click on the second item in the menu.
5	Go back to the position you were at before you clicked on the item in the menu.
6	Face east and move forward.
7	You need to shut down an electrically driven pump. Show how this is done.
8	Suppose you want to see the process of how 'crude' works. Show the steps taken to reach the page.

Note: Task no. 7 is applicable only to the lecturers.

Most difficulties were encountered with Task no. 7. Except for one lecturer who did not complete the task, all were given hints to assist them with the task. For task 1, two lecturers who struggled to find the equipment were shown the map as a hint to assist them. One lecturer could not point to the hotspots (Task 2) that highlighted the equipment in the VE and this lecturer was told to click on the 'show hotspot' button to display the hotspots. For task 6, all but one lecturer used the compass to perform this task. This lecturer who did not use the compass used the nodes on the map instead and panned left and right in the panoramas until s(he) was certain that s(he) was facing east.

The lecturers had different preferences when performing task 8. Some used the search engine and searched 'crude' and others clicked on the 'crude' link available on the home menu.

3.3.4 Lecturers' comments and suggestions

Most lecturers commented that the BP VR application was useful. In terms of system performance, two lecturers commented that the loading time was slow. However, these two lecturers were navigating the VR application while running CAMTASIA and the loading time was very much affected by this. No comments regarding the slow loading time were received from the others.

All except two lecturers found that navigation was quite easy after they had practised following the brief demonstration, with one adding *"...except for the hotspots colours and the tips"*. The two lecturers who did not find navigation easy had actually used the VR application before. One commented that "*there is no sense of direction even after using it several times*". Further comments and suggestions from the lecturers relating to the components and the presentation of the application are shown in Table 6.

Most lecturers had ideas on how to use the application as a teaching resource; these varied depending on the courses they were teaching.

Table 6 Comments and suggestions from the participants relating to the VR application.

Item	Comments	Suggestions
Hotspots	• The colour was difficult to see. • The colour made the equipment look rusty rather than highlighting the items.	• Use a completely different colour from the plant so that it could be clearly seen. • Display the hotspots by default instead of having users click on the button to display them.
Map	• Most lecturers commented that the map was useful. • The map was considered small and caused the items on the map to be too close to each other.	• Have a means of showing the direction in which the user is facing in the virtual plant. • Have indicators of the height of the equipment. • Add extra information such as informing users about the current location and where they are moving next.
Compass	• The compass was difficult to look at and most users did not realise it was there.	-
Diagrams (PFDs and P&IDs)	• Lack of links between the PFD and the pieces of equipment in the VE (i.e., when the link to the PFD of a piece of equipment in the VE is clicked, the same piece of equipment in the PFD should be highlighted). Note: Only few links are available instead of all components in the PFD.	• More links between the PFD and the panoramas.
Animation/ Video/ Interactive Page	• Mixed responses were received for the ‘pump shutdown activity page’, where one commented that it is very good and other three commented that it was frustrating and not intuitive. • Two lecturers did not like the induction video and one stated that it was too long. • One commented that the animation video of the process is useful.	• Have the instructions next to the button (of the pump in the activity page) instead of having the instructions displayed at the bottom panel when the tips button is clicked.
Functionality	• The search engine did not work well. • The lack of ability to go to the previous page.	• Have a ‘back’ button to allow a return to the previous page. • Have an improved search function.
360^{o} panoramas	-	• Have the information appear when the cursor hovers on a piece of equipment in the VE. • Have an indicator on the ‘highlighted green arrow’ to show the direction in which users are facing (north, south, east and west). • Show the scale and size of the equipment in the plant.

The suggestions related to using the application as a teaching resource included:

- The VR application could be used as a virtual field trip for students since the students could go back and forth looking at the virtual plant which is better than a physical field trip, which is a one-off trip (two lecturers).
- The VR application could be used to show the complexity of the process plant, which relates to a health and safety issues course (one lecturer).
- The animated pages could be used to show students how specific equipment works (two lecturers).
- The pump shutdown activity page could be used as part of his teaching material (one lecturer).
- The VR application could be used for students to perform calculation tasks provided that the values for certain equipment, for example, pressure, can be changed so that it provides students with the values to perform the calculation (one lecturer).

Though most had ideas about using the application as a teaching resource, most also stated that the content of the application did not relate to courses they were currently teaching.

3.4 Discussion

The objectives of the user study were:

i. To identify issues related to the VR application (which may corroborate the findings of the literature review).

ii. To assess the lecturers' opinion of the BP VR application and how it could be used as teaching and learning resource.

For the first objective, although most lecturers and students were able to complete the tasks given in the user study with minimal assistance, the comments from the lecturers suggested two main issues related to navigation and the user interface, which supports the issues identified in Chapter 2.

3.4.1 Navigation

The lecturers raised issues of not knowing the direction in which they were facing because there was no indicator on the map, which agrees with the same issues reported in (Cameron et al., 2008). Cameron et al. (2008) suggest to resolve this by including a compass that rotates according to the direction in which the users are facing in the virtual plant. Though a compass could be used to solve this problem, this approach may not be suitable for multilevel buildings because of the horizontal and vertical aspects of the building. Furthermore, in this user study, no participant used the compass except for task 6 (of Table 5), which specifically asked them to face in a particular direction. Therefore, the Y-A-H map (You-Are-Here map), as proposed by Darken and Peterson (2001), would be an appropriate cue to show the user's orientation.

3.4.2 User interface

The lecturers were concerned about the lack of links between information. This includes being disconnected from the previous page where they were navigating due to the lack of back button, and also the lack of links between the PFD and the panoramas. This suggests that using different pages to present connected information was not useful because it caused disconnection between information. Therefore, the information needs to be well integrated and linked to allow users to stay connected with the information. The links and integration between the information need to be done cautiously to avoid users experiencing cognitive overload.

Another issue was the difficulty in identifying hotspots due to their colour. This issue can be solved by the use of a bright colour to better highlight the hotspots (Marshall & Nichols, 2004).

For the second objective, most lecturers had positive attitudes towards the application. They agreed that it could be used as a teaching and learning resource as well as a medium for a virtual field trip (VFT).

3.5 Chapter summary

In short, the findings show that the lecturers have a positive attitude towards the application and they have preferences in using it as a teaching resource, be it as a classroom teaching and learning material or as a medium for a virtual field trip (VFT).

The findings also uncovered some issues related to the VR application, which are:

- Not knowing the direction they were facing because there was no indicator on the map, which agrees with the same issues reported in Cameron et al. (2008).
- The lack of links between information including disconnection from the previous page (due to the absence of a back button), and between the PFD and the panoramas.
- Difficulties in identifying hotspots due to their colour.
- Small size of map.

In line with the findings of the literature review, the first issue related to navigation was further investigated because this thesis focusses on investigating the acquisition of spatial knowledge based on different types of map. Furthermore, as suggested by Haik et al. (2002) and Witmer et al. (2002), users may experience excess cognitive load if applications developed for spatial knowledge acquisition are not minimised. The user study on spatial knowledge acquisition is discussed in Chapter 4.

The remaining issues found in this study relate to the design and functionality of the VR application. These findings provide valuable insights for the development of the milk powder production VR application. Steps were taken to address the highlighted issues (e.g., the hotspots, size of the map, links between the information). For example, the milk powder production plant contains various pipelines and components that are silver, therefore, a bright and outstanding colour is considered for the hotspots. The multilevel plant is more complicated than a single level plant, therefore a larger size of map is needed to display the components on the map and at the same time not block any other information displayed on the screen. The approaches taken to address the issues are shown in Table 15 of Chapter 5 (page 146).

Chapter 4

User study 1: Spatial knowledge acquisition in a complex large scale virtual environment

This chapter reports the user study carried out to answer the research question, "*How do different types of map affect the acquisition of spatial knowledge in a virtual complex multilevel building?".* Complex multilevel buildings refer to buildings with large equipment that does not fit within a single level, i.e., it occupies more than one level.

The outcomes of the study will provide valuable insights for the development of similar VR applications with similar purposes. To answer the research question, a VR application of a dryer area of an indoor five-level milk powder processing plant was developed.

Section 4.1 describes the background to the maps evaluated in this user study and the hypothesis of the study. The following section (Section 4.2), describes the VR application developed for this study. The assessments involved in the user study are described in Section 4.3. Before the main user study, a pilot study was conducted (Section 4.4) to identify any issues regarding the VR application and to seek participants' opinions on its ease of use. The pilot study was also used as a test of the main user study. The findings of the pilot study informed some modifications to the main user study, which is described in Section 4.5. The measurement and scoring methods of the assessments in the main user study are described in Section 4.6. The results and discussion of the study are presented in Sections 4.7 and 4.8, respectively.

4.1 Background

The maps evaluated in this user study were based on maps used by other researchers for multilevel buildings. The maps provide an exocentric view of the plant, which is valuable for a multilevel building (Shumaker, Luo, Duh, Chen, & Luo, 2009). As discussed in Section 2.2.4, these maps have advantages and disadvantages if used for the multilevel building described in this user study.

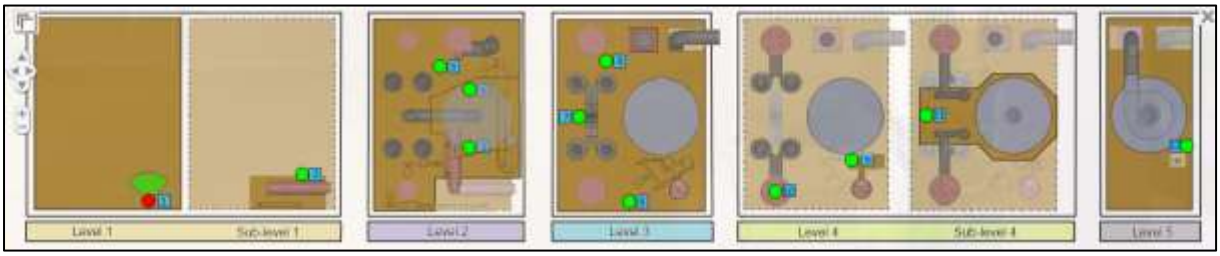


Figure 4-1 The 2D map.

For the present study, the issue with the 3D map is that objects on the map may block the view of other objects. To address this issue, a 2.5D map was designed, where each floor is displayed separately allowing the objects on the map to be displayed in a cut-away form. Since the present study used a point-to-point map approach, there was a limitation in designing the maps; all maps were developed in a static manner instead of in an interactive form where users have the ability to interactively rotate them at different axes. For the 3D map, a rotation function was included allowing a view from different angles of the map (refer to Section 4.1.1). Further details of each map evaluated in this study are now described.

4.1.1 The 2D, 2.5D and 3D maps

The 2D map (Figure 4-1) separately displays a top-down view of each level of the plant in a sequence starting from the lowest level (left) to the highest level (right). The labels for each level are at the bottom of the map. The map is oriented this way to make efficient use of the screen space. In a landscape orientation, it may cause the map display to be very small. Although a zoom in/out button is available, it is not certain that the users will use it; therefore, this size is considered better than a landscape orientation.

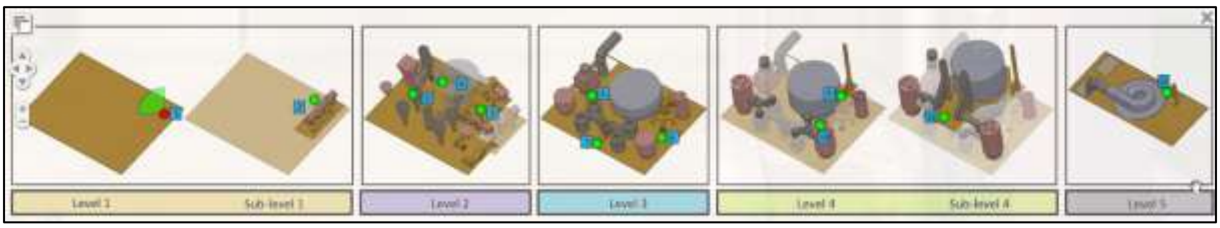


Figure 4-2 The 2.5D map.

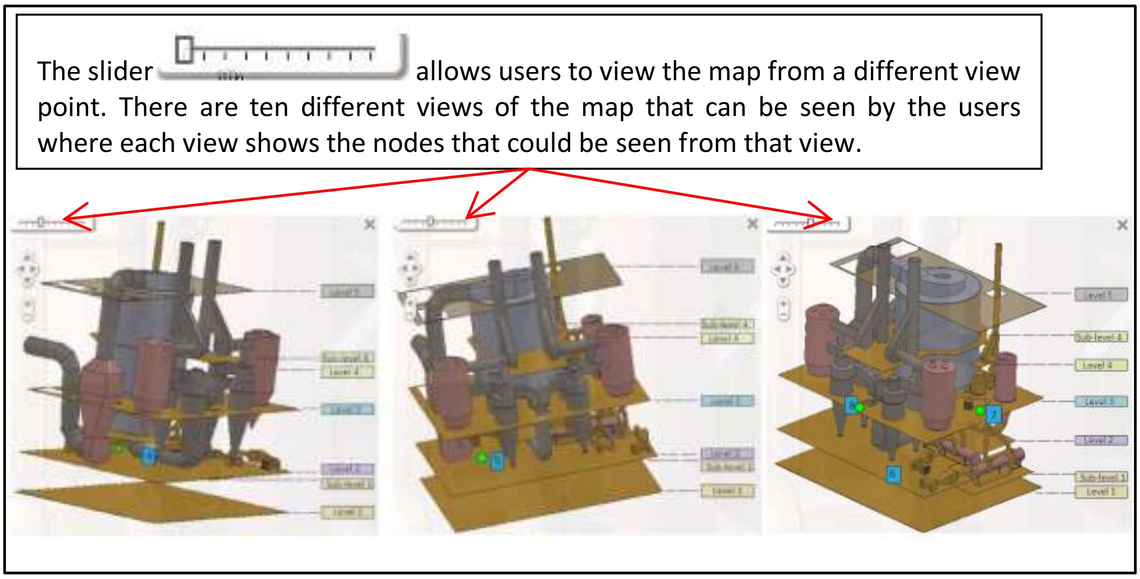


Figure 4-3 The 3D map.

The 2.5D map (Figure 4-2) is a graphical projection of the 3D map but presented as separate levels similar to the 2D map. The 2.5D map is arranged in a sequence from the lowest level (left) to the highest level (right) with the level label at the bottom of the map. This map is oriented this way to reduce the chances of objects blocking other objects.

The 3D map is a replica of the building where each level of the building is stacked one on top of the other (Figure 4-3). A slider is added at the top left corner to allow a view of different angles of the map. There are 10 different views of the map available; each view shows the nodes (locations of interest) that can be seen from that view. Each level in the building is labelled accordingly.

The presentation of the 2D, 2.5D and 3D maps was similarly designed so users of each map had essentially the same layout. All maps have the building levels labelled. All maps display the same equipment relating to the spray dryer in the milk processing plant. Other items, not related to the spray dryer, are not displayed on the map. In the 3D map, it was not possible to show all the equipment at once because some items are hidden in some views but the rotation function allows users to view the hidden equipment.

4.1.2 Hypothesis

Maps assist users to gain immediate survey knowledge without first acquiring landmark and route knowledge (Thorndyke & Hayes-Roth, 1982; Whyte, 2012). Therefore it is expected that there would be a difference in the survey knowledge acquired by participants using the different types of map and no difference in landmark and route knowledge.

A 2D map provides better spatial horizontal information than the 3D map (John, Cowen, Smallman, & Oonk, 2001), and a 3D map provides better spatial vertical information (Fontaine, 2001; Luo, Luo, Wickens, et al., 2010). However, when a multilevel building has equipment extending over more than one level, the objects on the map could hide the other objects. A 2.5D map is expected to overcome this problem because it represents a combination of both the 2D and 3D maps. Pieces of equipment on the 2.5D map are presented in a cut-away form that reduces the chance of blocking other objects. Therefore, it is expected that a 2.5D map would provide both spatial horizontal and vertical information of the environment.

The study hypothesised that there will be differences between the survey knowledge acquisition of the participants with the 2D, 2.5D and 3D maps. In addition, it is expected that the 2.5D map will provide the participants with better survey knowledge than the 2D and 3D maps because it provides a 3D cut-away representation of the equipment in the plant, in a separate floor, which has minimal blocking of other equipment on the map.

Therefore, the hypothesis of this user study is:

$H_{1:}$ There is a difference between the scores of the survey knowledge assessment of the participants with the 2D, 2.5D and 3D maps.

4.2 Description of the VR application

The VR application was constructed based on different locations of interest (nodes) in the dryer area of an indoor five-level milk powder production plant. There were 12 nodes with each node incorporating a 360^o panorama of the location. The nodes were selected by a lecturer in CAPE based on the equipment s(he) thought was important in milk processing.

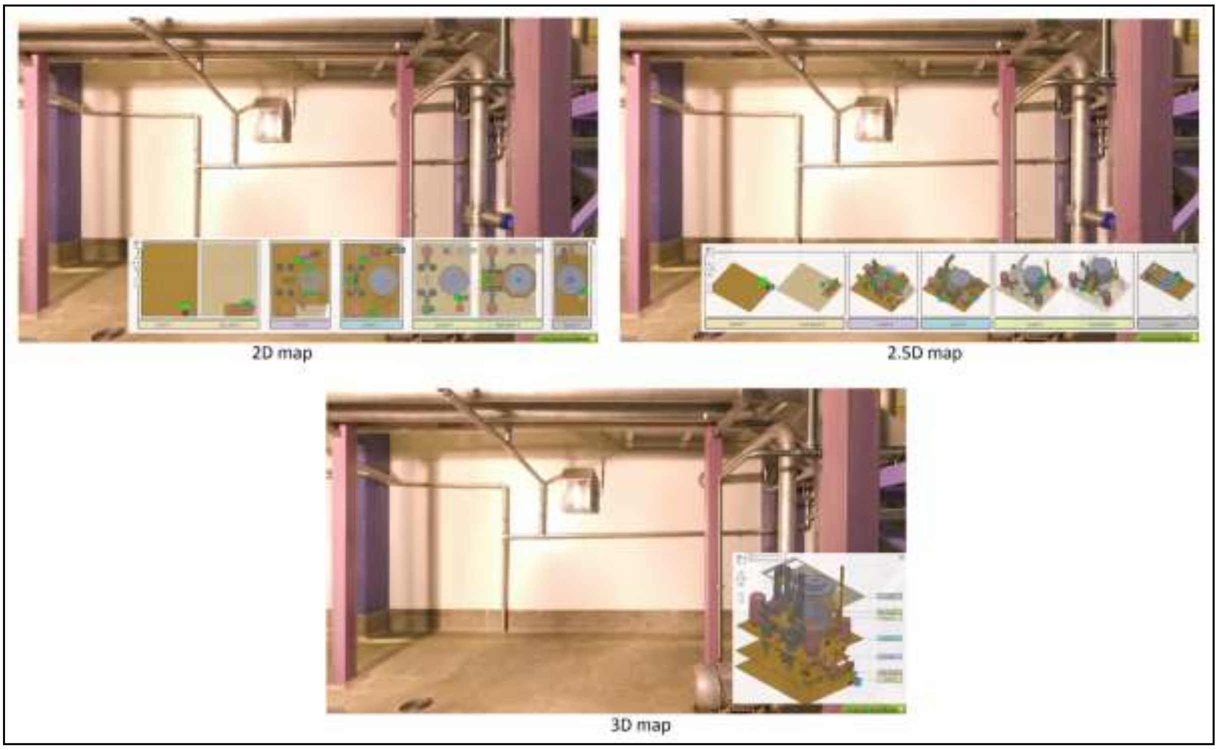


Figure 4-4 The position of the maps in the VR application of a milk dryer plant.

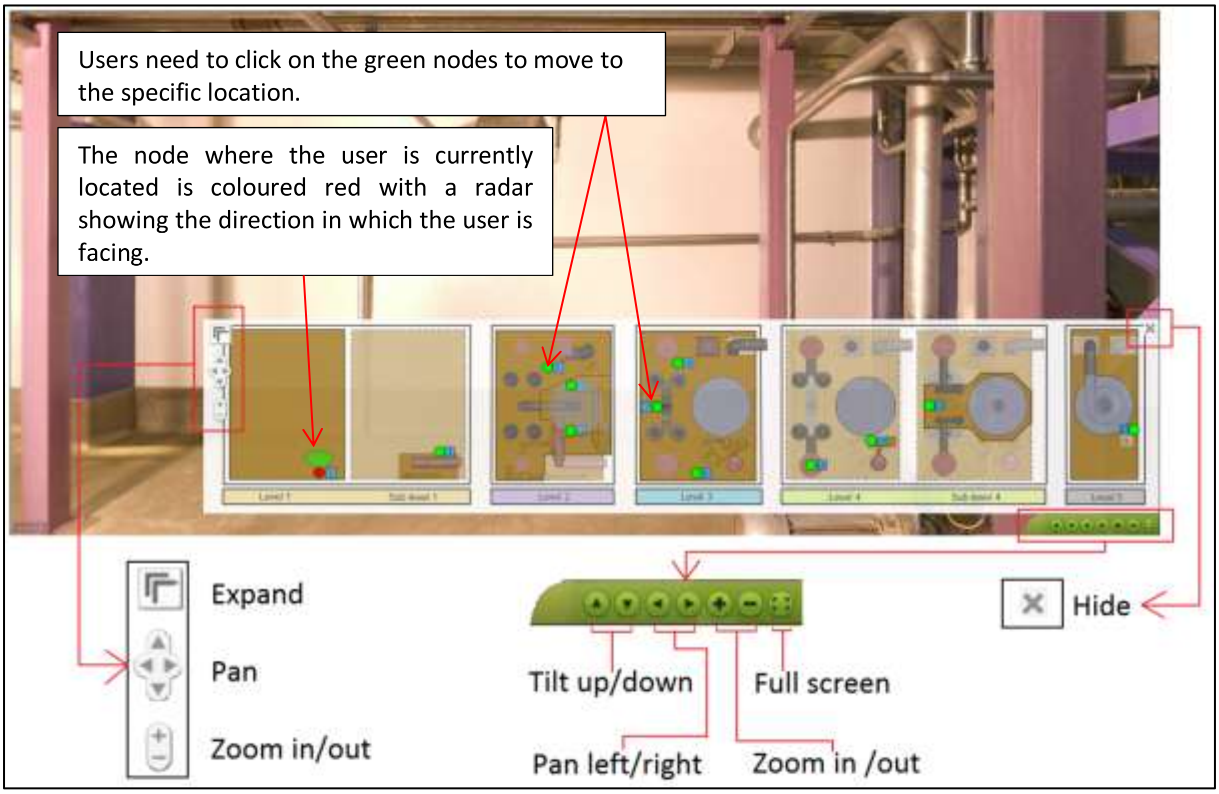


Figure 4-5 The interface of the map and the VR application for the milk dryer plant.

Figure 4-6 The expanded map of the milk dryer VR application.

The VR application was developed using PanoZona[14], which is open source software for developing a virtual tour. All maps are placed at the bottom of the display area, as shown in Figure 4-4. The interface for the application is shown in Figure 4-5. The map displays the equipment in the dryer area, with green nodes representing locations to which users can move. Moving between nodes is achieved by clicking on the green nodes on the map. The node where the user is currently located is coloured red (see Figure 4-5). The buttons  shown in Figure 4-5 allow users to zoom in/out, pan left/right and tilt up/down in the 360^{o} panoramas at the current location.

Figure 4-7 The map is hidden when the ‘hide’ button is clicked.

[14] http://panozona.com/wiki/Main_Page

This can also be done using the left button of the mouse to pan/tilt and using the mouse wheel to zoom in/out. At the top left of the map, are buttons that allow users to expand, zoom in/out and pan the map, and at the top right of the map is a button to hide it. Clicking on the 'expand' button  expands the map, including the map frame, as shown in Figure 4-6. The 'hide' button  is used to hide the map. Once the map is hidden, another button appears to allow users to re-display the map (Figure 4-7).

4.3 Assessment of spatial knowledge

This section discusses the assessment of the landmark, route and survey knowledge and the selected assessments for this user study. Various measurements are available to assess an individual's acquisition of spatial knowledge after navigating an environment. Satalich (1995) provides a list of assessment methods for measuring landmark, route and survey knowledge.

Landmark knowledge: Landmark knowledge can be tested using the l*andmark recognition test*. Since landmark knowledge is about identification of available landmarks in the environment, the *landmark recognition test* is concerned with the ability of the individual to distinguish landmarks (as shown in the images) that have been sighted in the navigated environment.

In addition to the *landmark recognition test*, Satalich (1995) includes the *landmark placement test* and *landmark orientation test* as measurements of landmark knowledge. The *landmark placement test* is concerned with placing landmarks in the correct position on a map and the *landmark orientation test* is concerned with knowing the landmark's position relative to other landmarks. Although these tests are proposed as measurements of landmark knowledge, these measurements appear to be more related to the assessment of survey knowledge since both require the individual to have a mental map of the environment in order to place the landmark at its correct position and orientation.

Route knowledge. Route knowledge can be measured via the *landmark sequencing test*. Since route knowledge is concerned with the sequence of landmarks (e.g., which landmark comes after which landmark), the test requires the individual to select the landmark that appears first between two landmarks on the same route based on given images (Satalich, 1995). This approach is similar to a measure used by Coluccia et al.

(2007) and van Asselen et al. (2006). Another approach to measuring route knowledge is the *route distance estimation task*, which measures the distance between two landmarks.

Survey knowledge. Survey knowledge can be measured using the *Euclidean distance estimation task*, where the individual determines the distance between two landmarks. The difference between this measurement and the *route distance estimation task* is that this measurement involves a direct distance between the landmarks (in a straight line) whereas the *route distance estimation task* refers to the distance between two landmarks based on the route the individual can walk to move from one landmark to the other.

Another way to assess survey knowledge is by using the *map drawing task* (Billinghurst & Weghorst, 1995), where the individual is required to draw on a piece of paper the environment they have navigated. Scoring is done by averaging the scores given to the drawing by two experts (Billinghurst & Weghorst, 1995) or by counting the number of errors made in the drawing, such as the omission of a landmark, wrong placement or inaccurate placement (Taylor & Tversky, 1992).

A more detailed measurement for the *map drawing task* was used by Darken (1996) who measured the total sum of *map distance error, map direction error*, and *map land error*. The *map distance error* measured the differences between the distances between the landmarks on the drawn map and the distances of the same landmarks on the actual map. The *map direction error* measures the angle differences between the landmarks in the drawn map and the differences on the actual map and the *land map error* measures the differences between the landmarks' attributes (size, position and orientation) compared with those on the actual map. These error rates were summed as the *total map error,* which is the final measurement for this test.

4.3.1 The selected assessment methods

The various measurement methods could be classified into metric and loose measurements. Metric measurements refer to exact measurements such as the distance between two landmarks as in the route *distance estimation task*, or the angle difference between two landmarks in the *map direction error.* A loose measurement refers to approximate measurements such as counting the errors made in the *map drawing task.*

Although many existing studies use metric measurements to assess survey knowledge, the use of loose measurements would be more appropriate for measurements of the spatial knowledge acquired in multilevel buildings in this user study. The reason is that the point-to-point navigation map does not provide the actual walking path available from one landmark to another and, therefore, it is impractical to use a metric measurement such as the *route distance estimation task* for assessing route knowledge.

In addition, the approach when navigating such a building in the physical world is concerned with correctly identifying the vertical and horizontal locations. Using the horizontal or vertical locations of landmarks as references is one strategy when people navigate in a multilevel building (Hölscher, Vrachliotis, & Meilinger, 2005). For example, the question *"Where is the book shop?"* would be answered with *"It is located at the right corner at Level 3"*, instead of providing an exact measurement of the location.

An issue with the *map drawing test* is the user's ability and interest in performing the drawing task. In a pilot study conducted by Maliki (2008), participants were not willing to draw a map of the place from where they had migrated, but were more willing to visualise the place using 3D models of houses and other elements. Although that study was in the context of drawing maps in landscape architecture research, a method asking someone to draw may have the same impact in the present research. Therefore, the approach of using 3D models to visualise the mental map could be used as an alternative for the *map drawing task.* In this approach, instead of asking the participants to draw a representation of their mental map, they were asked to put the 3D objects representing the landmarks of the navigated environment in their correct positions in a model of the building.

In conclusion, since loose measurements are used instead of metric measurements, the assessment methods used in the user study are a(n):

- Map Drawing Test
- Landmark Recognition Test
- Landmark Sequencing Test
- Object Placement Test

4.3.2 Spatial ability measurement

An individual's spatial ability affects the acquisition of spatial knowledge (Darken & Cevik, 1999; Wolbers & Hegarty, 2010). Therefore, the participants' spatial abilities were also measured to correlate participants' spatial abilities and their acquired survey knowledge based on the different maps used in the navigation task. According to Darken and Cevik (1999), an individual's spatial ability level affects the individual's acquisition of spatial knowledge. Therefore the individual's spatial ability needs to be determined to see if it has an impact on the acquisition of spatial knowledge.

Spatial ability in general refers to the ability to generate, maintain, and manipulate mental visual images; and can be divided into spatial relations, spatial orientation and visualisation (Lohman, 1979). Spatial relations involve the ability to mentally rotate a simple visual stimulus, spatial orientation involves the ability to make judgements from a different perspective, and visualisation, which is the most complex task, involves the ability to manipulate visual patterns, as indicated by their level of difficulty and complexity.

Since this thesis is concerned with measuring survey knowledge, which includes the orientation between one landmark and another, and the orientation of the landmark itself, the two factors of spatial ability involved are spatial relations and spatial orientation. Therefore, assessments related to these two factors were selected to assess the participants' spatial abilities.

The test chosen for *spatial relation* is the Mental Rotations Test (MRT) (Peters, Laeng, et al., 1995), as shown in Figure 4-8.

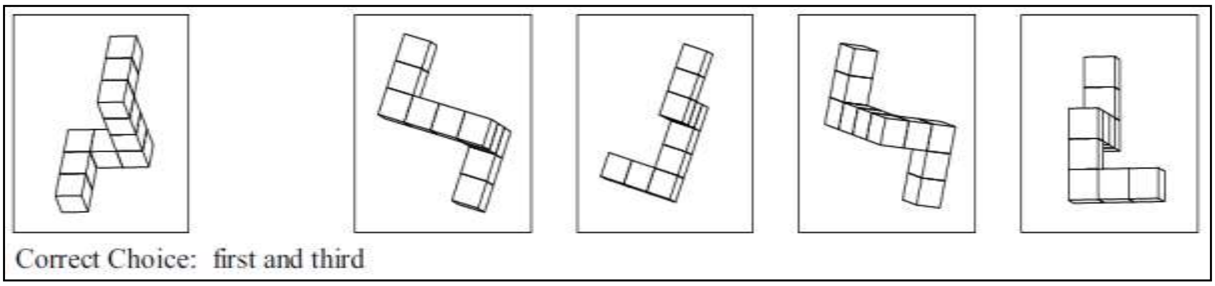


Figure 4-8 A sample question of the Mental Rotation Test (Peters, Laeng, et al., 1995)

[Copyright clearance to reproduce image not obtained]

Figure 4-9 A sample question of the Card Rotations Test (Ekstrom et al., 1976).

In the MRT, participants are asked to select two rotated versions of given 3D objects. Each question consists of an image of a three-dimensional line drawing and four other similar drawings. Two of the four options are the rotated version of the given image and the remaining two are not (but look similar). Participants are asked to select the two rotated versions of the given image. In total, there are 24 questions (two sets of 12) and participants are given 3 minutes to answer each set. Scores are given only if two options are correctly selected.

The MRT was chosen because it is more suitable and is used as a standard test. It involves 3D objects compared with other tests such as the Card Rotations Test (CRT), which is similar to the MRT except that it uses 2D objects (Ekstrom, French, Harman, & Dermen, 1976) (see Figure 4-9).

For *spatial orientation*, the Perspective Taking Test (PTT) (Hegarty & Waller, 2004) was used in this study. The PTT measures the ability to judge the location bearings of an object from any given position (Figure 4-10). The PTT requires participants to judge the location bearing of given objects from imaginary positions. There are 12 questions in this test and participants had five minutes to complete them. The score is the average difference between all attempted items and the actual bearings.

Another test to measure *spatial orientation* is the Guilford-Zimmerman Spatial Orientation Survey (Guilford, 1956). In this test, participants are shown two different views of a landscape viewed from a boat and they must determine how the boat changed its position from the first view (top) to the second view (bottom) by selecting the correct options (Figure 4-11).

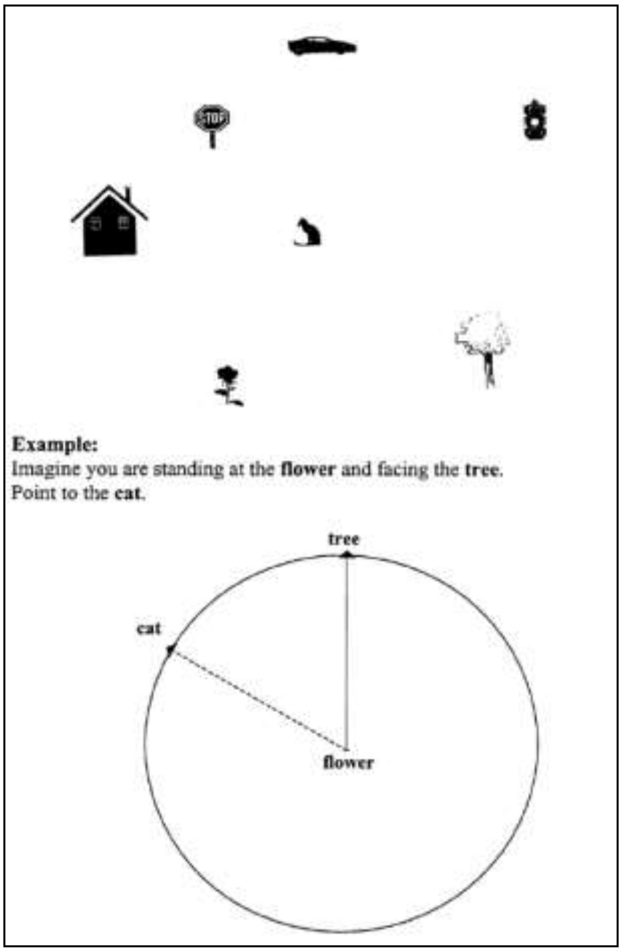


Figure 4-10 A sample question of the Perspective Taking Test. The dotted line indicates the correct answer (Hegarty & Waller, 2004).

[Copyright clearance to reproduce image not obtained]

Figure 4-11 A sample of question of the Guilford-Zimmerman Spatial Orientation Survey. (Guilford, 1956)

The PTT was chosen because it contains fewer questions (12) than the Guilford-Zimmerman Spatial Orientation Survey (Guilford, 1956), which has 67 questions that may cause stress or boredom in the participants.

4.4 Pilot study

A pilot study was conducted to identify any usability issues regarding the VR application and to test the clarity of the procedure and the related tests of the main study. No detailed scoring was performed for the participants' responses to the tests and, therefore, the Mental Rotations Test (MRT) (Peters, Laeng, et al., 1995) and the Perspective Taking Test (PTT) (Hegarty & Waller, 2004) were not included. Furthermore, these two tests are established tests and therefore do not need to be pilot-tested.

4.4.1 Participants

Seven participants from different educational backgrounds (five computing, one commerce and one CAPE student) volunteered for the pilot study. The participants were observed and notes on any issues or comments were taken throughout the study.

4.4.2 Procedure

The pilot study was conducted on a desktop computer with a mouse as the main interaction device. It consisted of a:

i. Practice session,
ii. Navigation task,
iii. Spatial knowledge acquisition tests (map drawing test, landmark recognition test, landmark sequencing test, object placement test), and a
iv. Short interview where the participants were asked their opinion about the ease of using the VR application.

4.4.2.1 Practice session

Each participant was given a brief demonstration on how to navigate the VR application. After the demonstration, the participants were asked to practise until they were comfortable with it. The objective of the practice session was to familiarise the participants with navigating using the application. The demonstration and practice sessions were conducted using another application with the same type of map and functions but different panoramas. The reason was to avoid any learning effects from the tested panoramas. Once participants were comfortable and decided to stop practising, they were asked to perform the *navigation task*.

4.4.2.2 Navigation Task

This task required them to navigate the VR application by clicking on the nodes according to the sequence numbers given on the map. Figure 4-12 shows part of the sequence in the 2D map. The nodes on all maps were numbered in the same sequence. The *navigation task* provided participants with a guided navigation. Thus, they were not asked to search or look for any specific targets in the environment.

The reason for providing a guided navigation was to allow all participants to have the same exposure to the environment in the same sequence. This is similar to a guided tour conducted during a physical field trip where each location is visited according to a specific sequence. Although it may limit the ability to gain survey knowledge as the participants could not explore the virtual environment freely, is aligned with the focus of the present study, which emphasises secondary survey knowledge (using the map as a source of survey knowledge).

Participants were allowed to go to each node only once. They were asked to pay attention to the equipment and the environment at each node. No time limit was set. Upon completing the task, they were asked to perform the next test.

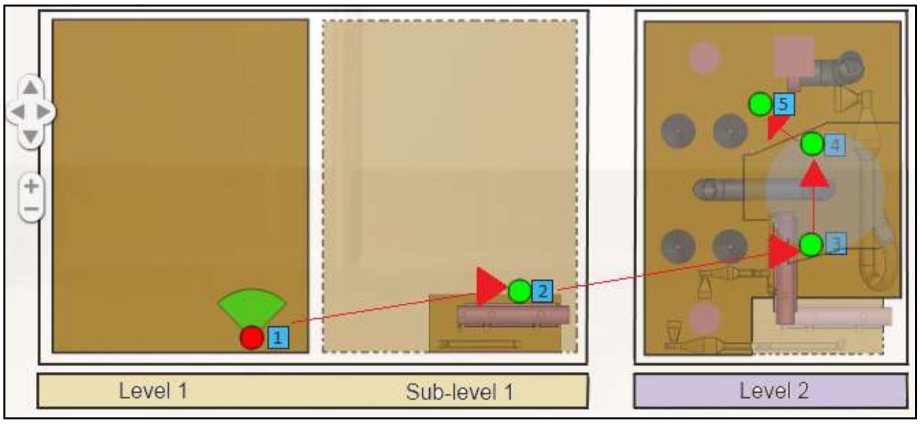


Figure 4-12 Part of the sequence of the nodes on the map.

4.4.2.3 Spatial knowledge acquisition tests

The procedures for the map drawing test, landmark recognition test, landmark sequencing test and object placement test are described in this section.

Map drawing test. The participants were asked to draw on a piece of A4 paper the environment they had just navigated.

Landmark recognition test. The landmarks in this study were the equipment components in the panoramas of the process plant. The components were chosen as they were displayed on the map. In addition, participants were told to pay attention to the environment and the equipment in the panoramas when performing the *navigation task.*

The participants were presented with 10 images, five were screenshots of the landmarks in the panoramas and the remaining five were images of landmarks that were not shown during the *navigation task*. Participants were then asked to classify the items of equipment into ‘In the process plant’ and ‘Not in the process plant’. They were not told the number of landmarks that should be in each category. Participants were told to be as accurate as possible but if they were not sure about the classification, they could mark them as ‘not sure’. An example of the question is shown in Figure 4-13.

Landmark sequencing test. This test required the participants to select images of a landmark that appeared first between two landmarks on the same route (Satalich, 1995).

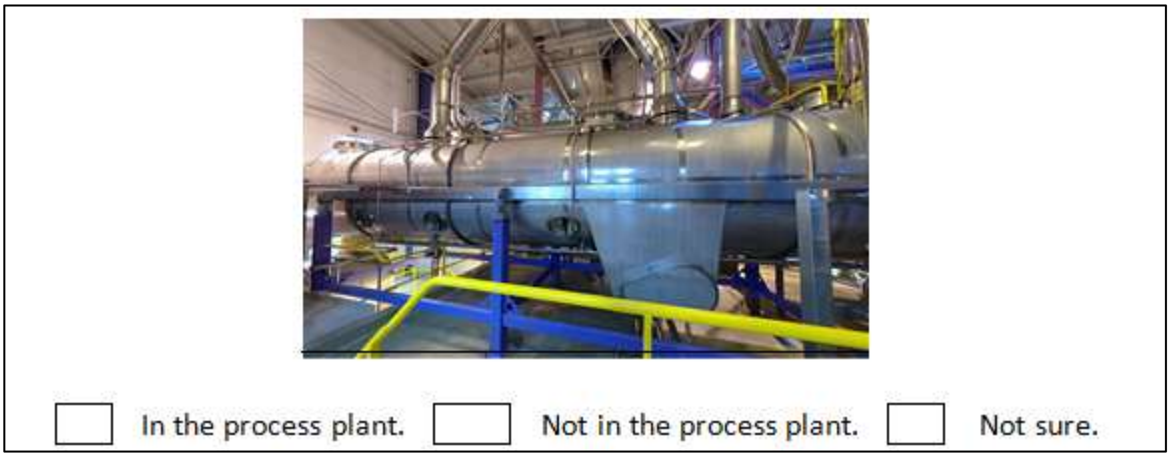


Figure 4-13 A sample question for the landmark recognition test.

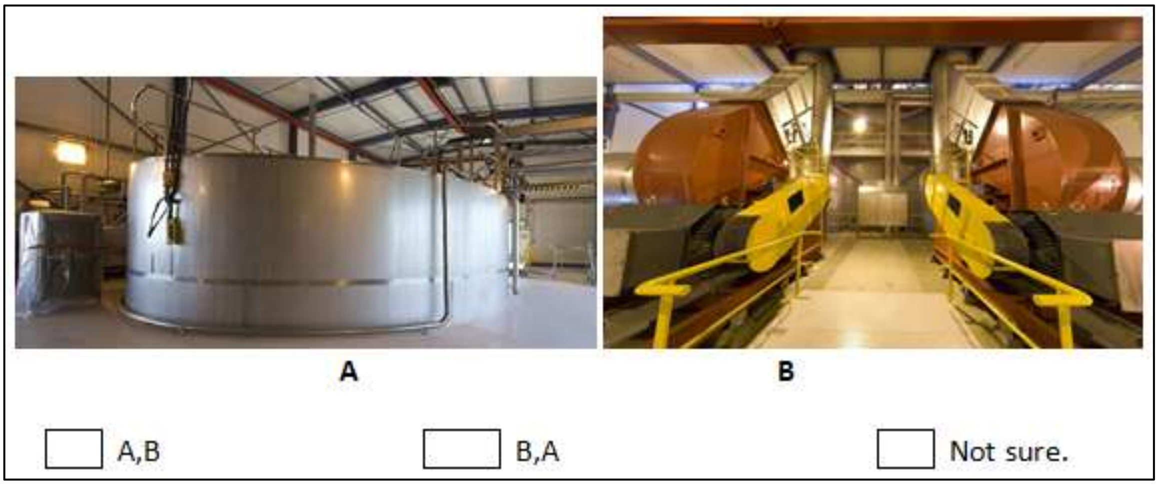


Figure 4-14 A sample question for the landmark sequencing test.

Participants were presented with four pairs of images comprising screenshots of landmarks captured from the panoramas where each pair comprised images of two different landmarks at two different nodes. Participants were asked to identify which landmark (of each pair) they encountered first on the route during the *navigation task*. Like the *landmark recognition test*, participants were also told to be as accurate as possible but they could omit any pair of pictures if they were unsure about the sequence. An example question is shown in Figure 4-14.

Object placement test. As described in Chapter 2, survey knowledge refers to having developed a mental map of the environment, which means participants have a visual representation of the environment. This visual representation was assessed through the *map drawing test* earlier. However, considering the fact that different participants may have different drawing abilities that result in them having difficulty in expressing the vertical and horizontal positions of the equipment in the process plant, this test allows them to provide the vertical positions, horizontal positions and orientation of the objects. This was done by asking participants to physically place the 3D models of the relevant equipment on a base according to their respective positions in the process plant.

Figure 4-15 shows the arrangement for this test. Participants were given physical 3D models of the dryer, cyclone, bag filter and air blower in the plant. These four items were selected because there was only one of each of them in the plant.

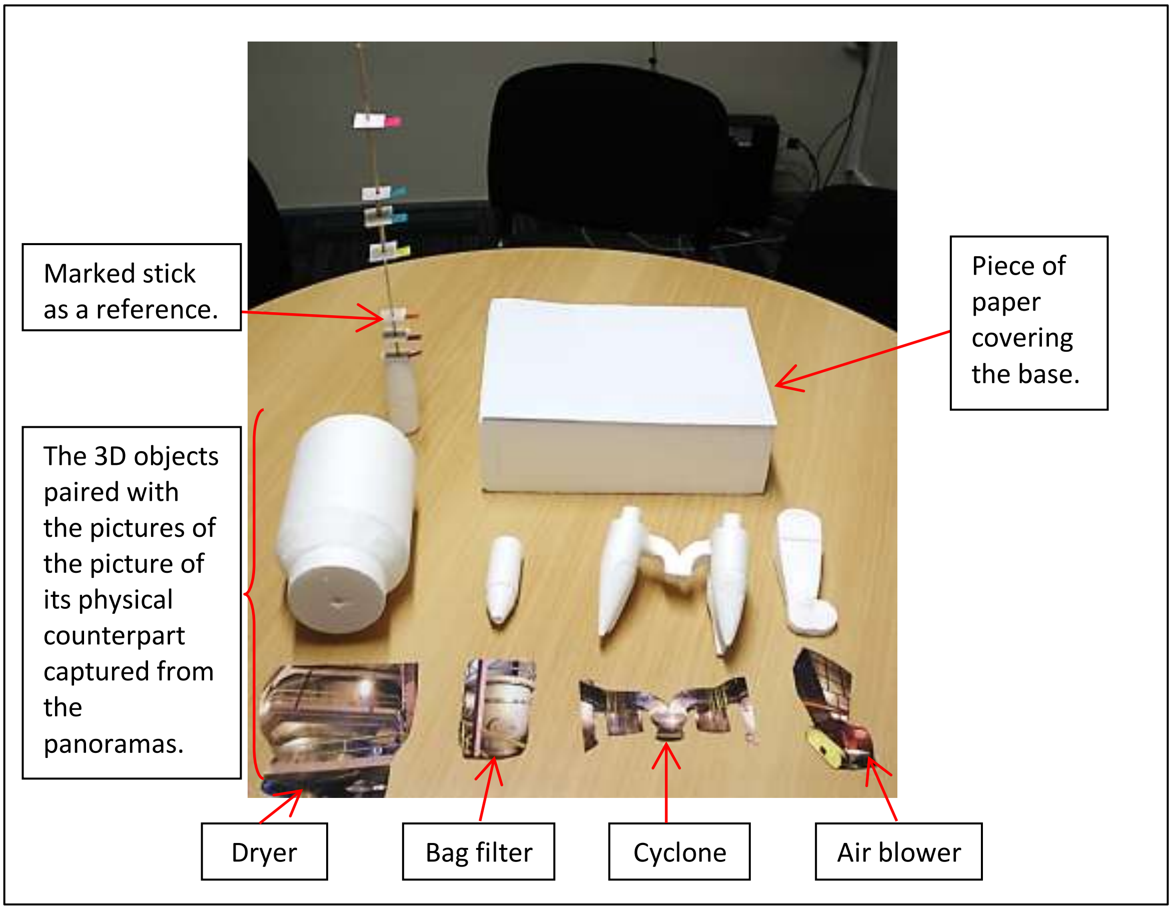


Figure 4-15 The settings for the object placement test.

Each 3D object was paired with an image of its physical counterpart captured from the panoramas. The participants were also given a base on which the 3D models could be placed. The base was covered with a piece of paper so that the marks made where the sticks that were inserted into the base could be identified later for measurement. Participants were told that the 3D models and the base were scaled to 100 times smaller than the size of the physical plant. All 3D models were made of polystyrene.

A marked stick was placed next to the base. The reason for putting the marked stick next to the base was to provide the participants with an indicator of the height of each level in the building. This is shown by the red dashed lines in Figure 4-16. Each mark on the stick is labelled with the respective level.

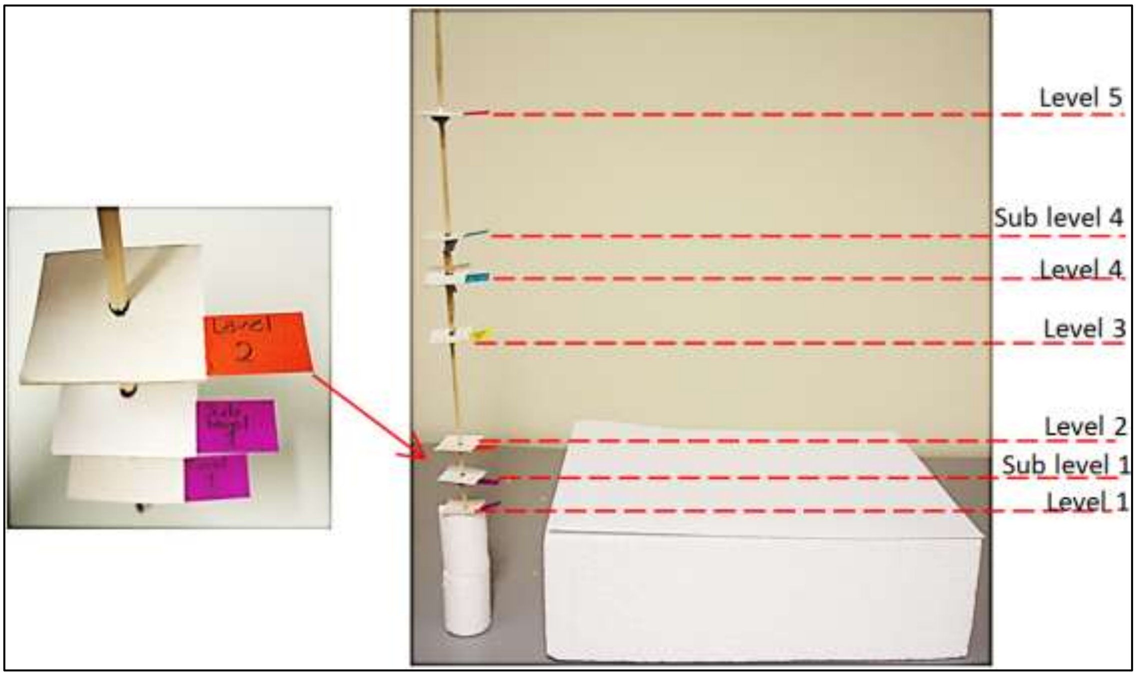


Figure 4-16 The marked sticks with the respective levels of the building, used as an indicator to show the respective levels of the building.

The participants were also given a set of sticks marked with the respective levels in the building (Figure 4-17). In total, there were 28 sticks with 4 sticks for each level of the building. The bottom of each stick was marked in black indicating the depth to which the stick should be inserted into the base.

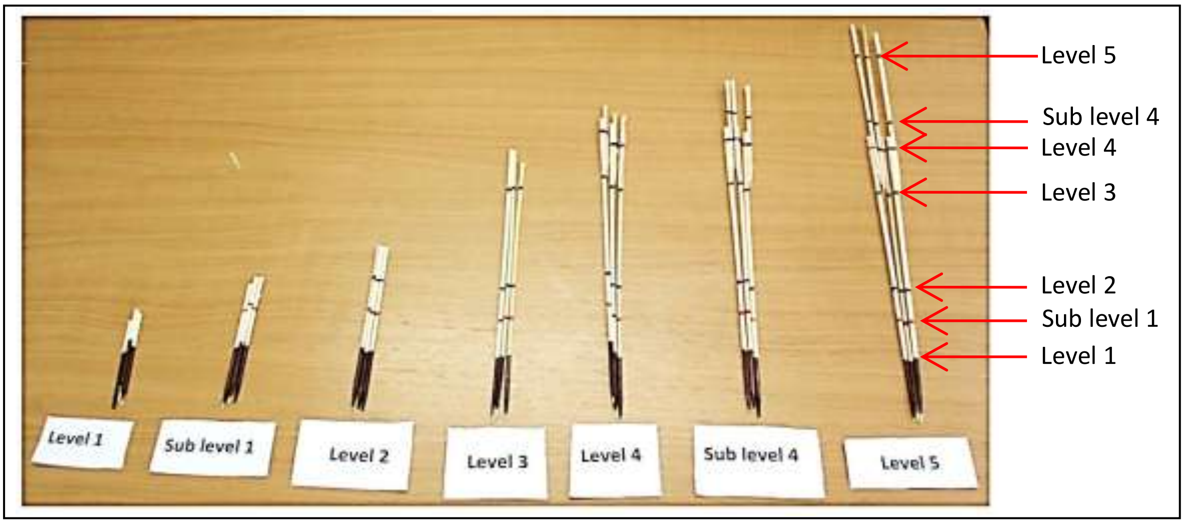


Figure 4-17 The marked sticks according to the respective levels.

In order to place the 3D models on the base, the participants needed to select the stick representing the level where they intend to place the 3D model. Participants were allowed to put each 3D model at any level they thought it was located and were shown how to place the 3D models on the base provided. They were also given an opportunity to practise before performing the actual test.

An example of the objects placed during the practice session is illustrated in Figure 4-18. There are two ways of placing the objects: first, place it at a specific level (e.g., Level 2, Level 3) and second, place it in between two levels (e.g., between level 2 and 3, between level 1 and sub Level 1). If the participant intended to place an object on level 3, the bottom part of the object needs to be at the level 3 mark on the stick. For instance, 'Object A' is placed at level 3. Therefore the bottom of 'Object A' is placed at the mark which indicates level 3. The other object, 'Object B', is placed between levels 3 and 4. Therefore, the bottom of Object B is between the marks that indicate levels 3 and 4.

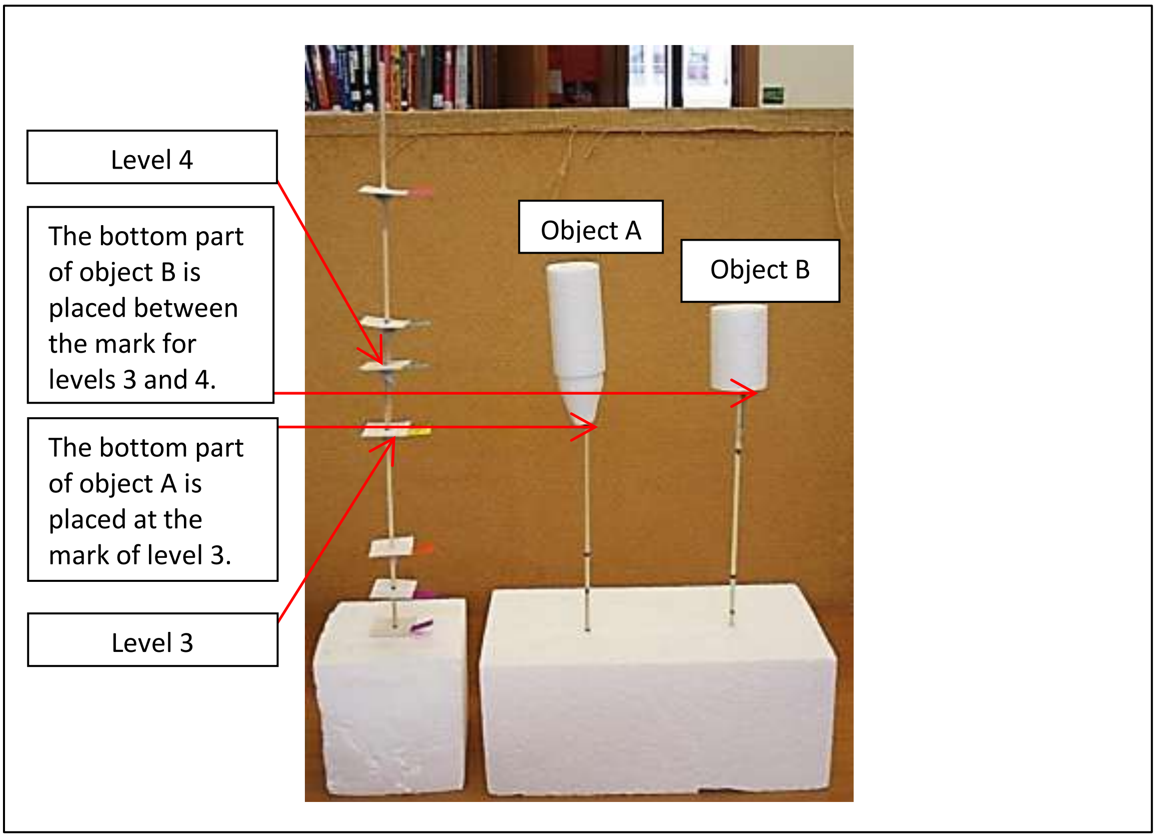


Figure 4-18 Example of the objects placed on the base.

Participants were informed that they could ask for assistance if they were unsure how to place the objects.

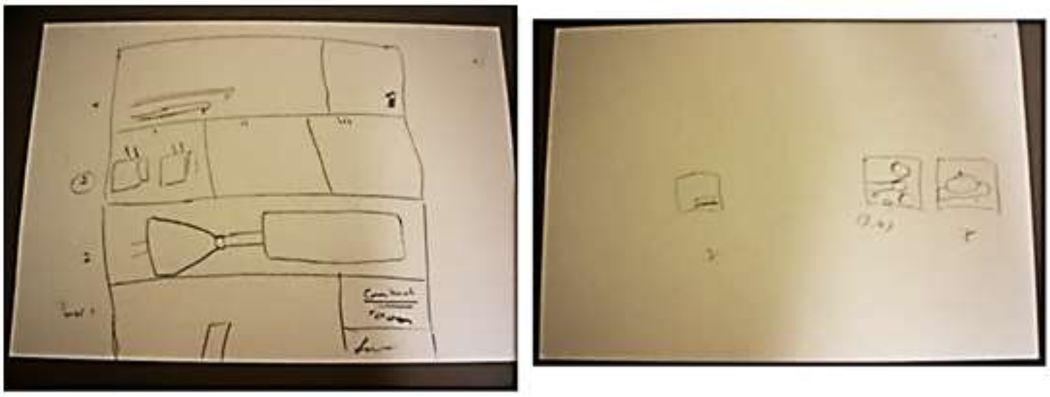
4.4.2.4 Short interview

Upon completion of the tests, the participants were asked about the ease of using the VR application and if they encountered any problems with it.

4.4.3 Summary of findings

The findings of the pilot test are as follows:

- All participants commented that the VR application was easy to use with a little practice.
- None of the participants used the 'expand' button  when using the VR application. This suggested that the size of the map was reasonable. Furthermore, most participants performed the *navigation task* without hiding the map, which further suggested that the size of the map was not an issue for the participants.
- Four participants obtained all correct answers for the *landmark recognition test* and three participants obtained all correct answers for the *landmark sequencing test.*
- For the *map drawing test,* most participants were surprised when asked to perform this test and seemed to struggle with it. One did not show any interest and drew only a bit to comply with the instruction. Most participants drew the environment with floors stacked above each other (see Figure 4-19(a)); some drew the floors separately (see Figure 4-19(b)). The drawings by the participants varied considerably in quality and quantity and did not provide enough data for analysis.
- In the *map drawing test,* the dryer was drawn by all participants. This suggested that the dryer was considered a noticeable landmark. The dryer was also the first 3D model placed by most participants in the *object placement test*, suggesting that it was used as a reference point for placing the other 3D models.
- Participants were more comfortable with the *object placement test* than the *map drawing test*.



(a) (b)

Figure 4-19 Two drawings by participants.

4.4.4 Modifications to the VR application and the related tests

The findings of this pilot study resulted in some modifications to the VR application and the related tests in the main user study, as described below:

- The ‘expand’ button  was removed from the VR application because it was not used by the participants.
- As a few students managed to get full marks in the *landmark recognition test* and *landmark sequencing test,* both tests were modified to make them more difficult by including additional images. The images included in the *landmark recognition test* were increased to 16 (eight were landmarks and eight were not) and for the *landmark sequencing test,* the number of image pairs was increased to seven.
- The *map drawing test* was omitted from the main user study because the participants found it too difficult and there was little interest in performing the test, which is similar to the finding of Maliki (2008). In addition, the differences between the participants’ abilities to draw maps may influence the scoring of the drawn map (Hutchinson, 1994). Therefore, only the *object placement test* was used to measure survey knowledge.

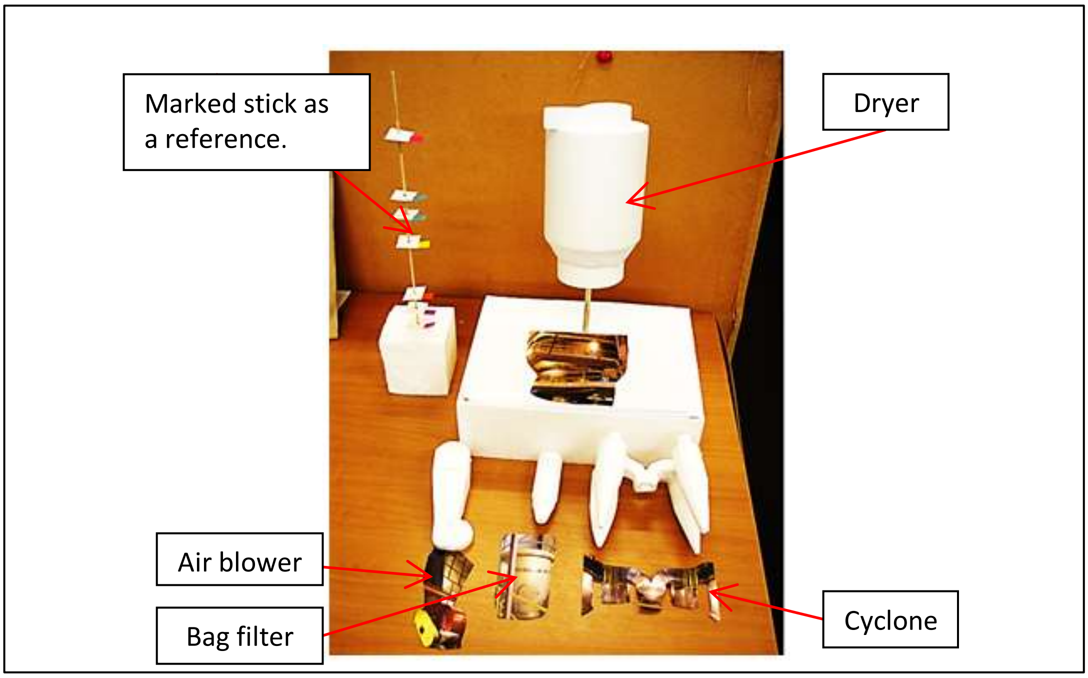


Figure 4-20 The settings for the object placement test

- Modifications were made to the *object placement test* whereby the 3D model of the dryer was initially placed at its actual position on the base before asking the participants to place the other 3D models (Figure 4-20). The dryer was chosen because all participants in the pilot study placed it first and used it as a reference point for placing other objects. The participants were required to place the remaining 3D models (cyclone, air blower and bag filter) relative to the position of the dryer.

4.5 Main User study

This section describes the procedure in the main user study. This user study was approved by Lincoln University Human Ethics Committee.

4.5.1 Participants

Since this study is related to engineering education, the participants were recruited from CAPE. Thirty students (17 male and 13 female) volunteered. Fourteen were 1st Professional students and the remaining 16 were 3rd Professional students. A between-subjects design was used where each participant was tested with only one map condition (2D, 2.5, 3D map) to avoid any learning effects.

4.5.2 Procedure

The procedure for each participant in the main user study was:

i. Participants signed a consent form after reading written information about the objectives of the study (Appendix B.1).

ii. Participants completed a general information form that asked about their year of study, exposure to any physical process plant and experience with VR applications (Appendix B.2).

iii. Participants completed the Mental Rotations Test (MRT) (Peters, Laeng, et al., 1995) and the Perspective Taking Test (PTT) (Hegarty & Waller, 2004).

iv. Participants were asked to practise using a similar VR application (with different panoramas) during the practice session.

v. Participants performed the navigation task.

vi. Participants completed the *landmark recognition test* (Appendix B.3) and the *landmark sequencing test* (Appendix B.4). The participants were told to be as accurate as possible because marks would be given for correct answers and deductions for any incorrect answers. No points were given or deducted when the images were marked as 'Not sure'.

vii. Participants performed the *object placement test.*

4.6 Measurement and scoring methods

This section describes the scoring method used for the *landmark recognition test*, *landmark sequencing test* and *object placement test*.

4.6.1 Landmark recognition test and landmark sequencing test

The Holzinger (1924) scoring method was used for both the *landmark recognition test* and the *landmark sequencing test*:

$$S = R - \frac{1}{(n-1)}W$$

where S is the total score, n is the number of available options in the test, R is the number of correct answers and W is the number of incorrect answers. This equation incorporates a small penalty for each incorrect answer. Therefore, participants with the same number of correct answers would not obtain the same scores if they had provided a different number of incorrect answers as well. For example, there are 16 questions in the *landmark recognition test.* Participants who got three questions correct without any incorrect question would get three marks and participants with the same number of correct questions but with one question wrong would get 2.933 marks.

4.6.2 Object placement test

The total score of this test is the sum of the scores given to the objects placed at the *correct vertical position*, *correct horizontal position* and *correct orientation.* This provided a loose measurement for this test since scores were given to objects placed at approximately the correct position.

4.6.2.1 Correct vertical position

The number of objects placed at the correct level (vertical position) was counted regardless of the horizontal position of each object. To do this, the distance of each object (cyclone, air blower and bag filter) from the base was measured to see if it was placed at the correct level. The distance was measured from the point where the stick was inserted into the objects.

As shown in Figure 4-18 of Section 4.4.2.3, the objects can be placed in either the dedicated level (based on the mark on the stick) or at any position (between the marks on the stick). Figure 4-21 shows the objects placed by a participant (left) and the correct vertical positions of the objects (right). In this example (Figure 4-21 left), the cyclone was placed at level 3 and the air blower was placed at level 4 (based on the marked scale on the sticks). The bag filter was not placed on a specific level. Therefore, the distance between the bag filter and the base was measured as 4 cm.

The vertical positions of the objects on the left (the example) and right (the correct position) were compared. In the right figure, the cyclone and the air blower are the two objects that are positioned at a dedicated level (based on the same reference point, marked as ‘X’). The bag filter is the only object that is positioned between levels 2 and 3.

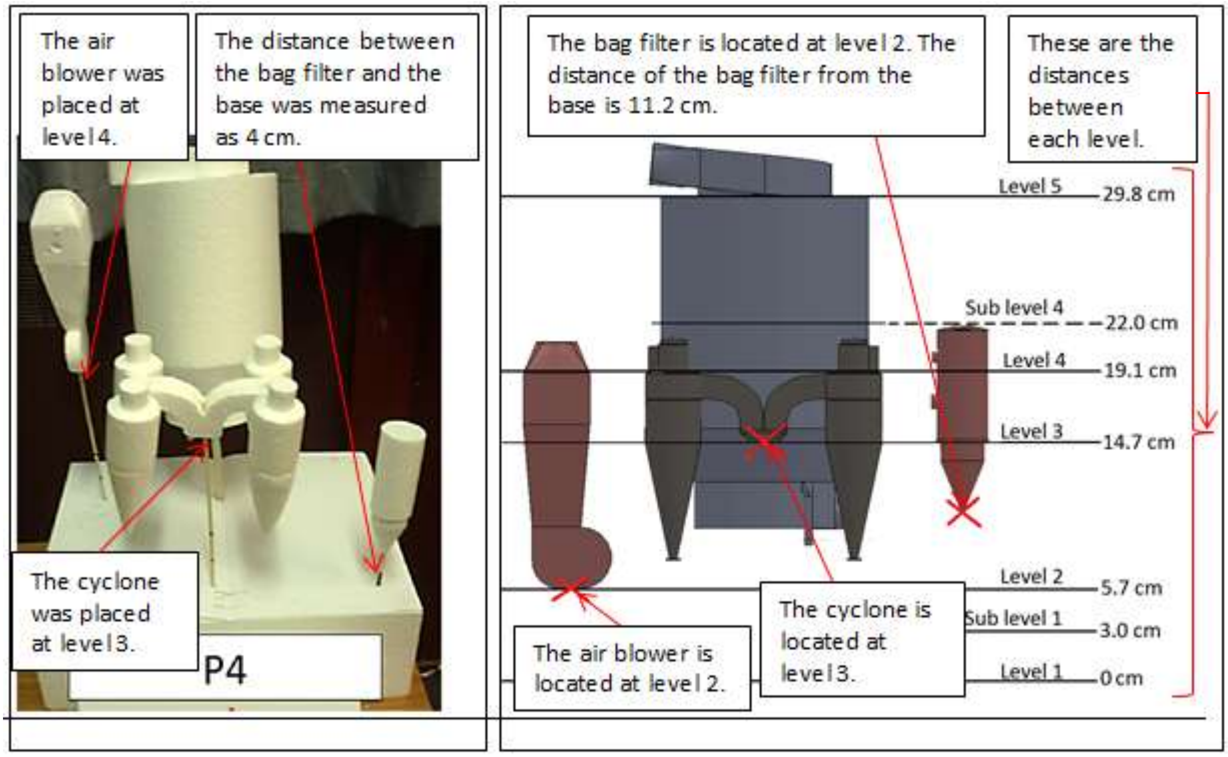


Figure 4-21 The positions of the objects placed by the participant (left) and the correct vertical positions (right).

The objects placed by the participants were considered correct if they were placed within the correct level. For example the vertical position of the cyclone was considered correct if it was placed at level 3 (or within level 3, which is between 14.7 and 19.0 cm from the base). This indicates that, if an object is placed between two levels, the lower level is chosen as the intended level. This is to comply with the instructions that asked the participants to place the objects at the intended level at the point of the object where the stick is inserted.

One mark was given for each object placed in the *correct vertical position.* In this example (Figure 4-21), only the cyclone is in the correct position. Therefore only one mark was obtained by the participant. The marks were averaged across all objects to give the score of each participant.

4.6.2.2 Correct horizontal position

One mark was given for each object approximately placed in the *correct horizontal position* (as explained below), regardless of their *vertical position.* Since participants were told to place the object relative to the position of the dryer, the dryer is used as the reference point. Figure 4-22 shows the correct horizontal positions of the objects.

The cyclone is considered to be placed at the correct position if it is placed 'opposite' the dryer (Figure 4-22). Similarly, if the air blower is placed in the 'left' area and the bag filter in the right area they are considered correct.

In order to determine if the objects were placed approximately in the correct area, tracing paper (with gridlines and boundaries of the areas) was put over the paper with the marks made when the stick when through the paper (Figure 4-23). If the marks of the respective objects were completely within the correct area, a score of one was given to the object. In the example in Figure 4-23, the cyclone and the air blower were placed at the correct *horizontal* position, therefore, the total marks are two. The marks were averaged across all objects to give the score for each participant.

When participants placed an object outside the boundary of an area, rules were applied to the measurement. For the air blower and the bag filter, no tolerance was given for any objects placed beyond the boundary.

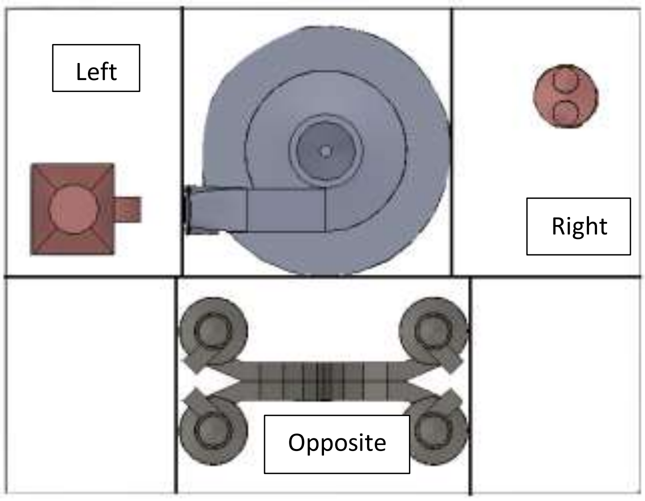


Figure 4-22 The correct horizontal positions of the air blower, bag filter and cyclone.

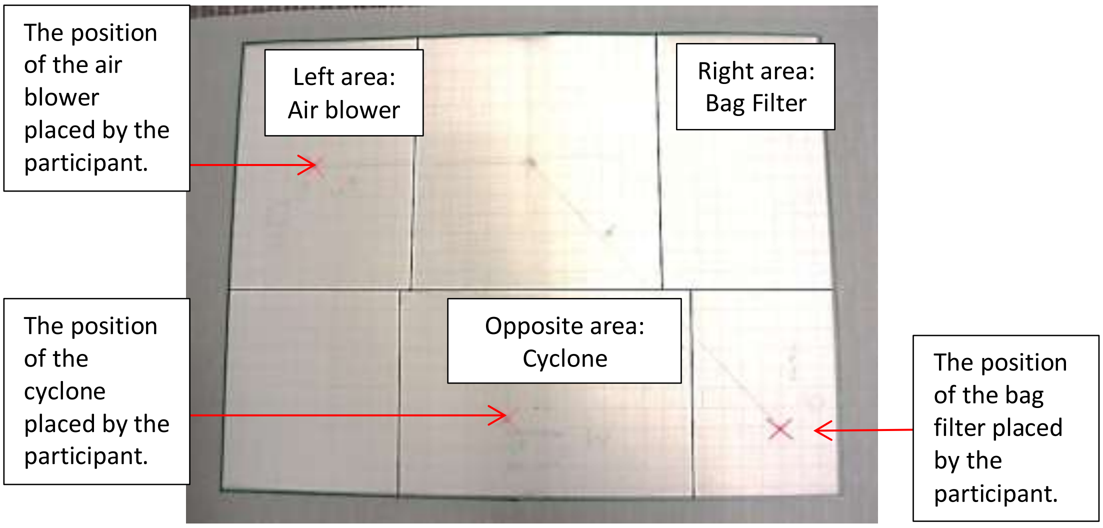


Figure 4-23 The tracing paper on top of the paper with the marks of the objects' placement.

The reason is that the distance of the centre point of the object (where the stick is placed) to the outermost part of the bag filter and the air blower is less than 2.5 cm. Therefore, if the mark (made by the inserted stick) was at the boundary, the bag filter or the air blower is actually placed slightly beyond the boundary (see Figure 4-24), which is already considered as the tolerable level.

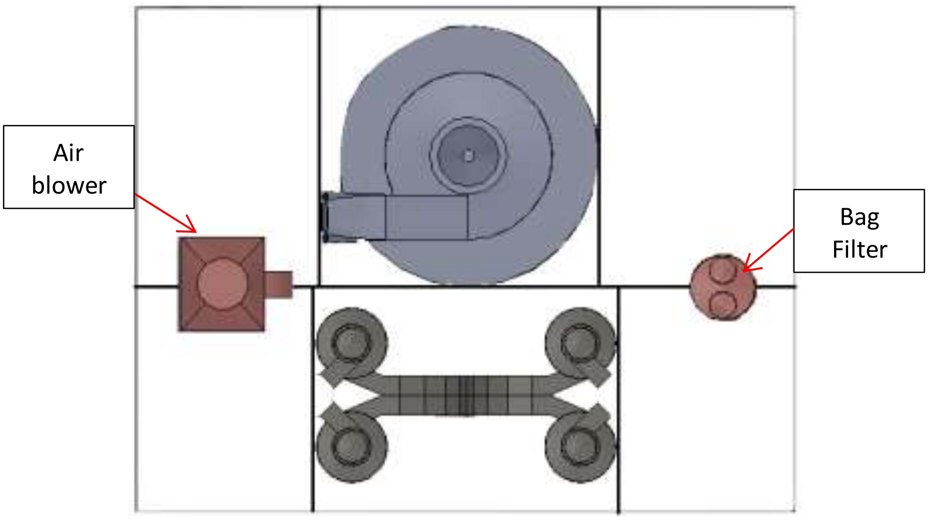


Figure 4-24 The positions of the bag filter and air blower when they are placed at the boundary.

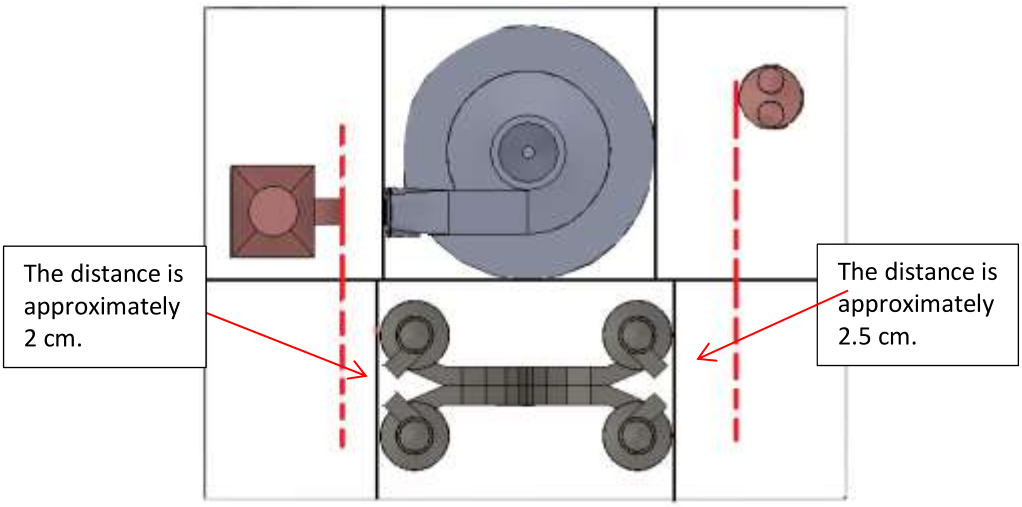


Figure 4-25 The distance between the cyclone and the air blower and bag filter.

Therefore, no further tolerance was allowed. A tolerance of 2 cm was given for the left side of the cyclone. The limit was no more than 2 cm because the distance between the left of the cyclone and the air blower is approximately 2 cm. Therefore, if the tolerance was more than 2 cm, the cyclone would be considered placed ‘opposite the air blower and the dryer’ instead of ‘opposite the dryer’. The same applies to the bag filter where the tolerance is 2.5 cm because the distance between the right side of the cyclone and the air blower is approximately 2.5 cm (Figure 4-25).

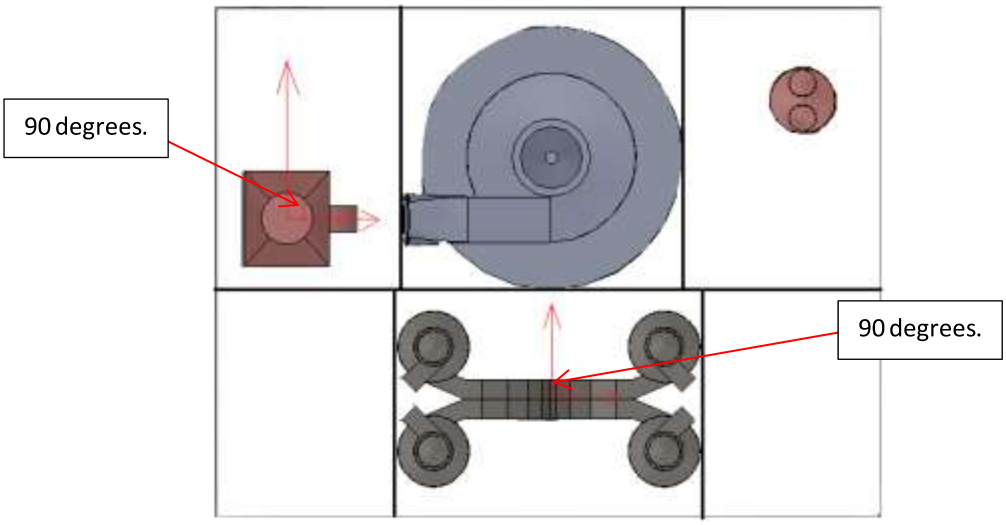


Figure 4-26 The orientations of the cyclone and the air blower.

4.6.2.3 Correct orientation

One mark was given for each object placed in approximately the correct *orientation*, regardless of the vertical and horizontal positions. Figure 4-26 shows the orientation of the objects.

Only the cyclone and air blower were considered in this measurement because the bag filter is cylindrical. A tolerance of 10˚ was given for each measurement (e.g., the orientation of the air blower was considered correct if placed between 80 and 100 degrees). The reason for giving a 10˚ tolerance is that the measurement is done manually, which gives a less strict measurement of the orientation.

The scores for the cyclone and the air blower were averaged; this result is the score obtained by the participant for this measurement.

4.6.2.4 Total scores of the object placement

The total score for object placement is the sum of the scores obtained for the correct *vertical* position, correct *horizontal* position and correct *orientation.*

4.7 Results

The information in the general information form indicates that all participants had been in process plants (ranging from 1.5 hours to 12 months) either through field trips, work visits or summer jobs. Half of the participants had no experience in non-immersive VRs (e.g., a desktop virtual tour of a museum, computer games); the other half had experience ranging from less than once a month to a few times a week. No students had experience with immersive VRs such as a CAVE.

The remaining sections provide the average scores of all participants for each test, grouped according to the map used for the user study. Individuals' scores are given in Appendix B.5.

4.7.1 Landmark recognition test and landmark sequencing test

In the *landmark recognition test*, two participants marked more than one option as answers, which resulted in invalid answers; no marks were given for these questions. The Shapiro-Wilk test of normality indicates that the data from the *landmark recognition test* and *landmark sequencing test* were normally distributed, therefore a one-way ANOVA was used for the analysis. A one-way ANOVA found no significant difference (at $p < .05$) between the 2D map, 2.5D map and 3D map for the mean scores for these tests (Table 7).

Table 7 The mean scores and the one-way ANOVA results for the landmark recognition and sequencing tests with different types of map.

	2D map	2.5D map	3D map	(F(2, 27)	p-value	η_p^2
	Mean (SD)	Mean (SD)	Mean (SD)			
Landmark recognition test	12.45 (1.30)	11.80 (1.87)	12.80 (1.65)	0.97	.39	.07
Landmark sequencing test	4.5 (0.8)	3.6 (1.27)	4.1 (1.3)	1.67	.21	.11

Note: The maximum possible score for the *landmark recognition test* is 16 and for the *landmark sequencing test,* 7.

4.7.2 The object placement test

During the *object placement test,* all participants verbally stated the level (vertical position) where they intended to place the objects before they performed the test. The reason may be because they were unsure of how to use the marked sticks to place the objects. The verbal information provided by the participants made it easier to identify if the objects were placed at the indicated level or between two levels.

Only nine of the 30 participants placed some of the objects between levels[15]; the objects were five cyclones, four bag filters and two air blowers. For these objects, two cyclones and two bag filters were considered placed in the correct *vertical* position. The remaining participants placed the objects at the definite level[16], based on the marks on the sticks. The bag filter was mostly placed at a definite level although, in the correct position, it is located between levels (levels 2 and 3).

For the *horizontal* position, most objects placed in an incorrect area were not positioned near the boundary except for four air blowers and three bag filters that were placed approximately 2 cm from the boundary. Only two cyclones were placed approximately 1 cm from the boundary.

The mean scores (and standard deviations) for the *object placement test* are shown in Table 8.

[15] The object is placed between the levels (e.g., between level 2 and 3, between level 3 and 4) instead of at the dedicated levels based on the marks on the stick.
[16] The object is placed at definite levels (e.g., level 2, level 3, level 4) based on the marks on the sticks, instead of placing them between these levels.

Table 8 The mean scores (and standard deviations) of the participants for the object placement test with different types of map.

	2D map	2.5D map	3D map
	Mean (SD)	Mean (SD)	Mean (SD)
Correct vertical position	0.37 (0.19)	0.30 (0.25)	0.27 (0.21)
Correct horizontal position	0.37 (0.29)	0.60 (0.38)	0.37 (0.33)
Correct orientation	0.39 (0.21)	0.55 (0.16)	0.30 (0.26)
Total scores	1.13 (0.44)	1.45 (0.42)	0.93 (0.43)

Note: The maximum possible total score for the *object placement test* is 3.

The test of normality indicated that the data for this measurement were not normally distributed ($p < .05$), except for the total scores. Therefore, a one way ANOVA was used for the total scores and a Kruskal-Wallis test[17] was used for the other tests.

The one way ANOVA shows a main effect of the maps on the total scores, ($F(2, 27) = 3.70$, $p = .04$), $\eta p^2 = .23$. Therefore, the null hypothesis for H_1 was rejected. A post hoc analysis using multiple comparisons with Bonferroni correction indicated that the total scores were significantly different for participants using the 2.5D and 3D map ($p = .04$). No significant differences were found in the total marks of the 2D and 3D map ($p = .92$) and the 2D and 2.5D map ($p = .33$).

For the scores of *vertical, horizontal* and *orientation*, a Kruskal-Wallis test indicated no significant difference between the 2D, 2.5D and 3D maps (Table 9).

Table 9 The median scores and the results of the Kruskal-Wallis test scores of participants using different types of map.

	2D map		2.5D map		3D map		χ^2 (2, *N* = 30)	*p*-value
	Median	Mean Rank	Median	Mean Rank	Median	Mean Rank		
Vertical	0.33	17.55	0.33	15.05	0.33	13.90	1.17	.56
Horizontal	0.33	13.80	0.50	19.00	0.33	13.70	2.69	.26
Orientation	0.50	15.10	0.50	19.20	0.50	12.20	5.89	.05

[17] The Kruskal-Wallis Test is a nonparametric test equivalent to the one-way ANOVA.

4.7.2.1 *Descriptive analysis*

This section provides a descriptive analysis of the results of the *object placement test.* The total number of objects placed by the participants in their correct respective positions, including objects without a correct placement, is shown in Table 10.

The largest number of objects placed correctly for both *vertical* and *horizontal positions* was by participants using the 2.5D map; that same group had the smallest number of objects placed incorrectly in either the *vertical* or *horizontal* positions. None of the participants using the 3D map managed to place any objects correctly in both their vertical and horizontal position. In addition, none of the participants managed to place all objects at the correct vertical positions.

To further explore the participants' performances in each test, the data in Table 10 provide an overview of the participants' abilities to visualise the objects' placements in the virtual plant. The number of participants using the 2.5D map who placed all objects at the correct *horizontal* positions is higher than those participants using the 2D and the 3D map. This suggests that participants using the 2.5D map obtained a better knowledge of the objects' *horizontal* position than participants using the 2D and 3D maps

Table 10 The number of objects placed in their correct respective position, including objects without a correct placement by participants using different types of map.

Map	Objects	Both vertical and horizontal positions	Vertical positions only	Horizontal positions only	Both vertical and horizontal position incorrect	Total
2D map	Cyclone	3	2	2	3	10
	Air blower	-	2	2	6	10
	Bag filter	2	2	2	4	10
	Total	**5**	**6**	**6**	**13**	**30**
2.5D map	Cyclone	5	1	3	1	10
	Air blower	2	-	4	4	10
	Bag filter	-	1	4	5	10
	Total	**7**	**2**	**11**	**10**	**30**
3D map	Cyclone	-	1	5	4	10
	Air blower	-	2	5	3	10
	Bag filter	-	5	1	4	10
	Total	**-**	**8**	**11**	**11**	**30**

Table 11 shows the number of participants who placed the objects in the correct *horizontal position*, regardless of *vertical* position. This provides an overview of the participants' abilities to visualise the objects' placements in the virtual plant. The number of participants using the 2.5D map who placed all objects at the correct *horizontal* positions is higher than those participants using the 2D and the 3D map. This suggests that participants using the 2.5D map obtained a better knowledge of the objects' *horizontal* position than participants using the 2D and 3D maps.

Table 11 The number of participants who managed to place the objects at the correct horizontal position regardless of the vertical position using different types of map.

	Horizontal positions		
Objects	**2D map**	**2.5D map**	**3D map**
Cyclone + Bag Filter + Air Blower	1	4	1
Cyclone only	3	3	2
Bag Filter only	3	-	-
Air Blower only	-	1	2
Bag Filter + Air Blower	-	-	-
Cyclone + Bag Filter	-	-	-
Cyclone + Air Blower	1	1	2
None correct	2	1	3

4.7.2.2 Orientation of the objects

Table 12 shows the number of objects placed in the correct *orientation*, regardless of the correct *horizontal* and *vertical* position.

Table 12 The number of objects placed in the correct orientation by participants using different types of map.

	Objects	2D map	2.5D map	3D map
Orientation	Cyclone	6	10	5
	Air blower	2	1	1
	Total	8	11	6

Participants using the 2.5D map placed the largest number of objects in the correct orientation; all managed to have the cyclone oriented correctly. For the air blower, only four participants managed to get the orientation correct; two with the 2D map, one with the 2.5D map and one with the 3D map.

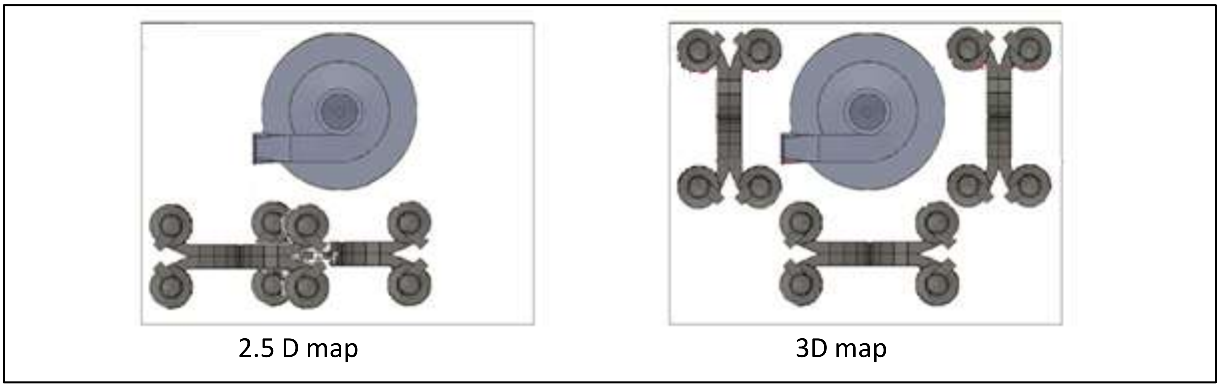


Figure 4-27 The orientation of the cyclone placed by the participants using the 2.5D and 3D maps.

An interesting aspect in the orientation of the cyclone was that all participants using the 2.5D map managed to place the cyclone in the correct *orientation*, although two did not place it at the correct *horizontal* position (slightly to the left) (see Figure 4-27). For the 3D map, only participants who managed to place the cyclone in the correct *horizontal* position had the cyclone oriented in the correct way. Those who did not, had the cyclone oriented to the left or right of the dryer.

Figure 4-28 shows the *orientation* of the cyclone placed by the participants who used the 2D map. Of the six participants who managed to place it in the correct orientation, four of the cyclones were placed in the correct *horizontal* position with the cyclone correctly oriented opposite the dryer. Of the remaining two, one was positioned to the right of the correct *horizontal* position of the dryer and the other to the left (see Figure 4-28 (a)).

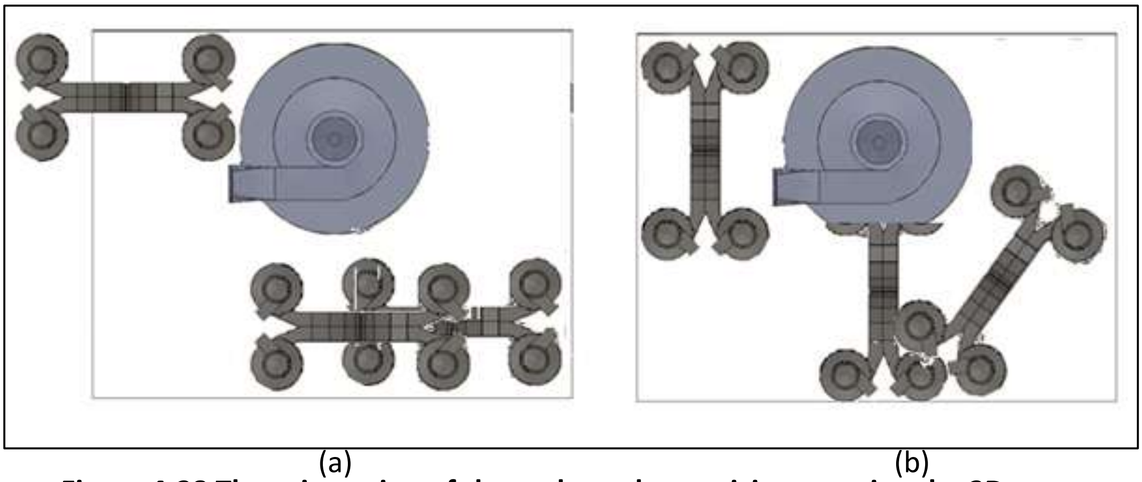


Figure 4-28 The orientation of the cyclones by participants using the 2D map.

The remaining four participants, who did not manage to place the cyclone at the correct orientation, placed it as in Figure 4-28 (b). Two placed it on the left of the dryer, one opposite the dryer, which is the correct *horizontal* position (note: the cyclone was placed in a lower vertical position so it did not go beyond the edge of the base) and one in the 45^o position.

The results suggest that, in terms of orientation, participants using the 2D map were more confused about the orientation of the objects than participants using the 2.5D map. This, however, is based on the orientation of the cyclone because the low number of air blowers placed correctly did not permit further analysis (refer to Table 12).

4.7.3 Correlations between spatial ability and the object placement test

Correlations were investigated to assess the relationship between the participants' scores in the MRT and PTT and the scores in the *object placement test*. For the PTT, two participants did not manage to complete all questions within the given time and their results were also significantly higher than for other participants (the total score for the PTT is the average difference between all attempted items and the actual bearings, hence a lower score indicates a better result). Therefore, these data items (participants using the 2D and 3D map) were treated as outliers and were removed from the analysis.

The Shapiro-Wilk test of normality indicated that the scores for the MRT are normally distributed but not those for the PTT. Therefore, the Pearson product-moment correlation coefficient was used for the MRT and the Spearman Rank Order Correlation coefficient was used for the PTT.

The results indicate that there was almost no correlation between the scores of the MRT and PTT and the *vertical*, *horizontal* and *orientation* and *total scores*, none of which is significant (Table 13).

Table 13 Correlations between spatial abilities and the object placement test.

	MRT*		**PTT****	
	r	***p-value***	r_s	***p-value***
Vertical	0.05	.80	-0.21	.29
Horizontal	-0.07	.72	-0.08	.67
Orientation	-0.20	.61	-0.14	.47
Total Scores	-0.08	.69	-0.20	.31

Note: * Pearson product-moment correlation coefficient. **Spearman rank order correlation coefficient. The PTT is calculated based on 28 data sets.

4.7.4 Gender differences

Gender has been found to be a factor affecting the acquisition of spatial knowledge (Kober & Neuper, 2011). Before the differences of the scores obtained in the *landmark recognition*, *landmark sequencing* and *object placement tests* were measured, the level of spatial ability of the male and female participants (based on the scores obtained in the MRT and PTT) were compared.

Spatial ability. The test of normality indicated that the scores for the MRT are normally distributed but not those for the PTT; an independent t-test was conducted to assess the differences between the scores obtained by the male and female participants in the MRT and Mann Whitney U-Test for PTT. In total, there were 17 male and 13 female participants.

An independent-samples t-test indicated that there was no significant difference between the male participants (M = 12.71, SD = 6.11) and the female participants (M = 10, SD = 4.80) in the scores obtained for the MRT, $t(28) = 1.31$, $p = .44$, $d = 0.49$.

The analysis of the PTT was conducted with 15 instead of 17 males, due to the data for two participants being removed as they were treated as outliers. A Mann Whitney U-Test found no significant difference between the male (Mdn = 23.17) and female participants (Mdn = 18.83) in the scores obtained for the PTT, $U = 94.5$, $p = .89$.

Total scores of the object placement test. During the user study, the participants were randomly assigned to the respective conditions (2D, 2.5D and 3D map), therefore the number of male and female participants was not equally divided between the conditions.

Regardless of the map type, an independent-samples t-test indicated that there was no significant difference between the male (M = 1.10, SD = 0.50) and female participants (M = 1.27, SD = 0.42) in the *total scores*, t(28) = -0.10, $p = .33$, $d = -0.37$.

A descriptive analysis is given in Table 14. The table shows the mean and standard deviations of the scores for the *landmark recognition*, *landmark sequencing* and *object placement test* grouped according to the gender of the participants. The results show that the male participants managed to obtain higher scores in most of the tests, based on the descriptive analysis.

Table 14 The means (and standard deviations) of the scores for the respective tests, grouped according to the gender of the participants.

	2D map		2.5D map		3D map	
	Male (*n* = 7)	**Female (*n* = 3)**	**Male (*n* = 3)**	**Female (*n* = 7)**	**Male (n = 7)**	**Female (*n* = 3)**
Landmark recognition test	12.79 (1.25)	11.67 (1.26)	13.17 (2.37)	11.22 (1.44)	12.71 (1.58)	13 (2.18)
Landmark sequencing test	4.57 (0.93)	4.33 (0.29)	3.83 (1.44)	3.50 (1.19)	4.14 (1.46)	4 (0.87)
Object placement test						
Vertical position	0.33 (0.19)	0.44 (0.19)	0.33 (0.33)	0.29 (0.23)	0.11 (0.19)	0.33 (0.19)
Horizontal position	0.38 (0.30)	0.33 (0.33)	0.67 (0.33)	0.57 (0.42)	0.44 (0.19)	0.33 (0.39)
Orientation	0.43 (0.19)	0.33 (0.29)	0.5 (0)	0.57 (0.19)	0.5 (0)	0.21 (0.27)
Total score	1.14 (0.48)	1.11 (0.42)	1.5 (0.33)	1.43 (0.47)	1.06 (0.19)	0.88 (0.51)

Note: [shaded box] indicates that the scores obtained by the female participants are higher than the male participants.

4.7.5 Observations

Most participants hid the map only at the beginning of the *navigation task* (i.e., when navigating the first two nodes) and later continued displaying the map while navigating. Only one participant (using the 2D map) used the zoom feature. One participant, who completed the *navigation task* using the 3D map, said that s(he) found the 3D map confusing.

For the *object placement test*, 16 participants chose to place the cyclone first on the base, 10 chose the bag filter first, and the remaining four chose to place the air blower first. Participants were not told anything about omitting objects if they were not sure about their placement. Five participants made remarks about not being sure about object placements; they were asked to guess. One, who used the 2D map, expressed uncertainty for all objects but managed to place the cyclone and bag filter in their correct *vertical position.* The remaining four expressed uncertainty about the bag filter's position and two (using the 2.5D and 3D maps) managed to place it in the correct *vertical position*.

A participant who used the 2D map was the only one who rotated the base at the beginning of the *object placement test*, so that the base was in a similar orientation to the 2D map in the VR application. This participant managed to get only the cyclone in the correct *horizontal position.* This further shows that the cyclone is easier to remember than the air blower and bag filter. Another participant stated that the top of the cyclone needed to be at level 4 and, therefore, s(he) carefully placed the cyclone so that its top reached level four.

Some errors were also encountered with the *object placement test* where four participants (one with the 2D map, one with 2.5D map and two with 3D map) placed the objects higher than the maximum height of the building, although they were expected to know the maximum height of the building based on the marked stick placed next to the base. Another participant (using the 2D map) placed the stick of the cyclone near the edge of the base causing the cyclone to be positioned beyond the maximum length of the base.

4.7.6 Results summary

The results are summarised below:

- There were significant differences in the total scores in the *object placement test* by the participants using the 2D, 2.5D and 3D maps, therefore, the null hypothesis was rejected. The highest scores were obtained by participants using the 2.5D map, although no significant difference was found between the scores of participants with the 2D and 3D maps.
- No significant difference was found in the *landmark knowledge* (based on scores in the *landmark recognition test*) or *route knowledge* (based on scores in the *landmark sequencing test*) for the different types of map.
- The variation in the number of objects placed at the correct *vertical* and *horizontal* positions and the correct *orientation* suggests that the different types of map affected different aspects of survey knowledge. The 2.5D map is the best for gaining survey knowledge compared with the 2D and 3D map. Between the 2D and 3D maps, the 2D map is better in assisting the participants with the placement of objects correctly in both vertical and horizontal positions, and the 3D map is better in assisting participants with orientation of objects (cyclone).
- No significant difference was found between males and females for the scores of the *object placement test*; however, the number of participants in each condition is small and unequal.

- No correlations were found between *object placement test* and the scores of the Mental Rotation Test or the Perspective Taking Test.

4.8 Discussion

This user study was carried out to answer the research question: "*How do different types of maps affect the acquisition of spatial knowledge in a virtual complex multilevel building?".* This question aims to investigate the differences that occur in the spatial knowledge acquired by participants with different maps: 2D, 2.5D and 3D maps.

Overall, the results confirmed the study's hypothesis (there is a difference between the scores of the survey knowledge assessment of the participants with the 2D, 2.5D and 3D maps). In addition, participants using the 2.5D map acquired higher *survey knowledge* (based on the scores of the *object placement test*) than participants using the 2D or 3D maps. This suggests that *survey knowledge* is better acquired when a 3D cut-away representation of objects is displayed in the separate map floors. As expected, no significant difference was found in *landmark knowledge* (based on scores in the *landmark recognition test*) or *route knowledge* (based on scores in the *landmark sequencing test*). This supports the claim that maps have a greater influence on *survey knowledge* than either *landmark* or *route knowledge.*

The effectiveness of the 2.5D map was also confirmed by the descriptive analysis of objects placed by the participants. Those using the 2.5D map had the highest number of objects placed in their correct position. The variations in scores for the *object placement test* suggest that each map has a different effect on survey knowledge acquisition, which is further discussed in the following sections.

4.8.1 The 2D map: The top-down view

All maps are presented in an exocentric view, with the ability to zoom in/out. A larger overview from the exocentric perspective can assist users to gain better spatial horizontal information (Luo, Luo, Wickens, et al., 2010). As stated earlier, the top-down view of the 2D map is more useful for distance and angle estimations between the objects than the 3D map (John et al., 2001). This study's results support this statement since placements for the horizontal positions of the objects by participants using the 2D map were better than the 3D map. However, placement was even more accurate with the 2.5D map (see Table 10 and Table 11, Section 4.7.2.1.

The reasons why the number of correct horizontal placements by participants using the 2D map was lower than for the 2.5D map could be explained by the similarities of the shapes of the objects on the map when viewed in a top-down manner. In a process plant or factory, pieces of equipment are often of similar shape (especially when cut at the respective levels), e.g., a dryer and air blower are cylindrical. This is different from elements in a landscape, e.g., tree, house, which have different shapes when viewed from above (see Figure 4-29).

The similarities among buildings (in this case the equipment) requires some visual skill to be able to identify them (Oulasvirta, Estlander, & Nurminen, 2009). Therefore, a 2D map is less useful when used in buildings with equipment of similar shape.

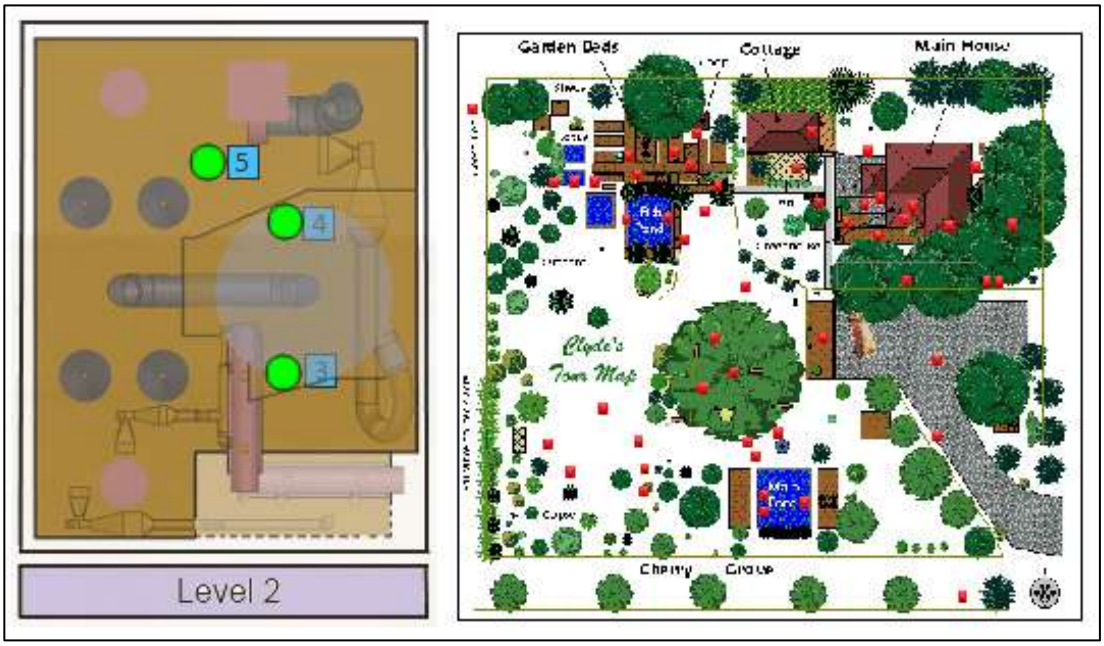


Figure 4-29 A 2D map of the process plant (left) and a garden[18] (right). A variety of top-down shapes are seen in the 2D map of the garden.

[18] http://www.victorrook.com/gardenva/gardens.htm. Credit to Victor Rook, used with permission.

4.8.2 The 2.5D map: The cut-away representation of the objects on the map

In general, participants who used the 2.5D map performed best in the *object placement test*. This suggests that the 2.5D map is the best aid to facilitate the acquisition of survey knowledge in the present virtual multilevel building.

The reason for this could be the cut-away presentation of the objects, which allows easy identification of the objects on the map. Although the cutaway does not preserve the shape of the objects, the ability to at least provide an indication of the equipment was found useful for object identification. It also minimises the blockings of objects by other objects (Andujar et al., 2010).

4.8.3 The 3D map: The rotation function

Although the 2D, 2.5D and 3D maps were designed so that participants were exposed to a similar experience, participants seemed to be more confused and potentially suffered from excess cognitive overload with the 3D map. The 3D map is useful in understanding shape (John et al., 2001) and therefore it is easier to identify landmarks than with the 2D map (Rakkolainen & Vainio, 2001). The 3D map is also useful in assisting users with spatial vertical information since it illustrates the vertical relations between the levels of the building (Fontaine, 2001; Luo, Luo, Wickens, et al., 2010). In the present study, features of the multilevel building caused some objects on the 3D map to be hidden because they were blocked by other objects (that go across multiple levels). Therefore a rotation function was included to allow participants to view objects on the map that were blocked by other objects.

Although Luo et al. (2010) found that the 3D map in their study was useful in delivering spatial vertical information, a different result was found in the present study; participants using the 3D map placed the lowest number of objects at the correct vertical position. The differences are due to the features of maps in the two studies. In the present study, the 3D map is based on a series of static images and is in the form of a point-to-point map. A rotation function was included to allow participants to view it from different angles. The result that a low number of objects was placed correctly at the vertical position suggests that the rotation function caused participants to potentially experience excessive cognitive overload because they had multiple views of the map from different angles. This may have caused them to develop a different mental view of the map. This view is supported by one participant's comment that s(he) felt confused with the rotation function. Although caution was exercised to avoid adding additional aids, as suggested by Haik et al. (2002) and Witmer, Sadowski and Finkelstein (2002), it was not expected that inclusion of the rotation function would cause this effect among the participants.

4.8.4 Common properties of the results

In addition to the different patterns of results for each map type, similarities/common properties in the results were also found among participants with each map type:

i. More objects were placed in the correct horizontal position than in the vertical position (refer to Section 4.7.2.1).
ii. Incorrect orientation of the air blower by the majority of the participants (see Table 12, Section 4.7.2.2).
iii. Incorrect orientation of the cyclone. This refers to the confusion in participants using the 2D and 3D maps (see Figure 4-27 and Figure 4-28, Section 4.7.2.2).

More objects placed in the correct horizontal position, than in the vertical position. The results indicated that most participants managed to place more objects in the correct horizontal position than vertical position (see Table 8, Section 4.7.2). In the same table, although the mean scores for the horizontal and vertical positions are the same for participants using the 2D map, the number of correct *horizontal placements* of the individual objects is higher than the *vertical placements* (Table 10, Section 4.7.2.1).

This finding is consistent with that by Luo, Luo, Wickens, et al. (2010) who found that a large overview from an exocentric perspective is more useful for delivering spatial horizontal information than vertical information. The better result for *horizontal* compared with *vertical* placement could also be seen in the results of individual participants (Table 11, Section 4.7.2.1), where, although none managed to place all three objects at the correct *vertical position*, some managed to place all three objects in the correct *horizontal position;* the highest numbers were participants using the 2.5D map.

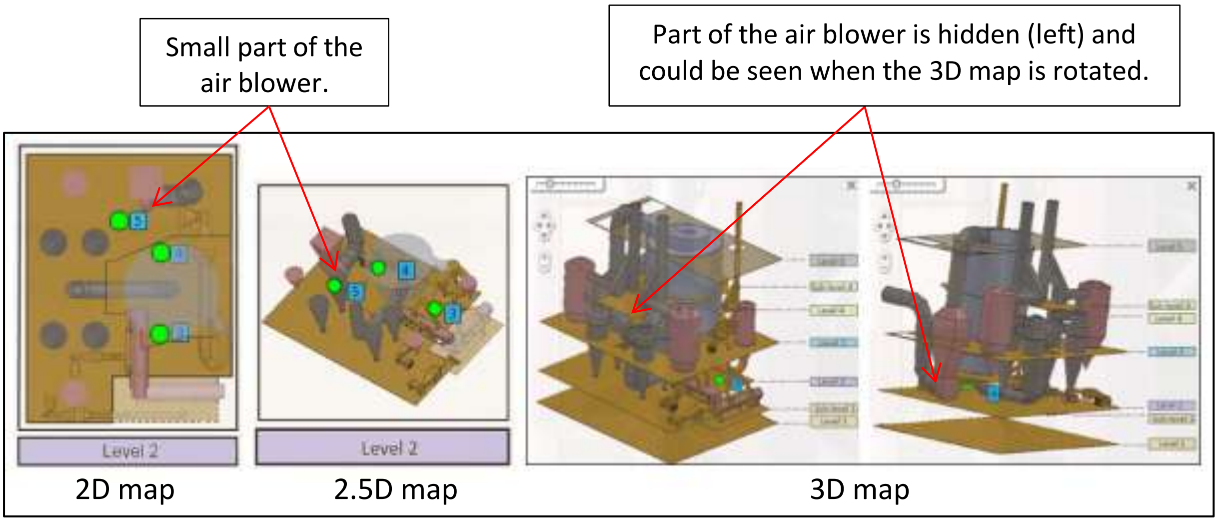


Figure 4-30 The small part of the air blower that indicates its orientation.

Although this demonstrated that the presentation of the maps was helpful in assisting the acquisition of spatial *horizontal* information, the same was not found for *orientation* information (Table 12, Section 4.7.2.2), which will now be discussed.

Incorrect orientation of the air blower. Only four participants managed to place the air blower with the correct orientation (two with the 2D map, one with the 2.5D map and one with the 3D map) (Table 12, Section 4.7.2.2). Only a small part of the blower was used to indicate its orientation, which resulted in a small display on the map (Figure 4-30).

As stated earlier, a larger exocentric view helps in the acquisition of spatial horizontal information (Luo, Luo, Wickens, et al., 2010). To enable a larger view, the zoom function as suggested by Wingrave, Haciahmetoglu and Bowman (2006) was included.

It was observed that although the exocentric view provided in the maps is useful for showing spatial horizontal placement, it was not considered enough to view details of the objects on the map, in this case, the small part of the air blower. Although this small part could be seen without zooming in on the map, participants may have overlooked it due to its size. Therefore, it is suggested that a large exocentric view is suitable for delivering spatial horizontal information but not helpful for a detailed view.

The zoom function, which enlarges the map, was not used by the participants. This could also be seen with the map 'hide' function where only few participants hid the map and then only at the beginning of the *navigation task* (i.e., when navigating the first two nodes) and later continued displaying the map while navigating. This suggests that they were not keen to use the functions, probably because using them requires effort by the participants.

Orientation of the cyclone. The orientation of a map is an important aspect of navigation. The study by Darken and Peterson (2001) demonstrated that the orientation depends on the navigation task performed by the participants. In their study, the participants navigated directly in the virtual environment (in an egocentric view) and used the map as an aid. The results demonstrate that, if the navigation task required the users to perform an exhaustive search (where the target is unknown), then a forward-up map (where the map is rotated according to the user's egocentric view of the navigated environment), is recommended. If the navigation involves a less exhaustive search (target is known), then a north–up map (where the map remains static but the indicator showing the users' direction during navigation is recommended (Darken & Peterson, 2001)). Since the present user study did not require participants to perform exhaustive navigation, as they need to navigate only according to the sequence number on the map, a north-up map was used for the 2D, 2.5D and 3D maps.

The results indicate that confusion regarding the orientation of the cyclone occurred with participants using the 2D and 3D maps. Four participants with the 2D map and five with the 3D map placed the cyclone in a different orientation, as shown in Figure 4-27 and Figure 4-28, Section 4.7.2.2. With the 2.5D map, all participants managed to place the cyclone in its correct orientation.

It is suggested that the reason for this confusion is not related to the orientation of the map with the panoramas in the VR application because, if this was the reason, participants using the 2.5D map would show the same confusion, which did not occur. In addition, the size of the map, which was a factor in the confusion for the air blower, is not likely to be the reason because the cyclone is not small and participants showed signs of remembering it (most chose the cyclone as the first object to be placed on the base).

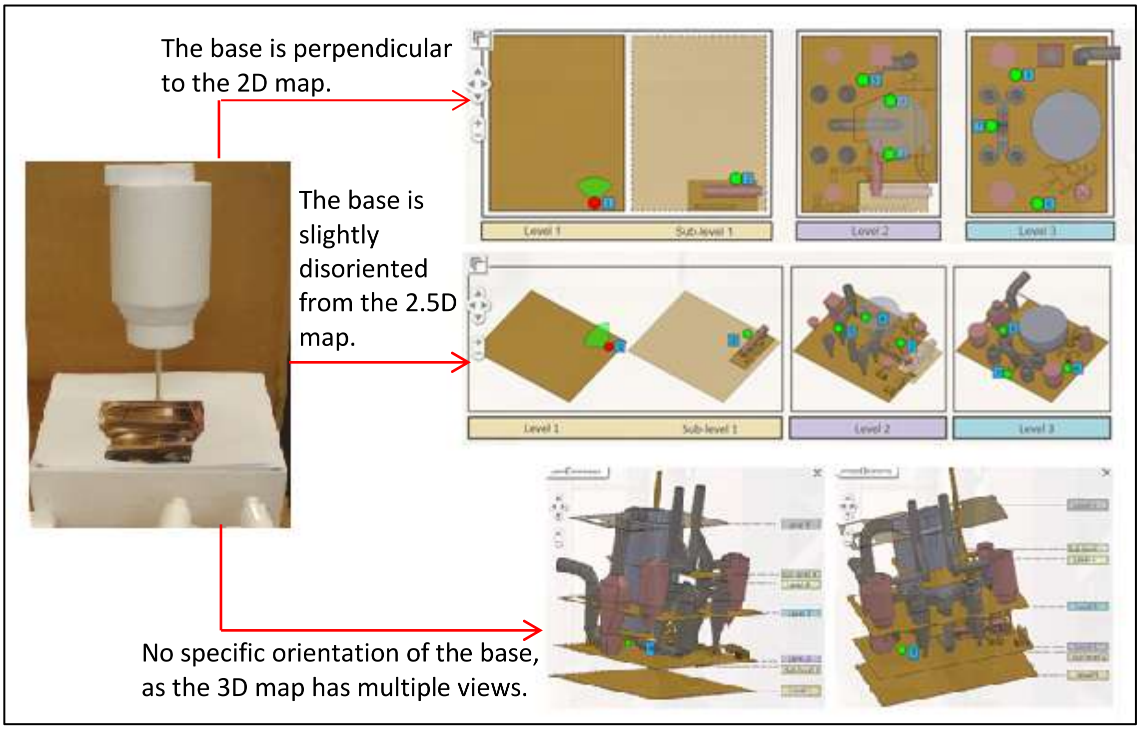


Figure 4-31 The orientation of the base with respect to the 2D, 2.5D and 3D maps.

Therefore, the reason for this confusion could be the orientation of the map with respect to the base used in the *object placement test*. The base was placed as in Figure 4-31, which meant it was perpendicular to the 2D map and slightly disoriented for the 2.5D map. The 3D map has multiple views; therefore there was no exact position of the base with regard to the 3D map.

The results of the *object placement test* demonstrated that some participants using the 2.5D and 3D maps placed the cyclone on the right and left area of the base, similar to the position of the cyclone on the 2.5D and 3D map layout, which suggests that these participants were confused by the orientation of the base and assumed it was in the same orientation as the map in the VR application.

More confusion occurred in participants using the 2D map, as the cyclone (in the *object placement test*) was oriented in different ways suggesting that another possible reason was confusion of the objects on the map when viewed top-down, as discussed in Section 4.8.1. This caused confusion in participants in identifying the cyclone on the map. The confusion could be due to the orientation of the 2D map in the VR application, where it was oriented in a manner to make efficient use of the screen space.

When the present study was conducted, it was not expected that the base would contribute confusion since it was rectangular and therefore provided participants with the ability to judge the long and short edges of the rectangular base. The participants were allowed to rotate the base as they wished, but only one participant (who used the 2D map), rotated the base so that it was in a similar orientation to the 2D map, before performing the *object placement test*.

4.8.5 Gender differences, spatial ability

Gender differences. Linn and Peterson (1985), Masters and Sanders (1993) and Voyer, Voyer and Bryden (1995) found that in the MRT, males obtained higher scores than females. The same was also found with male and female engineering students (Peters, Chisholm, & Laeng, 1995). The same was true for the scores in the PTT where males have less error in the test than females (Meneghetti, Pazzaglia, & Beni, 2012). The present study's results, however, do not align with these findings since there was no significant difference in the MRT and PTT scores between male and female participants (refer to Section 4.7.4). This could be explained by the small number of male and female participants so differences did not become significant in the results.

Gender has also been found to affect the acquisition of spatial knowledge (Kober & Neuper, 2011). In the present study, in general, regardless of map type, there is no significant difference between the male and female participants in their scores on the *object placement test*. This could be due to the navigation task where participants need to navigate according to the number sequence on the map shown, which requires less effort for navigation. Therefore, no difference in effort was required by the male and female participants.

Spatial ability. The results of this study produced no correlation between the participants' spatial ability and the acquisition of survey knowledge (based on scores in the *object placement task*), which does not support the findings of either Darken and Cevik (1999) or Wolbers and Hegarty (2010). The reason could again be explained by the navigation task requiring less effort so it could be performed by participants regardless of their spatial ability.

4.9 Limitations of the study

Map design. Since the present study used point-to-point maps, in a static form, no direct interaction could be performed on the map. Therefore the 3D map was developed with a rotation function where multiple views of the map could be shown to the participants. In addition, the 2D map was designed to make efficient use of the screen space and therefore it was orientated perpendicular to the base provided during the *object placement task*.

Navigation task. Another limitation related to the navigation task was that the participants were required to navigate according to the number sequence on the map, which did not allow in-depth exploration of the virtual environment. This may limit the ability to build up survey knowledge. However, since the present study focuses on acquiring secondary survey knowledge by using the map, the lack of exploration in the virtual environment is not a major concern, although it could be considered that other navigation tasks (e.g., searching for a specific target by exploring the virtual environment) might provide the participants with better acquisition of survey knowledge.

The above limitations (both in the map design and navigation task) were minimised by not restricting the time for performing the navigation task, which meant that participants were allowed to take their own time to explore and become familiar with the virtual environment. In addition, in the object placement task, the participants were allowed to rotate the base, which provided them with the flexibility to decide the way they wanted to view the base before placing the objects in the intended location.

Scoring. Other limitations related to the scoring. For the scoring of the *vertical position* of objects in the *object placement test*, the measurements were based on the points where the stick was inserted (marked as 'X' in Figure 4-18, Section 4.4.2.3). This may result in difficulties for participants who used other parts of the objects (instead of 'X') as their reference point to identify the *vertical position* of the object. Different preferences for reference points support the theory of Lynch (1960), which suggests that elements used as points of reference may differ from each other. This was demonstrated when one participant stated that the top of the cyclone needed to be at level four, and therefore she carefully placed the cyclone so that its top reached level four. This limitation was minimised by clearly instructing the participants to put the objects at the intended level based on the point where the stick was inserted, therefore giving the participants an indicator of where the sticks should be inserted into the object.

In addition, compared to the vertical and horizontal positions, where the measurements were based on the marks on the sticks (vertical) and also the marks on the paper made by the stick (horizontal), measurement of the objects' orientations was done manually (using a pencil to carefully draw a line matching the orientation of the object). This was compensated for by giving a 10˚ tolerance in each measurement.

4.10 Lessons learned

The findings of this user study provide useful insights for the map design of complex multilevel building (i.e., with equipment that extends beyond a single level).

- The map needs to be able to convey both the *horizontal* and *vertical positions* of the objects. A 3D cut-away presentation of the objects on the map (i.e., a 2.5D map) is a good approach for multilevel buildings with equipment stretching over levels because it provides the advantages of both the 2D and 3D maps by exposing both spatial *horizontal* and *vertical* information of the objects without blocking other objects on the map. Presenting the objects in a cut-away form, however, does not preserve the shape of the objects as a whole, but is still useful for object identification.

- A 2D map is not suitable for use in an environment with elements of similar shape (e.g., a processing plant, manufacturing factory) because it causes confusion when viewed in a top-down manner (especially when cut at the respective levels). Inability to identify the respective objects would affect the acquisition of spatial knowledge.

- The presentation of the 3D map in the present study is not ideal because it hides other objects. In addition, providing multiple views of the map from different angles, although exposing the users to more views of the map, may cause the participants to suffer from excess cognitive overload and become confused.

- The size of the maps presented in a panel that occupied about one third of the screen is considered useful in providing spatial *horizontal* information but not detail. To provide a detailed view, additional functionalities are needed such as a zoom function but this needs to be made available automatically (e.g., when the cursor hovers over a map element that requires detailed attention, the map will enlarge automatically). This is because participants were not keen to use functionalities that required them to pause from the navigation task.

Apart from the above, the present user study also provides valuable lessons related to *the object placement test* as a measurement tool.

- The base of the *object placement test* with its initial landmark should be given directly to the participants and they should be told that they can decide on the orientation before beginning the *object placement test*. Another option is to initially align the base according to the map type. This is to avoid any effect of the base's orientation on the placement of the objects.

Apart from the map design, the findings of this user study also suggest that the use of a point-to-point map with guided navigation is less exhaustive (e.g., guided navigation where users know where to move from one location to the other, instead of having to search for a specific location to move next) and could be used by the users regardless of their spatial ability and gender.

Chapter 5

A usability study of the milk processing VR application

This chapter describes the usability study conducted with the milk powder processing VR application developed by the Department of Chemical and Process Engineering (CAPE) (University of Canterbury) and HIT Lab NZ. The development of the VR application is based on a large scale multilevel working milk powder production plant and has been published in Herritsch et al. (2011), which was co-authored by the thesis author. Part of the usability study results discussed in this chapter have been published in Abdul Rahim et al. (2012).

The usability study was carried out to determine whether the VR application could be readily used by students as a learning resource. Usability has multiple components related to the following attributes (Nielsen, 1994):

- Learnability : The system should be easy to learn and users should not face difficulties in using it.
- Efficiency : The system should be efficient to use.
- Memorability : How to use the system should be easily remembered.
- Errors : If users make mistakes while using the system, it should be easy to recover.
- Satisfaction : The system should be pleasant to use so that users are satisfied when using it.

Conducting a usability study aims at detecting issues that would be faced by users of the system. This allows problems to be solved before the system is launched to its targeted audience. Having a usable system leads to satisfied users because they spend minimal time familiarising themselves with the system and are able to access information easily. Therefore, the objectives of the usability study were to:

i. Determine any usability issues with the milk processing VR application.
ii. Assess if the issues encountered in the BP VR application have been addressed in the milk processing VR application.

iii. Provide insights that will be useful for the development of future VR learning software. This is important because currently there are not many guidelines to help developers know the best approach to developing VR applications to support learning (Cobb & Fraser, 2005).

The chapter describes the VR application (Section 5.1), the usability study (Section 5.2), the results of the usability study (Section 5.3) and discussion and conclusions (Section 5.4).

5.1 The VR application

The development of the milk powder processing VR application is based on a large-scale milk powder production facility. It is a compact plant containing a diverse range of processing units. The information content of the VR application is presented in four panels: 'Info Panel', 'Pano Viewer', 'Process Flow Diagram' and '3D map' (Figure 5-1).

The information in all the panels is linked to each other. Having different panels linked is a unique feature of this VR application compared to other VR applications used in education. The inclusion of these panels in the design of the application is based upon the *multiple representations principle* (an explanation based on a combination of words and pictures is more effective than an explanation in either words or pictures only) and the *contiguity principle* (better learning takes place when the words and pictures are presented together instead of separately) (Mayer, 1997). The links between the panels allow users to see related information. The information presented in this VR application is also consistent with the graphical realism guidelines provided by Schofield (2010) who suggests that a sophisticated level of realism, a combination of abstract and realistic presentations and a multimodal approach (i.e., a combination of 3D environments and text information) should be used for effectiveness of engineering educational software packages.

The 'Info Panel' (top left Figure 5-1) contains text related to milk powder processing, the 'Pano Viewer' (top right) contains 360^{o} panoramas of the process plant, the 'Process Flow Diagram' (bottom left) is a diagram of the milk powder production process and the '3D map' (bottom right) displays a 3D model.

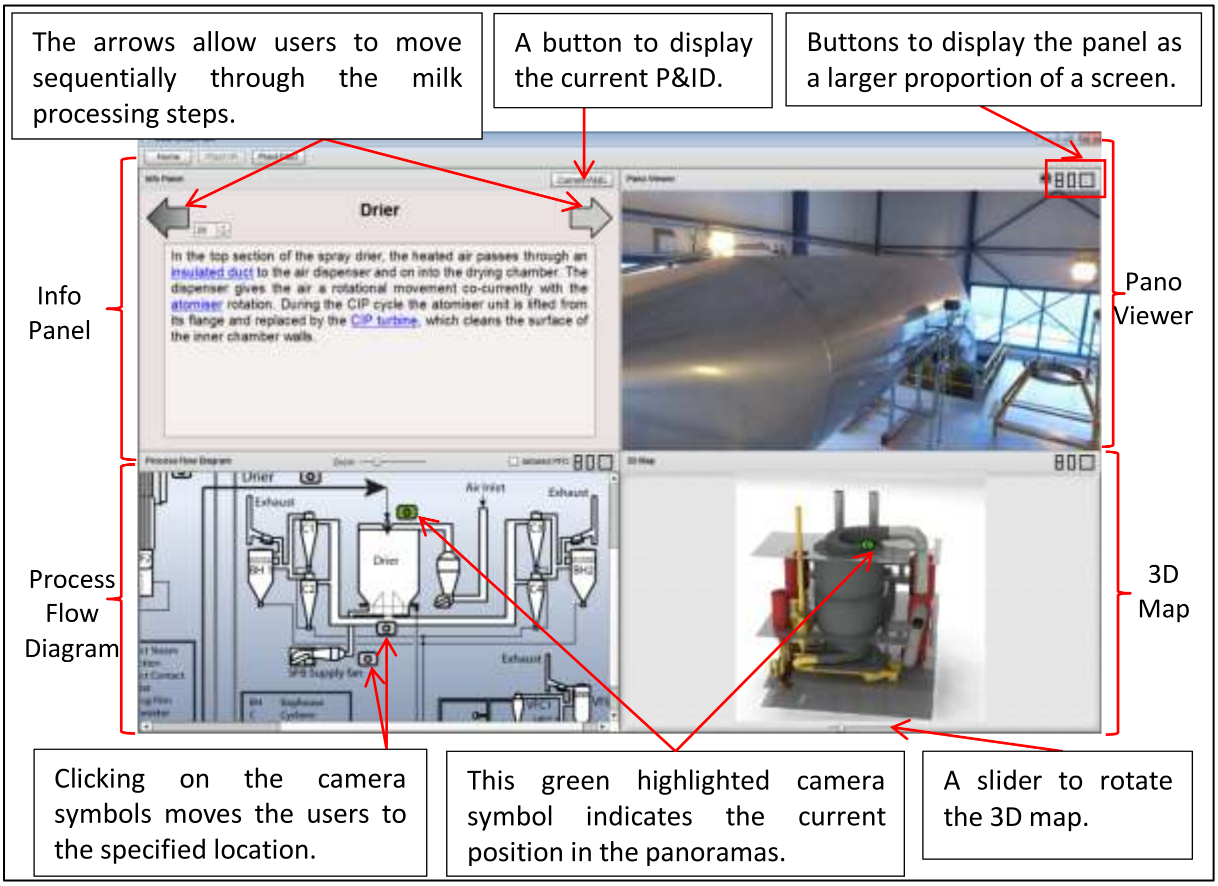


Figure 5-1 The four panels of the VR application displayed on the screen.

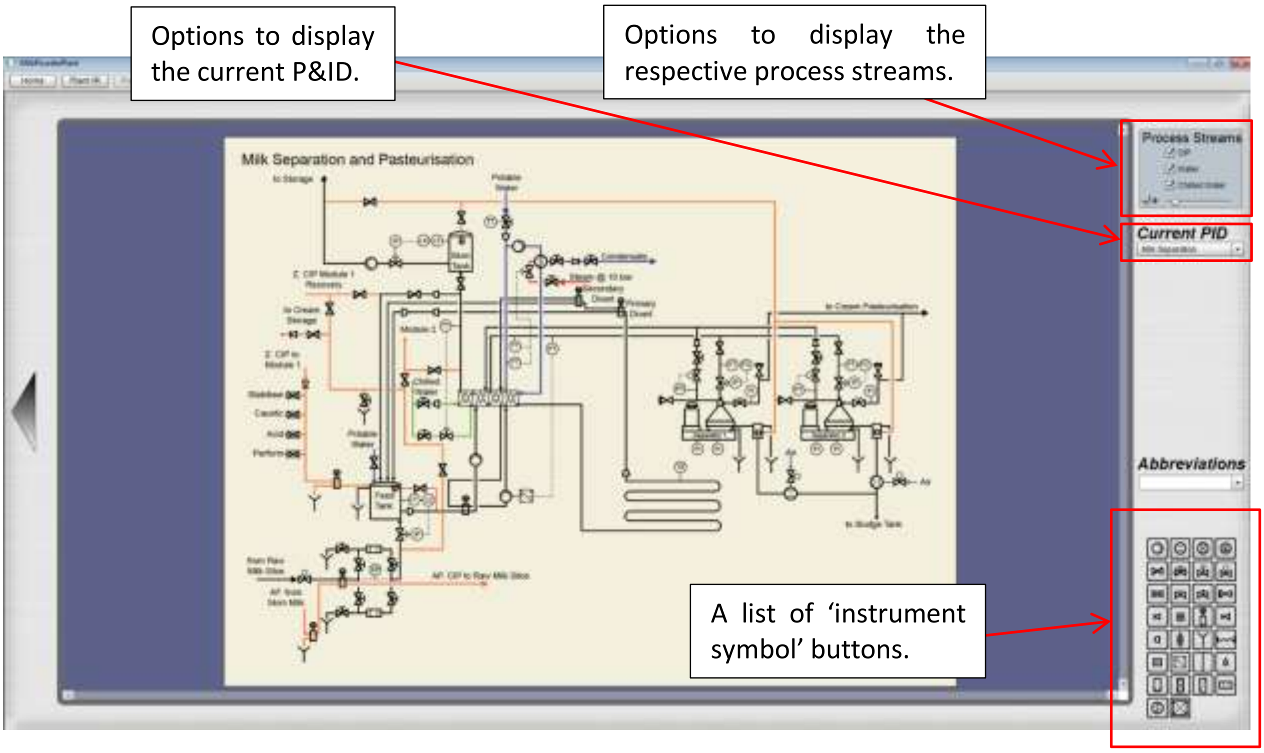


Figure 5-2 The interactive piping and instrumentation diagram (P&ID) of the VR application.

This 3D model is of the area where the user is currently located. For example, in Figure 5-1, the user is at the dryer area and, therefore, the 3D model of the dryer area is shown. The 3D map can be rotated to allow users to view it from different angles. The components of the map are coloured based on their function, for example, the piping lines are yellow. Since spatial knowledge is not the focus of this application, the 3D model is used as it provides a representation of the plant at once, allowing the users to view location of where each process takes place.

The information in each panel is linked to other panels allowing users to relate corresponding content. For example, in Figure 5-1, the current location of the user in the dryer area is shown in both the PFD and the 3D map by a green highlighted camera symbol.

In order to move from the location of one 360^o panorama to another, users can move using the arrows at the top of the 'Info Panel'. These allow users to move sequentially through the milk powder production process from tanker reception to the packaging area. Alternatively, users may move to a specific location by clicking on the camera symbols available in the PFD. This moves them to the specific 360^o panorama based on the PFD selection.

At the top of the 'Info Panel' is a button that enables a display of the current piping and instrumentation diagrams (P&ID) (Figure 5-2). The P&ID contains too many components and is therefore presented by itself. Users are able to display the current P&ID from the drop down menu and the respective process streams via the checkboxes. Clicking on one of the buttons from the list of 'instrument symbol' buttons at the bottom right allows a display of detailed information related to the respective instruments in a pop-up window, similar to the one shown in Figure 5-4.

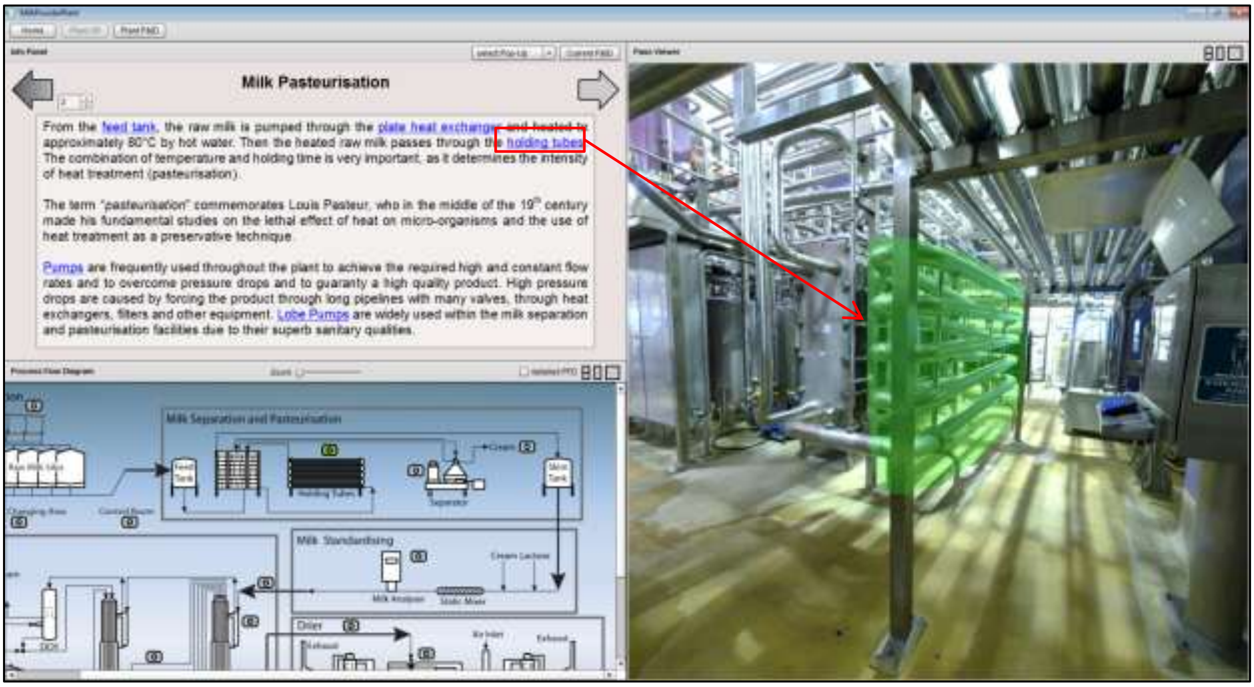


Figure 5-3 The hotspots and the 'Pano Viewer' panel displayed in half screen.

Figure 5-4 The pop-up window displays additional information related to the respective unit's operation.

At the top right of the panels is a set of buttons ( ) that allow the panel to be resized, see the example in Figure 5-3 where the 'Pano Viewer' panel occupies half the screen. A hotspot (highlighted area of interest) is also included in the VR application (Figure 5-3). When the cursor hovers over the blue text in the 'Info Panel' (in this example, the 'holding tubes'), the image of the holding tubes in 'Pano Viewer' is highlighted in green. At certain points, clicking on the blue text will display a pop-up window that contains additional information including videos and animations (Figure 5-4).

5.1.1 Specific user interface issues

A number of the features of the milk powder processing VR application were designed to address some user interface issues identified in the BP VR application (Table 15).

Table 15 User interface issues of the VR application and approaches taken to address them.

Issues		Approaches taken to address them
Ease of use	Users are confused about returning to the previous page (no 'back button').	• Four different panels displayed in one screen, allowing users to move to any area and able to look at all information at once. • The information in each panel is linked. • The buttons ( ) allow the panel to be displayed as a larger proportion of the screen and minimised back to its original size. This allows users to enlarge each panel and at the same time maintain their awareness between panels.
Links between information	Lack of links between the PFD the 360^o panoramas.	
Appropriate size and use of colours for the components in the application	Map is small.	
	Hotspots are difficult to see because of the colour.	• Green hotspots.
Suggestions		**Approaches taken to address them**
Guided tour	An additional suggestion, related to navigation, includes adding extra information such as the current location of the user and where they are moving next.	• Arrows at the top of the Info Panel allow users to navigate the plant based on the sequence of steps for milk powder processing.
Intuitive application	The application could be more intuitive (e.g., information appears when the cursor hovers over the equipment in the VE).	• Instead of information appearing when the hotspots are clicked, hotspots are displayed when the cursor hovers over the blue underlined text in the Info Panel. This provides users with a reference to the items referred to in the text information.
Informative map	Include an indicator to show the size of equipment.	• The 3D map in this VR application has a 'human figure' included for size comparison of the scale of the plant. The equipment on the map is coloured based on its functionality.

These issues included unclear hotspots, lack of links between the PFD and the 360^o panoramas, and the small size of the map, as discussed in Chapter 3. Table 15 summarises these issues and the approaches to address them. The issue related to navigation was not included as it was catered separately in Chapter 4. The search engine functionality is not yet included in this VR application but it will be included in future.

5.2 The usability study

This section describes the usability study conducted using the VR application.

5.2.1 Participants

The content of the VR application is detailed and covers topics for 3rd Professional students. Since this study is aimed for usability, this would not be an issue however, it is expected that 1st Professional students would face problems with the content of the application. Eight students (3 males and 5 females) volunteered to participate in this study. Four were 1st Professional students and the remaining four were 3rd Professional students of CAPE. Since this is a usability study, the number of participants met the guidelines of Nielsen (1994) who suggested a minimum of three.

5.2.2 Procedure

Participants were given a consent form with written information about the objectives of the study. Upon signing the consent form, the participants completed a general information form that asked about their experience with VR applications (see Appendix C.1 for both the consent and general information form). The participants then began the session which comprised:

i. A practice session.
ii. A series of tasks using the VR application.
iii. The completion of questionnaires.
iv. An interview session.

5.2.2.1 Practice session

Participants were asked to practise using the VR application from a printed user manual. No demonstration was given because they were expected to be able to use the system based on the information provided in the user manual. The participants were allowed to ask questions should there be any confusion or difficulties during this session.

5.2.2.2 Performing the tasks

Once participants had completed the practice session, they were asked to complete a set of prescribed tasks that covered the available features in the VR application. Participants were allowed to refer to the user manual while performing the tasks. The tasks (Table 16, Section 5.3.1) included:

- Manipulating the panel size (e.g., expanding the panel size).
- Moving to a specific area in the virtual environment.
- Displaying the PFD and P&ID, including the components in the P&ID.
- Displaying additional information available from the text information in the Info Panel.

There was no time limit for practising and performing the tasks. Participants were asked to 'think aloud' while performing the tasks and they were observed throughout the session. Notes on any issues or comments were made. The sessions were video recorded for reference to clarify particular issues noted in the user study.

5.2.2.3 Completing the questionnaires

After the tasks were completed, the participants completed two questionnaires, as described below:

i. A general usability questionnaire:

   The questionnaire consisted of various statements related to the general usability of the VR application (see Appendix C.2). Participants were required to state their level of agreement with the statements on a Likert scale ranging from 1 = Completely Disagree to 6 = Completely Agree. A six point Likert scale was used to allow a similar comparison with the general usability questionnaire used in the preliminary study using the BP VR application.

ii. An adapted version of the USE questionnaire (Lund, 2001):

   This questionnaire was modified to include only statements relevant to the VR application (see Appendix C.3). Participants were required to state their level of agreement with statements relating to ease of use, ease of learning and satisfaction on a scale from 1 = Strongly Disagree to 7 = Strongly Agree. This is a published questionnaire where its validity and reliability have been assessed. Therefore, a seven point Likert scale as in the original format was used.

5.2.3 Interview session

The participants were asked to identify both the items they liked and those they did not like about the VR application and if they had any suggestions for changes or improvements.

5.3 Results

The information from the general information form revealed that none had any prior experience with immersive VR (e.g., cave automatic virtual environment (CAVE)). Two had experience with non-immersive VR (e.g., a desktop virtual tour of a museum) ranging from once a month to a few times a month; the remaining six did not have any relevant experience.

The results are separated into four components: the tasks' performance (Section 5.3.1), the participants' agreement with statements related to the VR application (Section 5.3.2), the participants' agreement with statements in the USE questionnaires (Section 5.3.3), and the observations, comments and suggestions made throughout the sessions (Section 5.3.4).

5.3.1 Task performance

The participants took between 7 and 14 minutes to complete all the tasks listed in Table 16.

Five participants could perform each task without referring to the user manual. Only three participants referred to the manual when performing Task 1 (P3), Task 6 (P5), Task 8 (P6) and Task 12 (P5 and P6). Some very minor issues were encountered by the participants when performing some of the tasks, as described next.

Table 16 The task list for the user study of the VR application.

No	Task
1	You have just reached the dairy plant and now you are at the tanker reception area. The NEXT step is to get ready with the appropriate attire before you are allowed to enter the plant. Go to the place where you would do this.
2	From here, take the tour according to the sequence provided by the VR application. Stop when you have reached the 'Milk Separation' area. Point at the screen where the 'centrifugal separators' are in the virtual environment (VE).
3	You want to have a bigger view of the virtual environment (VE). Expand the window size to full screen. Once you have expanded it, return to the default size.
4	From here, go to the Vacuum Pump area (in the 'evaporators' area) via the PFD.
5	Point at the screen where the two-stage water ring pumps are in the 3D map.
6	You want to see the 3D map in detail. Change the window size to full screen. Rotate the 3D map.
7	You also want to view the P&ID of this area. Demonstrate how you could view the P&ID.
8	In the P&ID screen, display the process streams of the 'vacuum' in the 'evaporators'.
9	Within this page, demonstrate how you could display the 'current P&ID' of the 'milk separation'.
10	You want to see the details of the 'valves', which are listed in the instruments symbols. Demonstrate this.
11	Now, go back to the 'plant VR'.
12	You want to see the 'detailed PFD' of the dairy plant. Demonstrate this.
13	The 'detailed PFD' is quite big to be displayed in the small display area. Expand the window size to full screen. Show how you could zoom in/out and pan the display of the PFD.

For Task 1, participant (P1) selected the buttons in the PFD instead of clicking on the 'arrow' to go to the requested area. S(he) stated that he did not notice this in the manual. Since this happened to the first participant, immediate changes were made to the user manual with notes related to the arrows added to it (Figure 5-5). This problem did not occur with the remaining participants.

For Task 4, two participants (P3 and P5) clicked on the images of the vacuum pump before realising they should click on the green highlighted camera symbols in the PFD. However, both participants managed to click on these symbols without referring to the manual. Therefore this was considered a minor issue since it did not take long before they realised what was required.

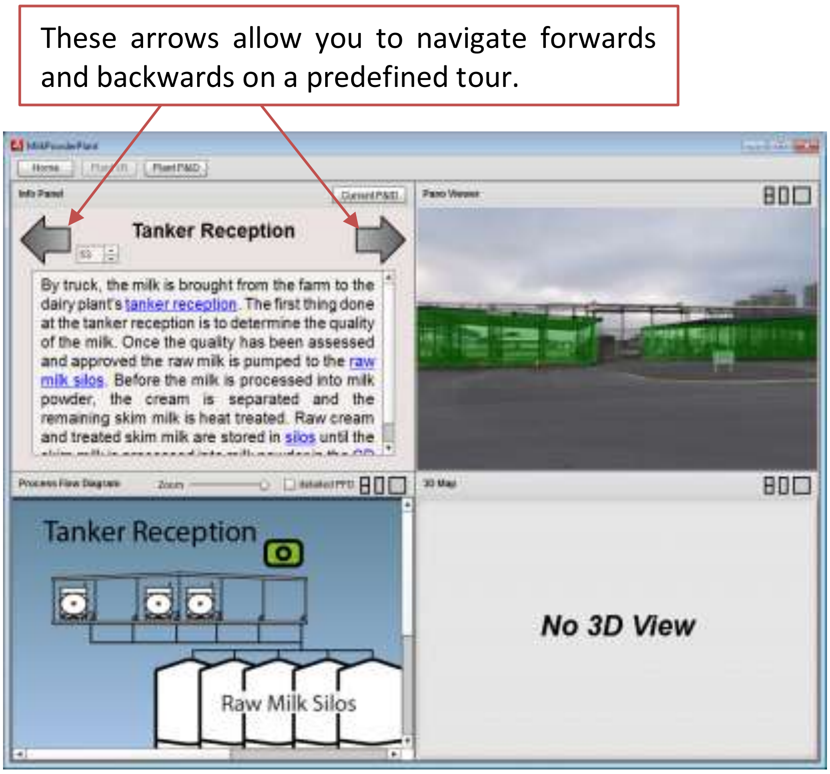


Figure 5-5 The notes relating to the 'arrows' added to the user manual.

For Task 7, two 1st Professional participants (P2 and P3) were confused because they had not been exposed to P&IDs. One (P2) asked *"What is a P&ID?"* when the instruction was read. This issue was not related to the VR application but more about the participants' lack of knowledge about process engineering at this point in their education.

In addition to task performance, one participant (P6) stated his confusion with the numbers in the box next to the arrow (Figure 5-6). However, these node numbers were shown only in the prototype version for reference purposes and were not intended for inclusion in the released version. No similar comments were made by other participants.

Observations throughout the sessions supported the view that participants could perform most tasks without referring to the manual, suggesting that the VR application can be used without additional instructions.

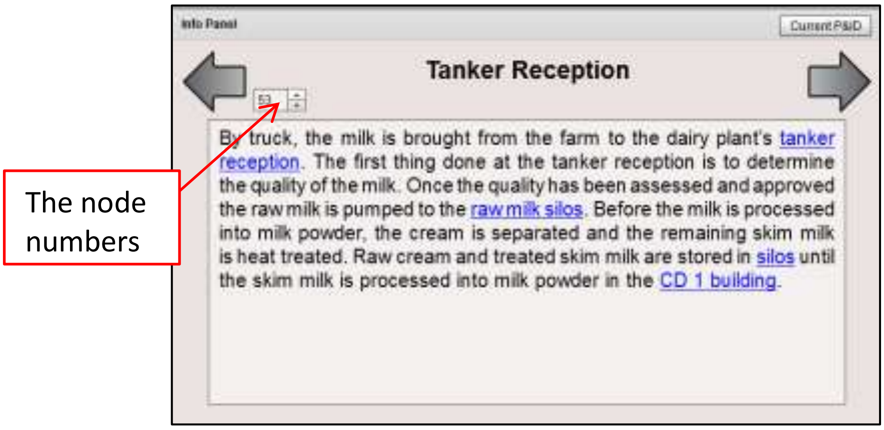


Figure 5-6 The node numbers in the Info Panel screen.

5.3.2 Agreement with statements related to the VR application

Figure 5-7 shows the participants' agreement with statements related to the VR application, on a scale of 1 = Completely Disagree to 6 = Completely Agree.

The responses to the statements *'I felt lost when I was in the virtual environment (VE) of the plant'* (no. 1) and *'I felt dizzy when I was navigating the plant'* (no.15) are mostly towards disagreement, suggesting that the participants did not have major problems navigating the VR application. Majority of the responses for the remaining statements are prone towards agreement.

The statements related to colour coordination of the 3D map (statement 6), the use of arrows in the Info Panel to move around the plant (statement 8), the usefulness of the sequence of navigation (statement 10), the hotspots (statements 13 and 14), and the links between the different panels in the VR application (statement 17), received the highest levels of agreement, where majority of the participants stated their agreement at the scale of 6 (Completely Agree).

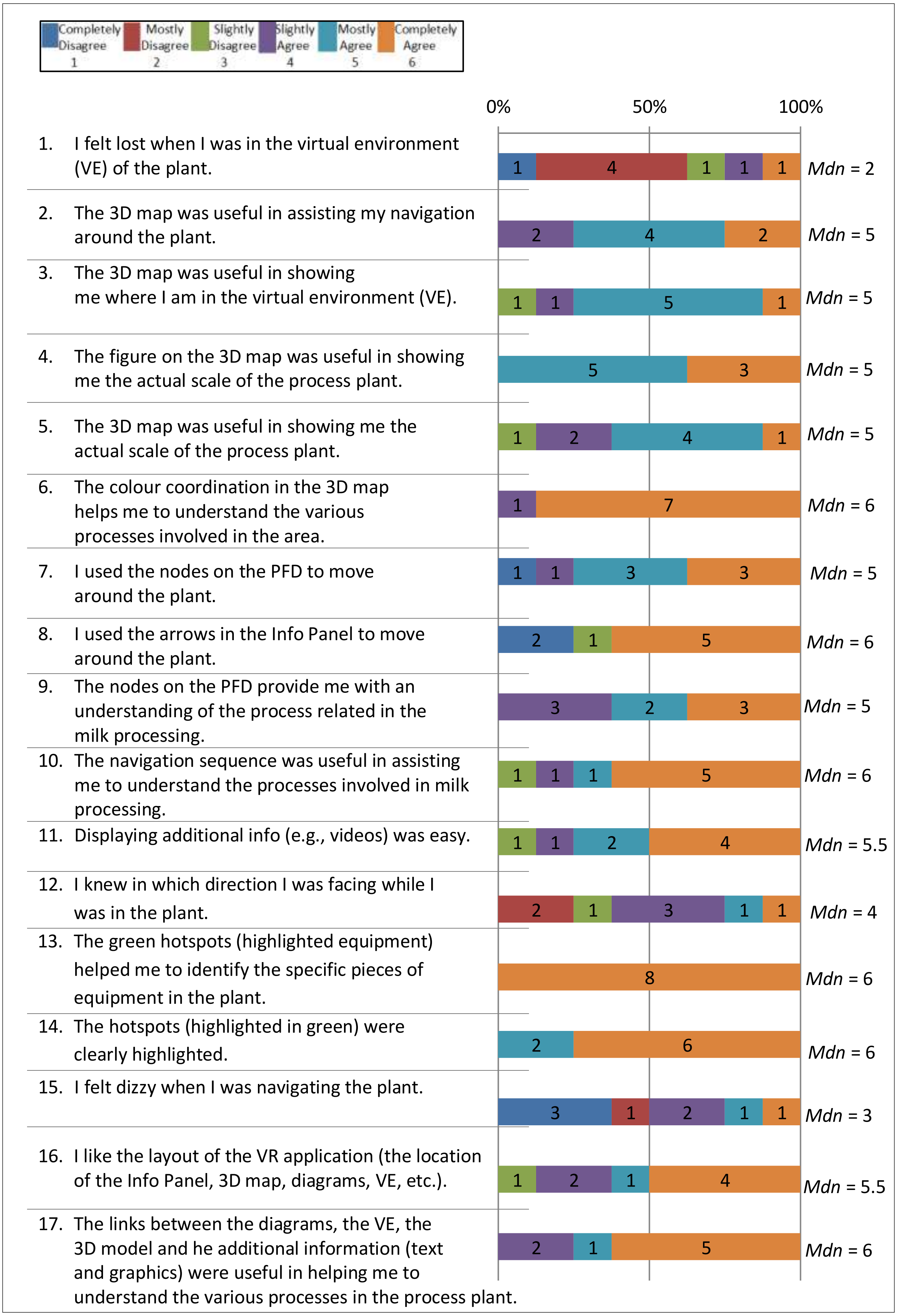


Figure 5-7 Participants' agreements with statements about the VR application. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

5.3.3 Agreement with statements related to the USE Questionnaire

Figure 5-8 shows the participants' agreement with statements in the USE questionnaire on a scale of 1 = Strongly Disagree to 7 = Strongly Agree.

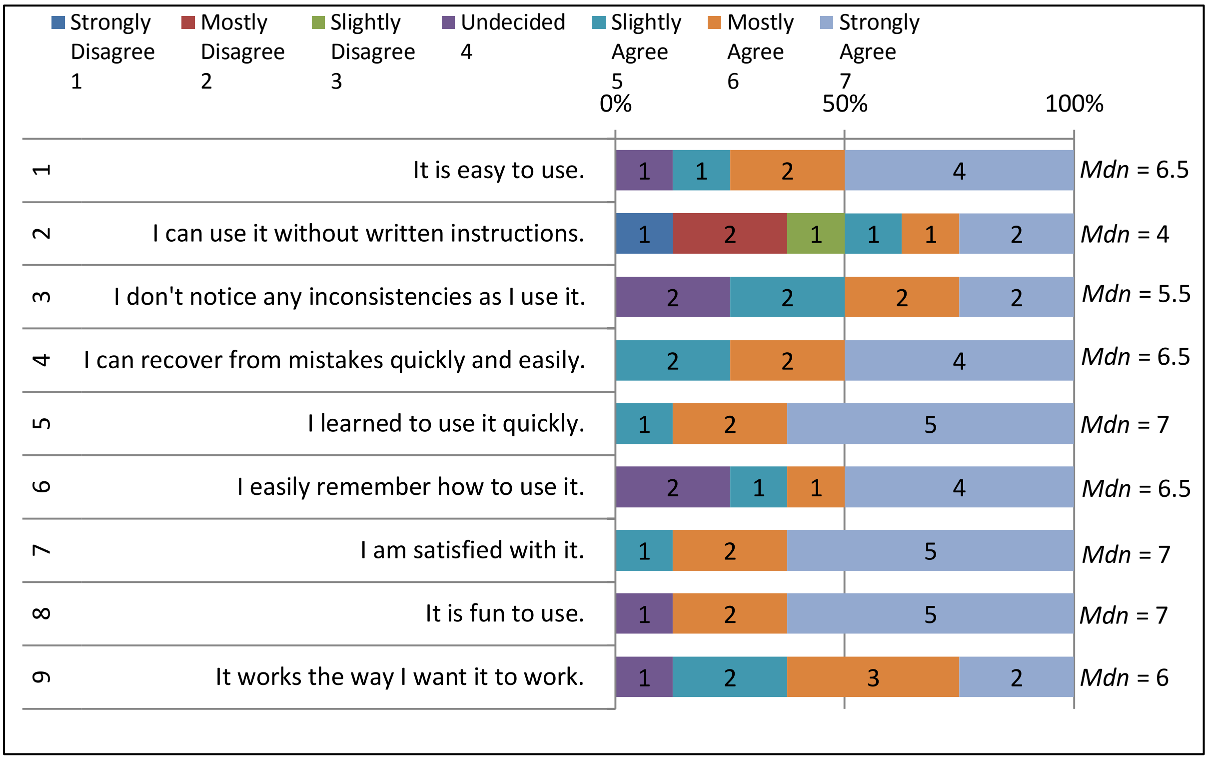


Figure 5-8 Participants' level of agreement with the statements in the USE questionnaire. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

Most participants agreed with all statements; the exception was the statement *'I can use it without written instructions'*, where the participants were split.

For further analysis, these statements were grouped into three categories: Ease of Use (statements 1 to 4), Ease of Learning (statements 5 and 6) and Satisfaction (statements 7 to 9) as they appear in Lund (2001). Therefore, each participant has three categories of data and the responses to the statements in each category were averaged. The results indicate that the VR application was rated high for Ease of Use (*Mdn* = 5.8), Ease of Learning (*Mdn* = 6.5), and Satisfaction (*Mdn* = 6.5).

5.3.4 Observations and participants' comments and suggestions

Most participants were observed as being fully engaged with the VR application. During the practice session, seven of the eight participants referred to the manual. Of these seven, five referred to the manual while using the VR application and the remaining two used the VR application immediately and referred to the manual halfway through the session. They took from 4 to 12 minutes to practise using the VR application. Nobody asked questions during the practice session.

One participant commented that the user manual was helpful and easy to understand. The ease of understanding the manual was observed as well to ensure that it is a useful reference for users when they are having problem navigating the application.

Another became quite excited when exploring the application. This participant (who referred to the manual only in the middle of the practice session) liked the hotspots feature, *"I just went through and clicked all the environment (referring to the different panels on the screen). … I got a bit excited and jumped into it. Now I refer to it (the user manual) and I realise I can see this (referring to the hotspots). I like this feature, now I know how the pump looks like. It is pretty easy; I can identify and see what they are used for* "(P4).

The remaining participant, who did not refer to the user manual, took 31 minutes to practise. The reason for the longer time appeared to be due to a high level of interest in the content. He was observed being very focused on the content of the VR application and visited all available nodes. At each node of interest, he read the text information, hovered over the hotspots, referred to the PFD, P&ID and the 360^{o} panoramas and viewed the additional information in the 'pop up window'. Although he was reminded that this study evaluated only the VR application, he continued exploring the VR application with great interest and stopped only when he reached the last node.

5.3.4.1 Aspects participants liked

All participants were asked what they liked about the application; all stated more than one feature. These responses were grouped into three main themes as below:

- Ease of Use - refers to comments made by the participants relating to how the VR application could be used without any difficulties.

- User Interface – refers to the presentation of the VR application, which also includes components such as the diagrams, hotspots, etc.
- Informative contents – refers to the educational value of the VR application.

Ease of Use. Most participants (six) liked the VR application because it was easy to use. This ease of use was observed during the practice session where all (except for the participant who took 31 minutes) took 4 to 12 minutes to familiarise themselves with the VR application. None asked questions during the practice session, which suggests that the VR application is easy to use.

One participant commented on the common symbols used in the VR application, *"It is easy to navigate because it uses common symbols; some of it is similar to MATLAB. It is very simple and you can understand what you have to do. This is like the Google street map" (P7).* Another factor that contributed to the 'ease of use' was the user interface where participants found that having the four different panels helped to move from one area to another easily.

User interface. Each participant had more than one feature of the user interface that they liked (see Table 17).

Table 17 The frequency of responses to each feature of the VR application.

Feature	Frequency of responses
Hotspot	5
Four panels (the integrated information)	5
3D map	3
Diagrams (P&ID and PFD)	3
Pop-up window	2
Panoramas	2
Arrows (sequence of tour)	1

Participants liked the hotspots feature since they were observed to hover the cursor repetitively over the text information in the 'Info Panel' so they could see more of the 'hotspots'. Some added that it was a good feature because it enabled them to see where the equipment was in the panoramas.

One participant commented that the four-panel display was intuitive and other participants commented that this feature helped them to navigate easily from one area to another and also to understand the process easily.

The participants felt that the 3D map provided a sense of scale and its colours helped to distinguish between the different parts of milk processing and provided connections with the 360^{o} panoramas, *"I like it when it is blue coloured here (360^{o} panoramas) and how it is also coloured in blue here (pointed to the pump in the 3D map) (and that) made it easier to connect both of them"* (P5).

One of the three participants who liked the diagrams commented, *"PFD is really good. I like how you can highlight the respective streams you want to see (the vacuum stream) in the P&ID"* (P8). Others commented that the process streams in the P&ID were not cluttered; they made it easy to see the flow and the colour indications were clear.

The list of 'instrument symbols' buttons available in the P&ID page was considered good by one participant because it exposed students to the symbols that were specifically used for different types of pump in the design process and the detailed information associated with them. This is important since in class they learn only about general symbols and pumps rather than specific ones.

Two participants commented that the 360^{o} panoramas provided them with an overview of how things are placed in the plant, *"The actual photos (360^{o} panoramas) are very useful. They give a sense of where everything is, how it interacts. I like it because I can look it up (in the 360^{o} panoramas)"* (P8).

Some participants also felt that the arrows for sequence navigation and the pop-up windows were useful, *"Pop-up windows are good. There is a lot of information. It shows the explicit part of the pumps. We have one lab with the technical parts of a pump, so we could see all sorts of pumps and things and play with it."* (P4).

Content. Four participants stated that they liked the overall content of the VR application. One stated that it provided an exposure that is not available in class, *"I learn all this equipment, it would be really useful to see what it looks like...we see images in the class...but it is hard to see how the equipment interacts with each other because you only see the individual equipment"* (P8). Some pointed out that tanker reception at the beginning was useful because they had been taught only about the main part of milk processing instead of the bigger picture such as how the raw milk is transferred. Some participants also found the VR application useful for their design projects and as preparation for lab work.

5.3.4.2 Aspects participants did not like

When asked what they liked least about the VR application, half of the participants could not point out anything and one added, *"there is nothing that I would like to do that I was unable to do" (P4).* This suggests that they were satisfied with the VR application. Although one possibility of the lack of response could be due to the participants experiencing survey fatigue and did not wish to spend extra time to come up with improvements, the thesis author disagreed as the time taken to complete the survey was less than 5 minutes, which is short and has lower chances of causing any survey fatigue.

Of the remaining participants, one stated that the VR application was fine but as a user of touch screens, he had a tendency to drag the 360^{o} panoramas to the left when he wanted to move to the right. Another two participants stated that the navigation speed was a bit fast, which made them feel a bit dizzy during the navigation. The remaining participant pointed out that the content of the VR application is too specific: *"Only in milk processing, so it is quite specific, but that is good too, because you have information about particular equipment like evaporators which are also used in other plants" (P5)*. Overall, the concerns highlighted by the participants could be classified as navigation speed, navigation style and content.

5.3.4.3 Suggestions

The 3D map received the most suggestions for improvement such as adding radar to show the direction the user is facing, putting a legend explaining the different colours and adding arrows to show the connections between the processes. Another suggestion was to have the hotspot displaying the name of the equipment when the cursor hovers over it.

5.3.5 Summary

The results are summarised as follows:

- All participants found the application was easy to use with a little bit of practice and most could perform the tasks without referring to the user manual.

- Only a few minor issues were encountered during task execution (e.g., not being aware of how to navigate in sequence and confusion with the 'node number' in the Info Panel). These were addressed by modifications to the user manual and the removal of the 'node number'.
- Participants rated the application very positively in the general usability questionnaire. This situation was further supported when participants stated that the ease of use, the user interface and informative contents were aspects they liked.
- There were hardly any aspects the participants did not like. Those they mentioned included the navigation speed being too fast, the navigation style being different from a touch screen and the content being too specific.
- The suggestions received related to the 3D map such as adding radar to show the direction users are facing, adding a legend explaining the different colours presented on the 3D map, and adding arrows showing the connections between the processes. For the hotspots, it was suggested to have the name of the equipment displayed when the cursor hovers over it.

5.4 Discussion and conclusion

The first part of this section (Section 5.4.1) discusses the results of the usability study in relation to the issues encountered in the BP VR application as described in Table 15. The second part (Section 5.4.2) discusses the results of the usability study in general.

5.4.1 Addressing issues in the BP VR application

Using linked panels with the ability to resize each panel has successfully addressed the issues of the small size of the map, the lack of a back button and the lack of links between the PFD and the 360^{o} panoramas experienced with the BP VR application. The use of green hotspots successfully addresses the issues related to the difficulty of seeing the hotspots.

Having the arrows and the 'figure' on the 3D map to address, respectively, the suggestions to have a guided tour and having an indicator showing the size of the equipment, were useful.

5.4.2 Usability of the milk processing VR application

The results of this usability study demonstrate that the VR application was easy to use regardless of the participants' previous experience with VR applications. One reason is that the exposure the participants had to other software made them familiar with the functionalities and icons (i.e., the buttons used to change the size of the panels used in the VR application).

Although a split response was received on agreement with the statement *'I can use it without written instructions',* it was observed that the participants who disagreed referred to the manual only for certain tasks or not all. This suggests that the application is easy to use and only occasionally the participants need the manual for some task. Other than the above statement, most participants have positive responses to the usability of the VR application.

The inclusion of the four panels, which is a unique feature of this VR application, was considered by participants as a main contributor to the ease of using the VR application, because participants were aware of different components of the information, including the process flow described in each panel. The links between panels not only contributed to the ease of using the VR application but it also helped users gain a better understanding of milk powder processing. This suggests that information that is connected to each other should be made visible to users; using multiple panels is one way of doing this. This follows the *multiple representations principle* and the *contiguity principle* of Mayer (1997).

Different levels of engagement with the VR application were found among the participants. Final year students exhibited a higher level of engagement than 1st Professional students, which may be due to the reasons stated earlier where the latter had not previously been exposed to all of the content (e.g., the P&ID) at that point of their education. This also suggests that the level of content detail in VR applications needs to be altered when used for students at different stages of their studies.

It was also observed that, during practice sessions, participants had different navigation styles. Some preferred to use the arrows to navigate in sequence with the milk processing steps but others clicked on the camera symbols in the PFD to immediately go to a specific location. This suggests that participants have different ways of navigating so providing options for flexible navigation is useful.

The use of different colours in the 3D map and the process streams in the P&ID were useful because participants found the colours assisted them to distinguish between different processes. With regard to the hotspots, the use of bright colours (green) as recommended by Marshall and Nichols (2004) was useful because they assisted users to identify the items mentioned in the text. The bright colour also helps to highlight important elements (Krygier & et al., 1997).

5.4.3 Lessons learned

The lessons learned from this study were:

- The visibility of information to users, such as having different panels (with linked information) displayed in a single screen (with the ability to resize each panel), helps to improve navigation and also maintains the user's awareness of the information related to the process in each panel. In addition, this also helps users link what has been learned in the class to the actual process shown in the 360˚ panoramas.
- The use of appropriate colours helps to highlight areas of interest and different processes.
- The use of common navigation symbols (e.g., symbols in MATLAB, MS Office) minimises the effort required to learn to use the application.
- Flexibility with navigation, such as guided and unguided tours, provides users with options for navigating according to their learning style and level of knowledge.
- Different levels of content need to be provided for different levels of student.
- Linking the text information to the item referred to in the text information (i.e., hotspots), is engaging and useful to the users.
- The interactive elements in the VR application were mentioned as useful because they allow users to engage with the related content information presented in different formats. The interactive elements also offer users the ability to learn at

their own pace since they could control what they wanted to see (e.g., displaying the respective streams in the P&ID).

- Displaying additional information in pop-up windows allows a neat presentation of the user interface as well as keeping the users connected with the screen they are currently navigating.

5.4.4 Conclusions

The results indicate that the milk processing plant VR application is easy to use and the participants have positive attitudes towards it. It is therefore a good platform to determine whether it is an effective learning resource for chemical and process engineering students (see the next chapters).

Chapter 6

User study 2: Students' attitudes towards virtual field trips

Field trips provide students with exposure to the real world and help them to relate this experience to the material learned in class. It helps students to understand concepts to an extent that is difficult to achieve via lectures and laboratory work (Lei, 2010).

Students, however, have limited on-site access because of issues such as safety concerns, cost and effort. To address such issues, VR applications have been developed and implemented, and used as a medium for a virtual field trip (VFT). A VFT can provide more flexibility than a physical field trip (PFT) because it can be conducted at any time and place (Çaliskan, 2011; Qiu & Hubble, 2002) and at the students' learning pace (Ku et al., 2011). Therefore issues related to safety, cost and effort are not a concern in a VFT.

A VFT is different from a PFT since it is not merely a replication of a PFT but allows the inclusion of information not available in the PFT such as videos, cut-away components of the equipment available during the PFT and 3D models. The flexibility of a VR application also allows the information to be presented in different formats and layouts. One approach that is taken in this thesis is to develop a VR application where different sources of information are integrated and linked to each other (as discussed in Chapter 5). This is a unique feature of the application and it allows the students to easily relate the environment seen in the real world (through the representation of panoramas) to the associated information (e.g., PFD, P&ID, videos, 3D models).

A user study was carried out to explore the use of the VR application as a medium for a VFT. The user study aims to explore and compare students' attitudes towards a VFT (both the session and the VR application) and a PFT. Assessing the students' attitudes is important to see if the students found the session was enjoyable and engaging since engagement is important to help students learn (Garner, 2004). In addition, assessing the students' experience with the VFT also helps to generate valuable lessons learned that would be useful for the development and organisation of a similar VFT. It is also planned to see if the ability to present information in an integrated manner is seen by students as a particular benefit of a VFT. The results were published in Abdul Rahim et al. (2013).

The user study was conducted with CAPE students. The first section (Section 6.1) describes the organisation of a PFT in CAPE and highlights issues related to the PFT. The next section (Section 6.2) describes the user study, which includes the study procedures. This is followed by Sections 6.3 and Section 6.4 that, respectively, present the results and discussion. The limitations of the study and the lessons learned are discussed in Sections 6.5 and 6.6 respectively.

6.1 The organisation of physical field trips in CAPE

The PFT is a non-compulsory trip organised for 3rd Professional students. The objective of the PFT is to increase students' experience of process plants including exposure to equipment and the processes associated with it (C. Williamson, personal communication, September 17, 2010). Exposure to process plants is also thought to help students with their final year design project. The PFT could take up to 4 days and the sites visited during the PFT vary from year to year.

In Semester 2, 2011, 27 (of 55) 3rd Professional students joined the trip. It was held from 5 to 8 September 2011; the group was accompanied by a lecturer from CAPE. It was initially planned for 17 to 20 August 2011 (the first week of the mid-term break) but had to be postponed due to heavy snow in Christchurch. The postponement resulted in fewer students (of the initial 49) joining the field trip.

The trip covered five different site visits comprising a gold mine, brewery, medium density fibreboard (MDF) manufacturing facility, an aluminium smelter and a fertiliser manufacturing site. Some reading material related to the sites was given to the students before the trip. The thesis author joined the PFT to observe the activities that occurred during the trip.

6.1.1 Observations from the physical field trip

During the PFT, observations were made by taking notes and having informal conversations with some students. Except for the brewery, which was a commercial tour designed for tourists, the site visits during the trip had a similar structure. Students were first given an overview of the process plant and were then put into smaller groups for a tour; each group was led by one or more process engineers. The time spent at each site, including the presentation and tour, varied from 1 to 1.5 hours.

Some sites provided the students with reading material; at the gold mine, each student was given a Process Flow Diagram (PFD) and, at the aluminium smelter, they were given a booklet, including diagrams and pictures, describing the plant processes. At the MDF, the students were not given the PFD, but it was shown during the presentation.

Other than observing the processes, the trip also exposed students to sensory experiences such as the opportunity to touch and hold the steel balls and stones used in the gold mining process, smell the product in the brewing kettles and taste the beer at the brewery, touch different types of settlements at the fertiliser manufacturing site, experience the heat produced by the aluminium smelting process and gain hands-on experience with protective clothing worn as part of the health and safety requirements. The students were also exposed to raw materials such as gold-containing mud before the extraction process at the gold mine. At the aluminium smelter, the high magnetic fields involved were demonstrated to the students using a metal spoon placed on one piece of equipment.

Students exhibited different preferences during the tour. Some were keen to ask the guide questions and others preferred to walk around and look at things by themselves. For example, at the MDF plant, one student walking next to the guide actively asked questions while others at the back of the group were talking to each other. However, when the guide stopped to provide explanations, all students paid attention and some asked further questions. Most questions during the site tour were related to the processes and equipment involved. During the presentations, some students actively asked questions related to the company's profile, profits, the processes in the plant, and tools and equipment used in the plant, whereas others just listened.

The students' levels of enthusiasm reduced towards the end of the trip. This could be seen at the fertiliser manufacturing site (the last site) where they seemed to be less active and did not ask many questions during the tour. An informal conversation with one student confirmed this observation where s(he) commented that s(he) was tired due to the long tour and journey to that site, resulting in her (him) being unable to concentrate on the tour.

In some situations such as the malt room at the brewery where it was noisy from the sound of processing machines, it was difficult for students to hear the guides' explanations. In the aluminium smelter, students were required to wear respirators and earmuffs making it difficult to hear. Some students walked around by themselves probably because they could not hear the guide's explanation.

In some situations, the students were unable to get physically close to the equipment in the process plant for safety reasons, but at the fertiliser manufacturing site, the plant was shut down for 2 hours because the company was conducting training for operators. This provided an opportunity for a closer look at the equipment and made it easier to hear the guide's explanation.

Students clearly enjoyed the social aspects of the trip. They were often chatting, telling jokes and sometimes singing together on the bus. The bus stopped at a country pub and several other places for lunch enabling the students to socialise. The last night of the trip ended with a dinner and karaoke.

6.1.2 Summary

Observations from the PFT are as follows:

- Almost all tours were similar; the tour started with a briefing that covered an overview of the process involved at the site. The students were then divided into small groups for a tour. Some sites provided reading material for the students.
- Students had different preferences during the tour – some actively asked questions but others preferred to walk and observe everything themselves.
- Towards the end of the trip, the students exhibited a reduced level of enthusiasm for the sites visited.
- Students had hands-on exposure to sensory experiences at some process plants such as touching and smelling the products and equipment.
- Some limitations were encountered during the field trip such as inability to hear the guide's explanation, inability to be physically close to certain equipment for safety reasons, and tiredness due to the schedule and the length of the trip.

- Students enjoyed the social time throughout the trip as they spent a lot of time together.

6.2 The user study

This user study was approved by Lincoln University Human Ethics Committee.

6.2.1 Participants

Nineteen 3rd Professional students from CAPE volunteered to participate in this study. Ten had experience of a PFT but the remaining nine had not. The participants were split into four groups; two groups consisted of participants with PFT experience (five per group) and the other two groups consisted of participants without PFT experience (five and four per group). The reason for smaller groups (two groups of each condition – with and without the PFT experience) is that it is easier to control and more attention could be given to each participant (e.g., to ask them to voice their opinions if they have not done so).

6.2.2 The virtual field trip

The user study was conducted in groups like the organisation of the PFT. The session for each group was conducted in a room where participants were seated opposite a screen onto which the VR application was projected (Figure 6-1). The members of each group went through the VFT session and completed a questionnaire related to it. The session took around 35–45 minutes and was led by a content expert of the milk powder processing plant used in the VR application. The expert acted as the 'guide' for the VFT where he navigated the VR application and provided explanations of the processes to the participants. Like the PFT, this was an interactive session where both the participants and the guide discussed what they were seeing and exchanged questions and answers. Only the guide interacted with the VR application while the participants watched and listened to the explanation given by the guide.

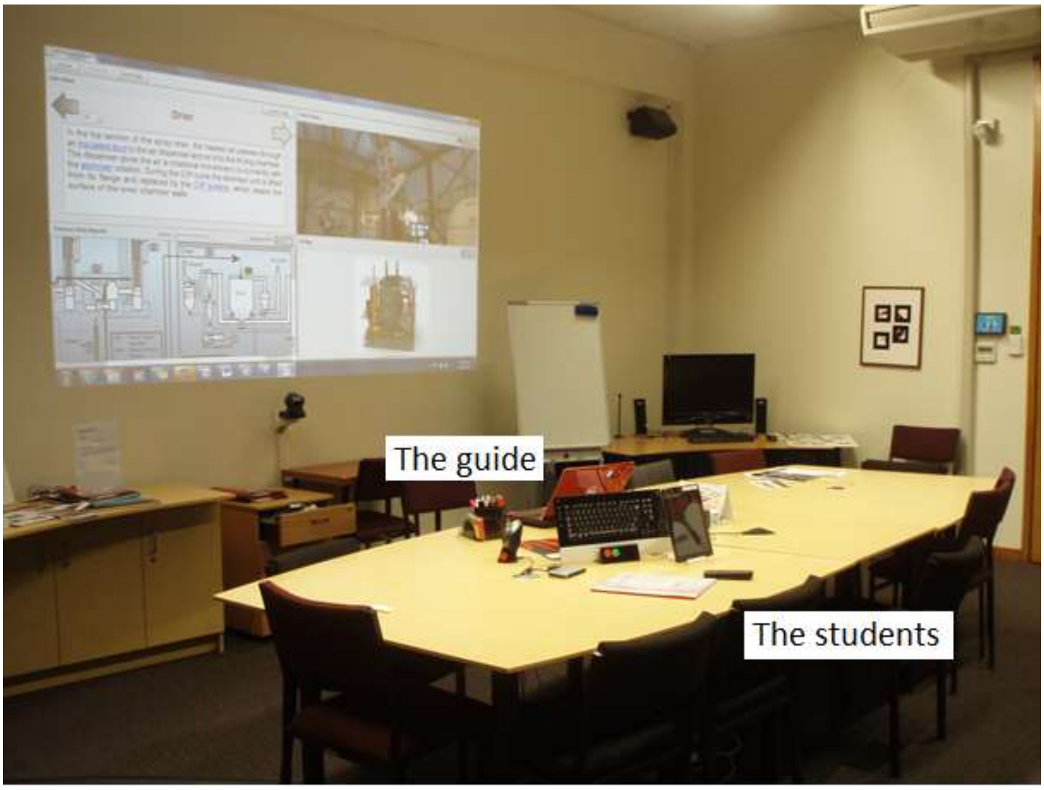


Figure 6-1 The arrangments for the virtual field trip session.

The guide began the session with an overview of milk powder processing described in the PFD. The participants were then taken on a virtual tour of the milk powder plant from tanker reception, to milk separation and pasteurisation, milk standardising, evaporator, and dryer and packing area. Throughout the tour, the guide provided explanations while interacting with the VR application. The guide essentially provided the same tour and explanation to all four groups, which included:

- The guide navigated the 360^o panoramas and related specific components to the corresponding item in the PFD.
- The guide showed the important equipment in the 360^o panoramas via the hotspots.
- At certain points of interest, the panels (‘Pano Viewer’, ‘Process Flow Diagram’ and ‘3D Map’) were maximised to allow the participants to have a better view of the components.

- The participants were shown detailed information including the videos (e.g., showing the processes that occurred inside a lobe pump) available in the pop-up window and the P&ID with the different process streams available.
- The guide interacted with the participants at certain points of interest, such as asking the participants to identify the centrifugal separators in the 360^{o} panoramas.

6.2.3 Questionnaire

The questionnaire used to assess the participants' attitudes towards physical and virtual field trips was adapted from the Students' Attitude Towards Scientific Field Trip survey. This questionnaire was chosen because its validity had been assessed, as discussed in Orion and Hofstein (1991). Although the questionnaire was designed for geological PFTs, Orion and Hofstein suggest that it could be used for other scientific disciplines and different field trip techniques.

The original questionnaire of Orion and Hofstein (1991) comprises statements related to the 'learning tool', 'individualised learning', 'social aspects', 'adventure aspects' and 'environmental aspects' of the PFT. In this present user study, statements under the 'environmental' and 'adventure' headings were removed because they were not relevant. Therefore, the questionnaire covered only 'learning tool', 'individualised learning' and 'social aspects', as shown in Appendices D.1 and D.2.

Orion and Hofstein (1991) grouped 'learning tool' and 'individualised learning' under 'learning aspect' and defined it as: *"This aspect examines the various components of the students' perception of a field trip as a learning event; e.g., the understanding of concepts using field trips, the field trip as an instructional tool to enhance the learning of concepts, and the field trip as a motivation for learning"* (Orion & Hofstein, 1991, p. 515) . The 'social aspects' are defined as *"Outdoor activities are usually perceived, at all ages, as social rather than educational events, particularly because the unusual constraints of the classroom are removed. Our observations show that, generally speaking, the social aspect of a field trip is at the expense of the learning aspect."* (Orion & Hofstein, 1991, p. 515) The existence of both social and learning aspects in PFTs was also noted in a study by Pace and Tesi (2004).

In addition to the modified questionnaire, there were open-ended questions that asked the participants their opinions about how their field trip experience contributed to their learning in engineering and the parts of the field trip that they enjoyed and did not enjoy.

The questionnaire was used to assess both the PFT and VFT. The questionnaire for the PFT is as described above. For the VFT, the questionnaire was similar to that used for the PFT but the term 'field trip' was changed to 'virtual field trip'. In addition, statements 20, 21 and 22 (as shown in Figure 6-5) were removed as they were not relevant to the VFT. An additional questionnaire asking the participants to state their level of agreement on a Likert-scale, with statements related to the VR application (adapted from Spicer and Stratford (2001)) was included. In addition, questions asking for suggestions to improve the VFT were also included.

The questionnaire by Orion and Hofstein (1991) has been assesed for its validity and reliability and therefore the present study used a 4 point Likert scale as in the original questionnaire. The same applies to the questionnaire by Spicer and Stratford (2001), where a 7 point Likert scale was used as in the original questionnaire.

For easy reference, the questionnaire used to assess the PFT is called Questionnaire-PFT and the questionnaire for VFT is called Questionnaire-VFT. These questionnaires are shown in Appendices D.1 and D.2.

6.2.4 Group interviews

In addition to the questionnaires, the participants were interviewed in a group to ask their opinions about the VFT. The participants who attended the PFT were also asked about their experiences and opinions about the PFT. The group interview was suggested by Kolivras, Luebbering and Resler (2012) as a way to obtain a detailed understanding of the reasons for any differences between the PFT and the VFT. Notes on the answers given by the participants during the group interview were written on A3 papers posted on the wall opposite the group. This was to allow the participants to look at the answers that had been made and, if they wanted to add more, they could voice the points. The questions asked during this session are in semi-structured interview format, as shown in Appendix D.3.

6.2.5 Procedure

The procedure for the participants in each group was:

i. Participants signed a consent form after reading written information about the objectives of the study (Appendix D.4).
ii. Participants attended the VFT session.
iii. Participants completed the Questionnaire-VFT.
iv. Participants were interviewed as a group and asked their opinions of the VFT.

In addition to the above procedure, participants who attended the PFT completed the Questionnaire-PFT and then were interviewed as a group where they were asked about their opinions of the PFT. This took place after they have signed the consent form.

6.3 Results

This section presents the results of the questionnaire, observations, and the users' responses in the group interviews and to the open-ended questions. A summary of the results is given at the end of the section.

6.3.1 Participants' attitudes towards physical and virtual field trips

For this analysis, the data were combined based on whether the participant attended the PFT:

- Group-PV: participants who attended both the PFT and VFT.
- Group-V: participants who attended only the VFT.

Both groups answered the questionnaire related to the VFT (Questionnaire-VFT) and only Group–PV (who attended both the PFT and the VFT) completed the questionnaire related to the PFT (Questionnaire-PFT), on a scale of 1 = Strongly Disagree to 4 = Strongly Agree. For reporting purposes, the statements in the questionnaire are displayed according to their respective categories and therefore differ from the sequence of the statements from the questionnaires provided in Appendix D.1 and D.2. Figure 6-2 shows statement 1 to 12 (learning tool), Figure 6-3 shows statement 13 to 14 (individualised learning), Figure 6-4 shows statement 15 to 19 (social aspect) and Figure 6-5 shows statement 20 to 22, which are only included in Questionnaire-PFT.

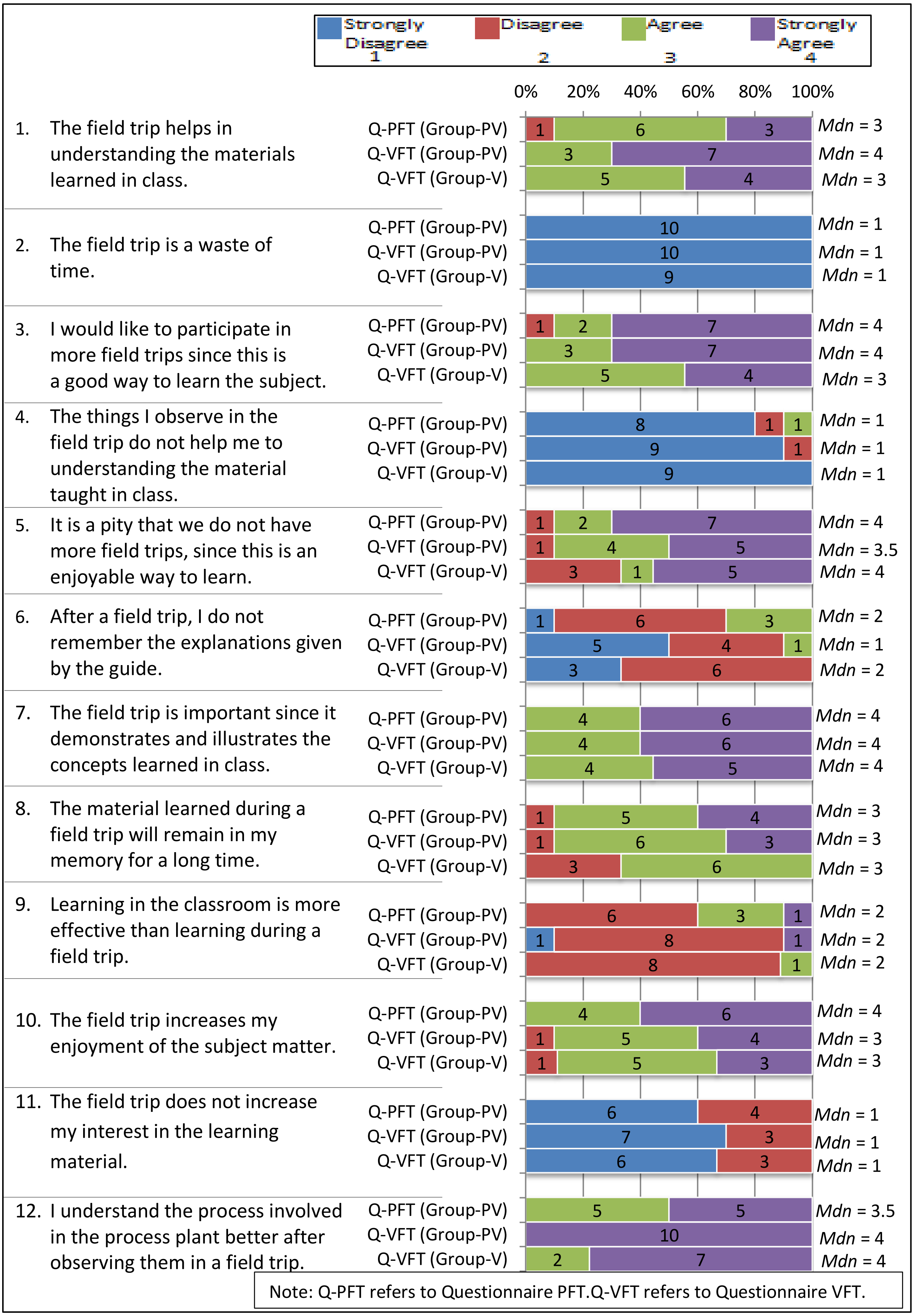


Figure 6-2 Participants' level of agreement with statements 1 to 12 in the questionnaire. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

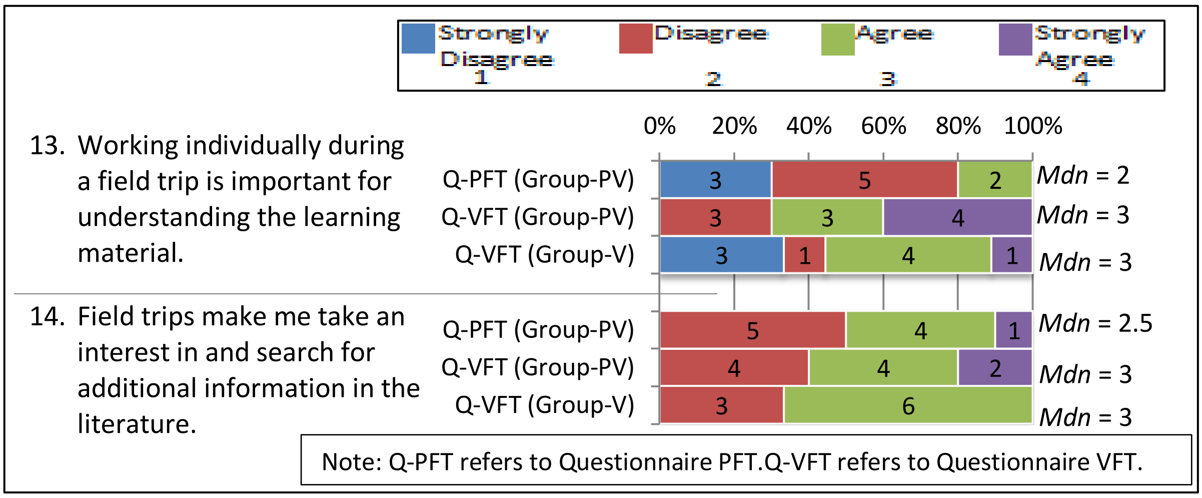


Figure 6-3 Participants' level of agreement with statements 13 and 14 in the questionnaire. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

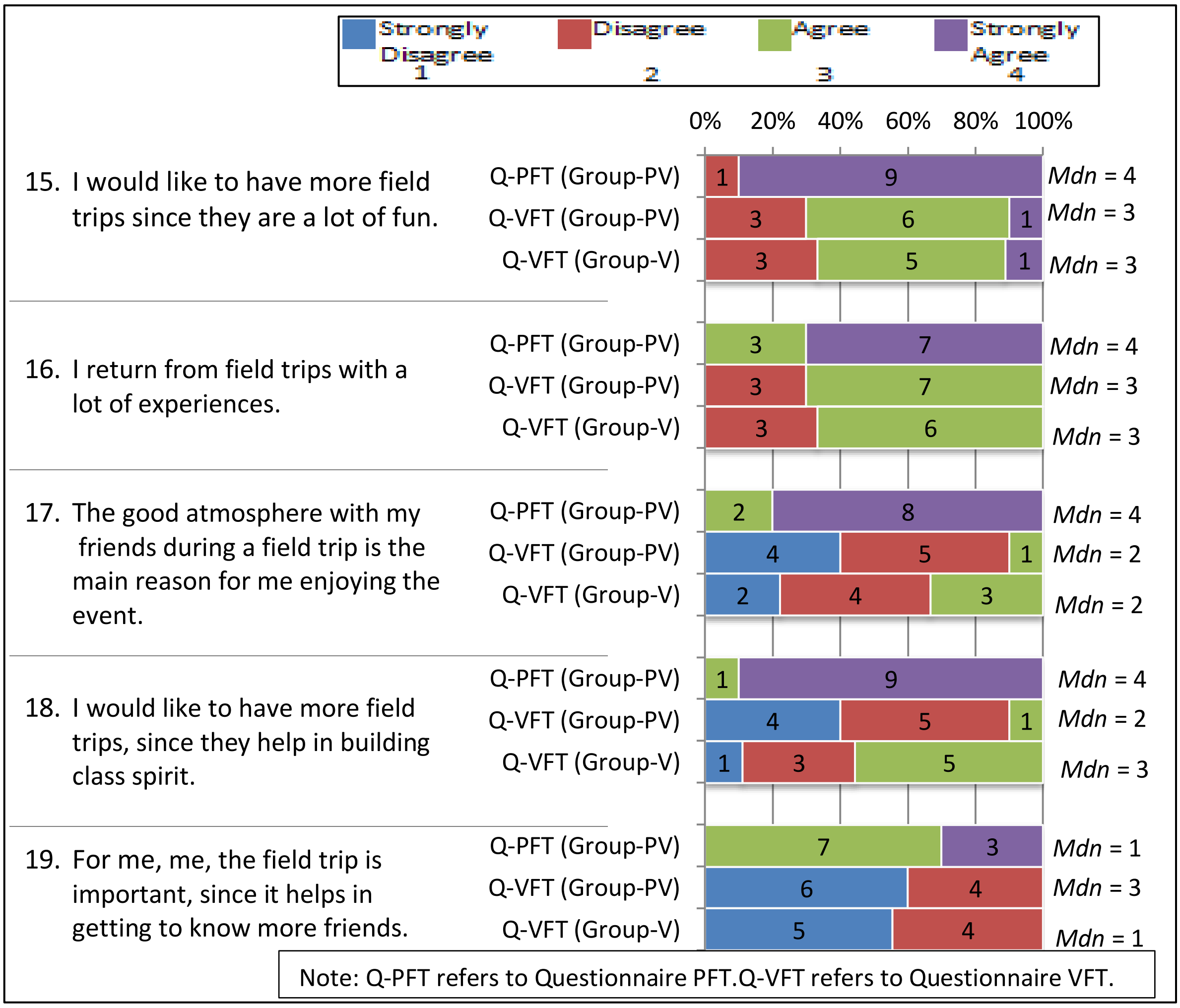


Figure 6-4 Participants' level of agreement with statements 15 to 19 in the questionnaire. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

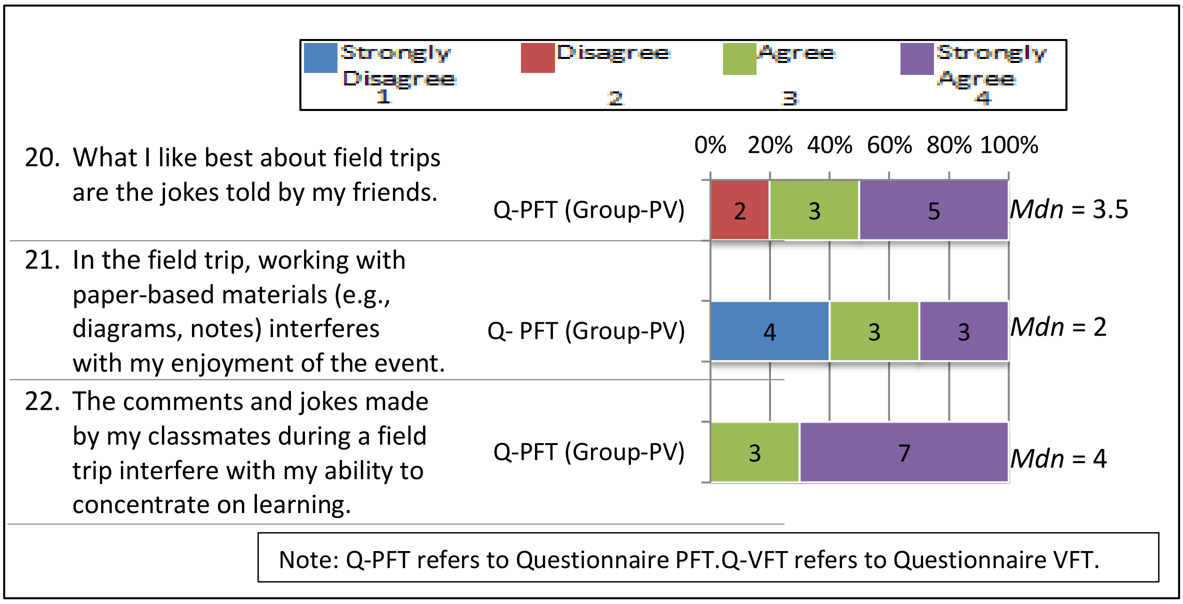


Figure 6-5 Participants' level of agreement with statements 20 to 22 in the questionnaire. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

For further analysis, the statements in the questionnaire were grouped into three categories: 'learning tool' (statements 1 to 12), 'individualised learning' (statements 13 and 14), and 'social aspect' (statements 15 to 19), as they appear in Orion and Hofstein (1991). Statements 2, 4, 6, 9 and 11 are reverse scored because they are reversed in meaning from the other statements. The individual responses to the statements within each category were averaged to give a single value for each category for each participant. In order to allow direct comparison between the PFT and VFT, statements 20, 21 and 22 of Questionnaire-PFT were removed from the analysis because they were not available in Questionnaire-VFT. Figure 6-6 shows the median for each category of statement.

The responses received from both groups (Group-PV and Group-V) for statements related to 'learning tool' about PFT and VFT were inclined towards agreement (*Mdn* ≥ 3) suggesting that the participants agreed that exposure to both the PFT and VFT was useful as a learning tool. The two groups had different views about 'individualised learning' (statements 13 and 14). Group-PV's responses for 'individualised learning' in PFT inclined towards disagreement (*Mdn* ≤ 2) and for VFT, their responses are inclined agreement (*Mdn* ≥ 3). For Group-V, their responses are between disagreement and agreement (*Mdn* = 2.5). Not surprisingly, participants felt that the 'social aspect' was better in the PFT (*Mdn* ≥ 3) than the VFT.

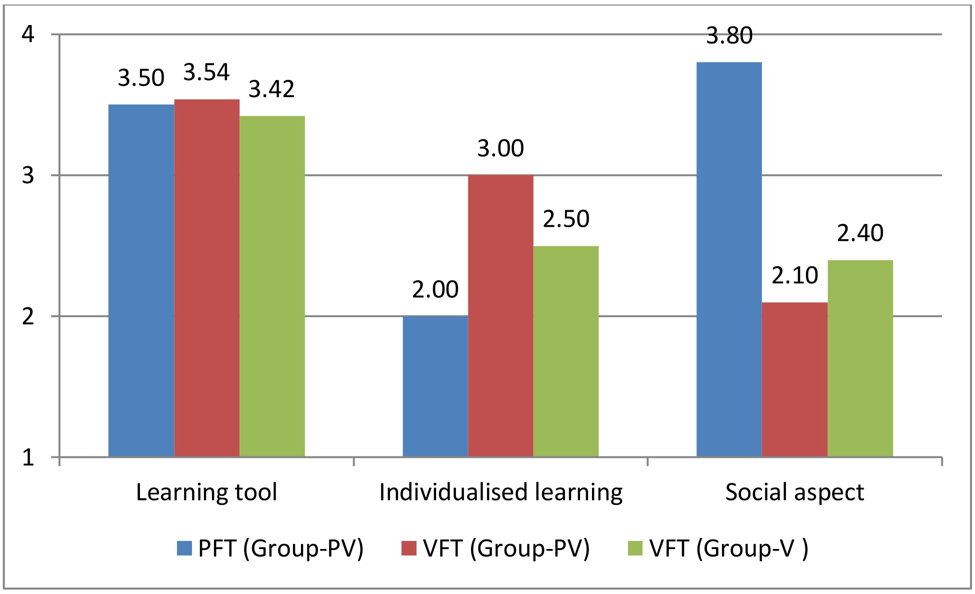


Figure 6-6 The median for each category based on the level of agreement stated by the participants.

Further analysis was performed on the participants' attitudes to the PFT and VFT of each group (Group-PV and Group-V), as shown in Figure 6-7.

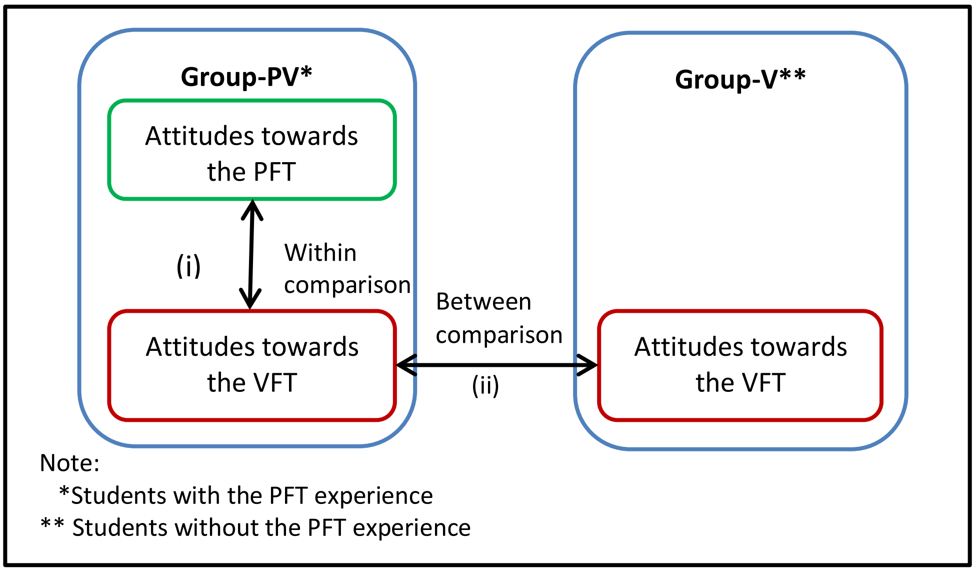


Figure 6-7 A comparison of students' attitudes towards the PFT and VFT in the two groups (Group-PV and Group-V).

Within group comparison. A comparison of attitudes towards VFT and PFT for participants with PFT experience (Group-PV). Due to the small sample size and non-parametric data, a Wilcoxon Signed-rank test was used. The results show that the participants' agreement with the statements related to the 'social aspect' was lower in the VFT (*Mdn* = 2.10) than the PFT (*Mdn* = 3.80) for Group-PV, *Z* = -2.840, *p* = .005. No significant differences were found in the 'learning tool', *Z* = -.831, *p* = .406, (VFT (*Mdn* = 3.54) and PFT (*Mdn* = 3.5)) and the 'individualised learning' aspects, *Z* = -2.388, *p* = .017, (VFT (*Mdn* = 3) and PFT (*Mdn* = 2)).

Between group comparison. A comparison of attitudes towards VFT for participants with PFT experience (Group-PV) and without PFT experience (Group-V). This comparison was made to assess if exposure to a PFT made any difference to the participants' attitudes towards the VFT. A Mann-Whitney U Test found no significant difference in the participants' attitudes towards 'learning tool', *U* = 32.0, *p* = .315 (Group-V (*Mdn* = 3.42) and Group-PV (*Mdn* = 3.54)), 'individualised learning', *U* = 25.5, *p* = .113 (Group-V (*Mdn* = 2.5) and Group-PV (*Mdn* = 3)), and 'social aspect', *U* = 26.5, *p* = .133 (Group-V (*Mdn* = 2.4) and Group-PV (*Mdn* = 2.1)) in the VFT for both groups.

To reduce type 1 error risk (the probability of rejecting null hypothesis when in fact it was true), Bonferroni-adjusted alpha levels[19] of .0167 per test (.05/3) were used.

6.3.2 Questionnaires

Figure 6-8 shows the participants' agreement with the statements related to the VR application (1= Strongly Disagree and 5 = Strongly Agree) by both groups (Group-PV and Group-V). Except for statement 5, the medians for all statements are inclined towards agreement, indicating that participants have positive attitudes towards the VR application. An interesting result was found with the participants' agreement with statement 5 (*The VR application could be used in place of a physical field trip*); participants who attended the PFT were more inclined towards disagreement (*Mdn* = 2) than participants who did not attend the PFT (*Mdn* = 4). The difference is not significant as indicated by Mann-Whitney U test (*U* = 27, *p* = .156).

[19] A method used to address the problem of multiple comparisons.

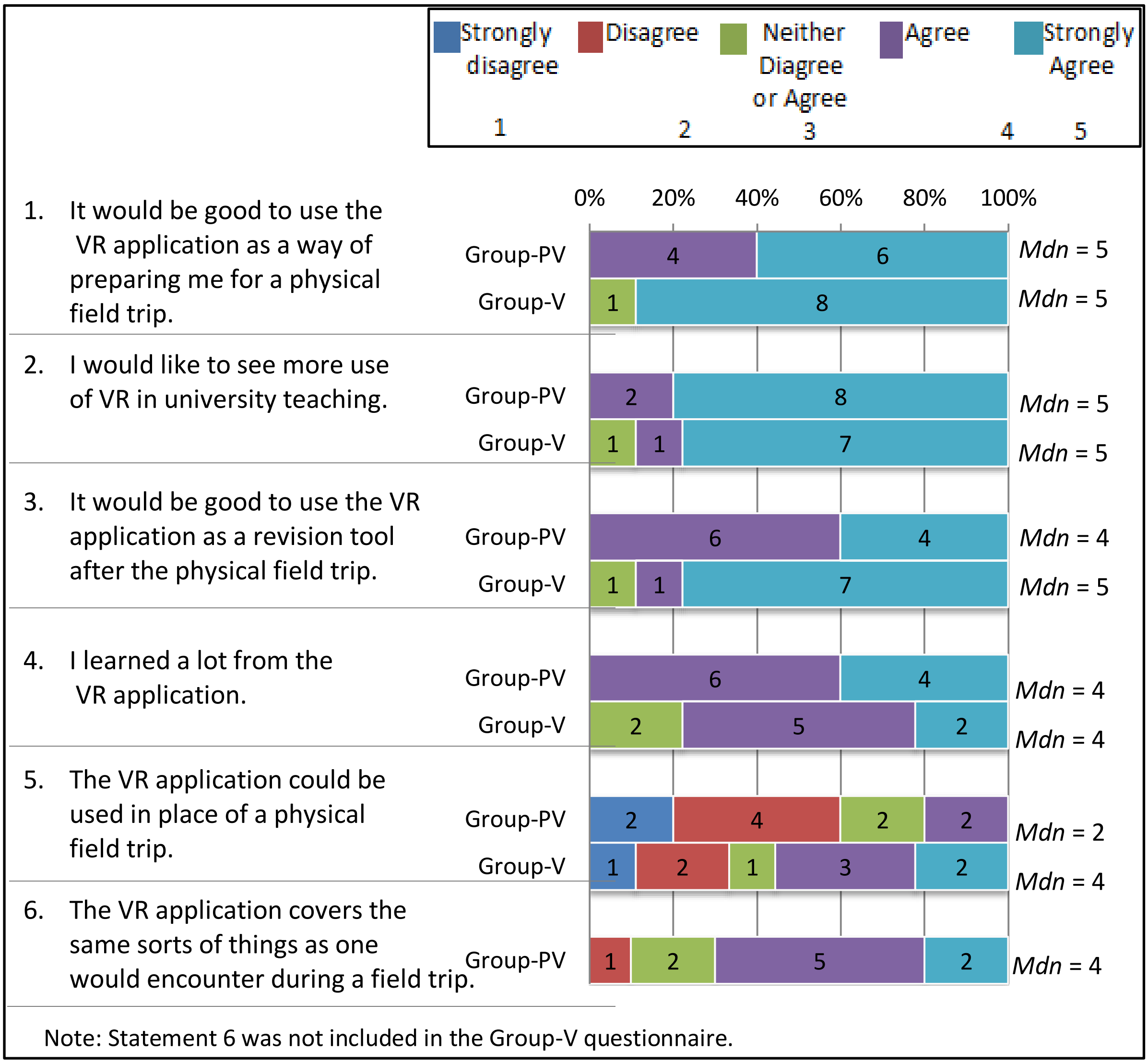


Figure 6-8 Participants' level of agreement with the statements about the VR application. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

6.3.3 Open-ended questions and group interviews

The written responses to the open-ended questions and notes taken by the author during group interviews were analysed and classified based on the common remarks made by the participants. The responses related to the PFT are based on the responses received from 10 participants (Group-PV) and the responses related to the VFT are based on all 19 participants (both Group-PV and Group-V).

The categories identified by Orion & Hofstein (1991) (learning and social aspects), were used as the basis of the classification. Other aspects also emerged as results of the data analysis. Data were grouped into participants' opinions on the contribution of both the PFT and VFT, their enjoyment in the VFT and PFT, suggestions for improving the VFT and whether they thought the VFT could be used as a replacement for the PFT.

6.3.3.1 The contribution of the physical and virtual field trips

The participants' responses revealed three broad themes:

- **Learning aspect:** The definition for the learning aspect was based on Orion and Hofstein (1991) as described in Section 6.2.3.
- **Career aspect:** This refers to the exposure to a variety of plants with different working environments and different processes within each plant.
- **People aspect:** This is related to the experience of people working in the plant such as their job scope and daily routine.

From these three aspects, only the learning aspect was experienced in both the PFT and VFT, and some aspects of learning differed between them. The career and people aspects were experienced only in the PFT.

Table 18 shows the themes and the subthemes derived from the analysis, including examples of responses from the participants.

In addition to the above, the responses received from the participants regarding the VFT also revealed that the features and appearance of the VR application contributed to learning aspects of the VFT. Participants stated that the information, including the links between the panels in the VR application, the hotspots, videos and animations helped them to better understand the processes occurring in the plant shown during the VFT (see Table 19).

Table 18 The different contributions of the PFT and the VFT.

THEME	SUB-THEME	Response example	
		PFT	VFT
Learning aspect	Exposure to the actual process of the material learned in class.	*Seeing the operations that we learn about in class, working in an industrial environment.*(P1) *It has given a practical/real world look into what we learn in the classroom.*(P2)	*Helps to visualise things we learned about in class.* (P7) *Probably easier than reading a book, however, it cannot completely replace book work, or actually seeing something. It is very good for visualisation of a process and understanding the overall picture of a process.* (P10)
	Exposure to a different range of industries in NZ and understand the related processes.	*It is rewarding to see the process in its entirety, where you can see the raw materials coming in and the final products coming out, and to learn how efficient the process is compared with other places that produce the same product, or how the plant does things differently to their competition.*(P9)	-
	Scale and size.	*It gives a good concept of scale.*(P7)	*It is really a good way of getting an idea of the scale of a process without having to visit a plant.*(P1X)
	Layout and position of the plant and equipment.	-	*Get to know the layout of the plant (e.g., location of control room, spacing between unit operations). This will certainly help in our design project course.* (P5X)
	Understanding the process.	*Seeing actual plants in operations helped me learn the daily operations of things that occur at a process plant. In addition, it helped me understand some of the concepts we had learnt in class and how they relate to real life situations/plants.* (P3)	*The virtual field trip helps to understand the processes involved. It allows for a more in-depth look at the equipment & processes than a real field trip.* (P5)
	Health and safety.	*It helps understanding regarding safety and hazards.* (P7)	-
	Learning at own pace, a lot of information in a short time.	-	*Allows me to go back to things if I can remember what was going on. If I get confused I can just go back a step.* (P8)
Career aspect	-	*It gives an indication of what areas of process engineering I want to get into.* (P2)	-
People aspect	-	*It is good hearing the experiences of the engineers who are guides throughout the trips and what they do on a day to day basis.* (P9) *The trip gives a "feel" of the plant. (By feel, I mean people's attitude at the plant, how workers interact, whether or not people enjoy working at the plant, etc.).* (P10)	-

Note: X refers to the participants without the PFT experience (e.g., P1X, P5X).

Table 19 The features of the VR application that assist in understanding the VFT.

THEME	SUB-THEME	Response example
VR application	Links between the 360˚ panoramas and additional information (e.g., diagrams, 3D model,).	*Being able to see the physical aspects, theoretical aspects and plan overviews in the same 'trip' is very beneficial.* (P10X) *Follow the process nicely, simple to understand. Great to see the actual plant alongside the PFD, aids in understanding the process.* (P8)
	Easy identification of the equipment (hotspots).	*It was good that the piece of equipment that had been talked about was highlighted in green, so you could easily identify what you were meant to be looking at.* (P9)
	Videos.	*The videos which show how the equipment works (pumps, hammers, powder packing) are really helpful. Seeing the moving parts gives a better understanding of how it works.* (P1X)
Guide	Explanation given by the guide.	*Good accompanying guides + written notes + explanation helps in understanding process engineering.* (P4X)

The details of Tables 18 and 19 are further discussed.

Learning aspect - Exposure to the actual process of the material learned in class. Participants felt both the PFT and VFT helped them to relate the concepts and theories learned in class to the actual processes in a plant. They also added that the VFT provides a more detailed explanation than the PFT. In the VFT, participants found the interface of the VR application, including the explanation by the guide, helped them to visualise and understand the processes learned in the class.

Learning aspect - Scale and size. Participants found that both the PFT and VFT were useful in showing the size and scale of the equipment used in the plant that were difficult to visualise by looking at pictures. In the VFT, this was gained via the 3D map with the help of the 'human figure' on the 3D map. One participant stated that the 3D map, which provides the layout of the plant including the position and spacing of the pieces of equipment, was helpful for their final year design project.

Learning aspect - Understanding the process. Participants felt that both the PFT and VFT provided them with an understanding of processes in the plant. The participants in the VFT group stated that this was gained via the different formats of information presented in the VR application and the guide's explanation. Although this is limited because the VFT covers only one type of process plant, the participants attending the PFT appreciated the exposure they had to different types of sites that allowed them to experience the different processes at each site (i.e., MDF, the fertiliser plant). One participant also stated that seeing actual problems at the plant was beneficial, *"Seeing how companies cope with different failures and changes was good to see as well. At the gold mine, they had water running over the ground because they could not stop the process to change/fix it. Gaining knowledge that things cannot always be replaced straight away was a very good thing to learn."* (P6), In addition, participants stated that the information they gained from the engineers was different from the lecturers because the engineers are more involved in solving real problems and not just focusing on the theoretical part.

Learning aspect - Health and safety issues. This was identified as a learning contribution only by participants attending the PFT because they had 'hands-on' experience with safety clothing. In the VFT, no 'hands-on' experience was available and the participants were only shown the red line room and the clothing needed before entering the milk processing plant.

Learning aspect - Learning at own pace, a lot of information in a short time. One participant stated that the VFT provided him with a lot of information in a short time and another three added that the VFT is useful as they could learn at their own pace. Although they were not using the VR application by themselves, they still had the opportunity to do so via the guide, i.e., one participant asked the guide to replay the 'pneumatic hammer' video as s(he) could not clearly see it at first.

People aspect. This is related to the experience the participants on the PFT gained from the people working in the plant such as their job scope and daily routine. In the PFT group, four participants felt exposure to people working in the plant helped them to gain knowledge related to the workers' experiences, *"It is good hearing the experiences of the engineers who are guides throughout the trips and what they do on a day to day basis."* (P9).

Career aspect. This refers to the exposure to a variety of plants with different working environments and different processes. Two participants of the PFT group viewed the exposure they gained by visiting various plants as an opportunity for career planning, i.e., whether they would like to work in this type of environment.

6.3.3.2 The enjoyment of the PFT and VFT

The participants' enjoyment of the PFT and VFT are described as below.

Physical field trip: When asked about things they enjoyed in the PFT, all 10 participants indicated that they enjoyed the 'learning aspect' which includes the exposure they had to the respective industries, sampling beers, seeing demonstrations and exposure to things learned in class. Two participants also enjoyed seeing how people do their job and listening to their work experiences (people aspect).

The 'social aspects' were also a part of the PFT that the participants enjoyed, as stated by 8 of the 10 participants (see Section 6.2.3 for the definition of 'social aspect'.) The participants stated that they enjoyed the evening activities after the site visits and dinner and karaoke on the final night, *"The socialising time we had at the Invercargill backpackers and the BYO + Karaoke and town in Dunedin with the field trip group."* (P3)

Four participants said they did not enjoy the dusty environment at the fertiliser manufacturing plant, being unable to listen to the guide's explanation at some sites and a boring talk at the MFD. They also stated items related to the schedule of the PFT; such as two visits a day, which led to tiredness, early morning trips and the length of the trip (some would have liked to visit more sites).

Mixed responses were received about the long bus ride. Some participants stated that they did not like the long bus ride but some added that they enjoyed the time spent together on the bus. One participant stated, *"Very long travel times but this brought the group together much more so not really a part I didn't enjoy."* (P2)

Virtual field trip. The responses received regarding the things the participants' enjoyed in the VFT related to the VFT session, the learning aspect, the self-engagement, interest and the VR application. Most participants enjoyed the VFT session because they found it interesting and engaging, they were exposed to the scale and size, and having a guide throughout the session so they could ask questions.

Eight responses related to the VR application; five participants enjoyed having an in-depth and interactive PFD and P&ID and the links between the information. Another three enjoyed the 360^{o} panoramas because they helped show the plant and the positions of the equipment.

When asked what they did not enjoy, 6 of the 19 participants stated "*Nothing"* and one stressed that it should not be used to replace a PFT, "*I enjoyed everything, however, want to stress that the VR should be a supplement to books and real field trips but not replace them completely."* (P10) One response related to the lack of social activities and two to the lack of people aspect, *"No people. How many operators? What are their roles in the plant?"* (P3X) They suggested having accompanying commentaries by some of the operators. One participant commented about the lack of physical interaction such as being able to physically walk in the plant.

Six responses related to the VFT session itself such as the inability to use the VR application themselves and that the VFT session was a bit fast and they wished to have more time to read the text information. Another one commented that the guide's explanations were good but could have been better rehearsed and one stated that too much information was given at once during the VFT session.

Other responses related to the VR application were about the lack of details including operating details (e.g., *"This is a MVR operating at … it processes xx tonne/hour of milk."* (P3X)) and the lack of audio and video for the actual operations. In addition, one participant stated the lack of size comparison in the 360 panoramas, e.g., no 'human figure' in the panoramas, although the 'human figure' is available in the 3D model.

6.3.3.3 Suggestions to improve the VFT experiences

One suggestion related to learning at their own pace either by using the VR application themselves, having a longer session with the VFT so that they had more time to read the text information in the application and also more time for a Question and Answer session or having an individual session with the guide so that they could ask more questions. Another suggestion related to the VFT session was to have exposure to the products at each cycle of the process whether through the actual materials or photos.

Suggestions related to improving the VR application such as having interactive panoramas where additional information is displayed when a point of interest is clicked in the panorama. Some other suggestions for improving the application were to include the operating details and commentaries by some of the operators who are experienced in the PFT. Examples of responses relating to the above suggestions are shown in Table 20.

Table 20 Examples of responses related to suggestions received from participants to improve the VFT.

Theme	Response example
Learning at their own pace	*I would like the time to go through and explore the software myself. I think all that is needed for VR is a very brief introduction to how the software is used and then it is ok for the students to use by itself.* (P10)
Exposure to the product at each cycle of process	*Even bringing along some samples of the raw materials added and final product, or products at each stage of the cycle, or maybe just a picture, just to get an idea of how each unit operation works on the product.* (P9)
Improvement of the VR application	*Be able to do a "fly-by" of the plant where you can just look through the whole plant, click on something and it will tell you more about it.* (P7) *It will be really great if there are accompanying commentaries by some of the operators. Something like a short documentary.* (P4X) *Operability notes - how is it controlled? For example, 'Track' a volume of milk through the process from reception to powder bagging - live data at each processing step regarding what occurred during the step, e.g., heated to X'C (x degree Celsius).* (P3X)

6.3.3.4 Physical or virtual field trip preferences

During the group interview, the participants were asked if they would choose the PFT or VFT if both were made available. All stated that they would choose the PFT but stated that the VFT would be useful as a preparation before and revision tool after the PFT. They added that the VFT should complement the PFT instead of replacing it. One suggested using it as a preparation tool such as having the VR application of each site they are going to visit during the PFT so that they can get the overview of the plant beforehand.

The participants agreed that the VFT is more informative than the PFT because it provides detailed information including aspects that are not available at the physical plant (e.g., the video inside the pipe), and the participants could clearly hear the guide's explanation. One participant suggested that the VR application could also be used as lecture notes or during lectures as s(he) felt engaged throughout the session.

Some participants added that the PFT or VFT really depends on the participant's objectives. If the participants want to learn something in detail, then the VFT is better because it is not noisy and has additional information such as the videos. The VFT, however, lacks experience with friends and the exposure to the people working at the plant (e.g., number of operators) as in the PFT. In a PFT, participants also had hands-on experiences such as the security procedures, wearing safety clothes, and physical exposure to the size and scale of the plant. The PFT can also give access to a wider range of plants, although this may not be the case if VR applications of various types of plants were available.

6.3.4 Observations

It was observed during the VFT session that some participants were actively asking questions of the guide. The questions related to the components and equipment in the plant, the related processes and the end product (the milk powder). Except for two participants who were seen talking to each other occasionally during the session, all participants seemed focused during the session.

6.3.5 Results summary

The summarised results of the study are:

- No significant differences were found between the 'learning aspect' and 'individualised learning' of the PFT and VFT. The only significant difference found was the 'social aspect' where it was rated higher in the PFT than in the VFT.
- Different types of questions were asked by the students during the PFT and VFT. In the PFT, students asked questions related to the company profile, in addition to the process related question. In the VFT, only process related questions were asked.
- The participants had positive attitudes towards the VR application and would like to see a similar approach in more university teaching.
- The responses as to whether the VR application could be used to replace a PFT varied; participants without PFT experience were inclined towards agreement but participants with PFT experience were inclined towards disagreement, although during the group interviews all stated that they would opt for a PFT instead of the VFT but added that the VFT is useful as a complement (preparation and revision tool).
- Participants added that the use of a PFT and a VFT depends on the participants' objectives, and more detailed information for learning was available from the VFT

than the PFT. However, the PFT provides physical exposure to the processes and hands-on experience in the plant.

- During the PFT, the participants enjoy the exposure they had at the different process plants and the social activities. However, they did not enjoy the tight schedule (e.g., two plant visits a day, which lead to tiredness), and also the dusty environment and being unable to hear the guide's explanations at certain sites.
- Both the PFT and VFT helped the participants to understand the steps occurring in the process and the scale and size of the pieces of equipment. The aspects missing from the VFT were the social activities, the existence of workers and the wider range of process plants (which would help them decide their career path).
- Participants found the VFT session was engaging and the explanations given by the guide together with information in the VR application were useful in helping them to understand the process. They also suggested the application could be used during lectures, e.g., as lecture notes.
- They also felt the P&ID and the link between the PFD and the 360 panoramas provided them with an in-depth view of the process. However, the VR application could have more content and features added such as operating details, size comparison in the 360^{o} panoramas, additional 3D images, videos and audios.
- Suggestions related to the VFT session included being able to learn at their own pace, improvements for the VR application and being shown the physical raw materials or images of them at each process cycle step.

6.4 Discussion

The aim of this study was to explore and compare students' attitudes towards a VFT and a PFT. The VR application used as the medium for the VFT contains integrated information and is not a direct replication of the PFT experience. Although the integrated information was not directly assessed, the present user study was used to see how this feature was perceived by the students in the study.

Overall, the results of the questionnaire do not demonstrate a significant difference between the students' attitudes towards the learning aspects of the VFT and PFT. However, there was a significant difference between the social aspect of the VFT and PFT where the attitudes towards the social aspect were higher for the PFT than the VFT. Further discussion is divided into:

- Students' preferences for the PFT and VFT.
- Opinions on the VFT.

6.4.1 Preferences for the PFT and VFT

All participants (during the group interview) stated their preference was to go on a PFT rather than the VFT and that a VFT could not be used as a replacement for a PFT. The questionnaire results, however, reveal that participants without PFT experience agreed that the VFT could be used as a replacement for the PFT, which is the opposite opinion to participants with PFT experience. The agreement of using a VFT as a replacement for a PFT is not consistent with a study by Spicer and Stratford (2001) where, in that study, students without PFT experience disagreed that the VFT could be used as a replacement for the PFT. Their perceptions were strengthened after they attended the PFT. This difference may be due to the different study design; where the VFT in Spicer and Stratford's (2001) study refers to students navigating the VFT application on their own without the presence of a guide; which causes some students to become 'lost' in the visited site of the VFT. In the present study, no participants were 'lost' during the VFT because only the guide interacted with the VR application.

Based on the above, if a PFT is made available, then participants would opt for the PFT rather than the VFT, which is consistent with the findings of Harrington (2009). However, if participants did not have the opportunity to attend a PFT, then a VFT may be an adequate replacement (Poland et al., 2003; Schofield, 2010), rather than not attending anything at all.

In addition, most participants agreed that the VR application could be used as a preparation and revision tool for the PFT, and as learning material in class in addition to lecture notes. Preparation for field trips is seen as an essential practice because field trip learning increased when proper preparation occurred before the trip (Falk, 1983; Orion &

Hofstein, 1994). Using the application as an additional learning resource agrees with findings by Krygier et al. (1997).

Several factors contributing to the differences in preference for PFT or the VFT were identified, and are now discussed.

Physical experiences in the PFT. The physical experiences (e.g., wearing safety clothes, touching the raw materials) are experiences that cannot be easily replicated in a VFT. These aspects that involve senses such as touch and smell were also identified in some other studies as reasons why students chose a PFT over a VFT (e.g., Arrowsmith et al., 2005; Lewis, 2008).

The experiences the participants had with the raw materials are reflected in the suggestion made for improving the VFT where one participant suggested having physical raw materials, or at least images of them, to be shown to them at each process cycle step. This suggestion, however, may also be due to the milk powder production process plant represented in the VFT, where no production materials could be seen in the process plant even if they visit it physically. This suggestion implies that exposure to the physical materials is considered important by the participants. In addition, suggestions about including more audio and video regarding the actual operations were made by the participants.

Apart from dealing with the physical experience, the participants also appreciated the exposure they had regarding the daily activities at the plant, which are not taught in class. Seeing failures, e.g., looking at how workers cope with a failure such as running water at the gold mine, was something that is not replicated in the VFT because the VFT shows a 'perfect' processing plant. A VFT is misleading when it demonstrates a non-problematic process or environment (Poland et al., 2003). A balance between a successful process and process failures in a field trip is useful to maximise learning (Chanson, 2003). Experiencing an unexpected situation also promoted higher learning in students (Spicer & Stratford, 2001).

Learning aspects. All participants agreed that both the PFT and VFT assisted their learning. The questionnaire responses revealed no significant difference between the participants' perceptions of the PFT and VFT as learning resources. The participants found the VFT provided them with detailed information and they gained a lot of information in a short time, which is not possible with a PFT.

The learning aspects differ between the PFT and VFT. Participants stated that both PFT and VFT provided them with exposure to the process of the learning material learned in class, the scale and size, and an understanding of the process. In addition, the PFT provided exposure to health and safety procedures and to a range of industries in New Zealand, although the latter advantage may not apply if the VFT were based on various process plants.

The participants' statements about being able to perceive the scale and size of the equipment in the plant, in the VFT and PFT, did not align with Lewis (2008), who states that even enlarged panoramas could not give a sense of the real size of big phenomena such as volcanos and mountains. The difference may be due to the difference in the media used; Lewis (2008) used only panoramas without any additional information. The present study used a 3D model of the process plant, with a 'human figure' as an indicator of the scale and size, which therefore provides participants with scale and size information.

Interestingly, though both the PFT and VFT assisted the participants in understanding the scale and size of the pieces of equipment in the process plant, knowledge of the layout and the position of the equipment is obtained only via the VFT. This is due to the ability to have an exocentric view of the plant layout through the 3D model. In the PFT, being in the physical plant did not help to visualise the plant layout due to the large size of the plant and the inability to visit every area of the plant because of health and safety restrictions. In addition, this may also be due to not being given a map that shows a representation of the plant.

The participants stated that the VFT provided more detailed information than the PFT. This opinion differs from Stumpf, Douglass and Dorn's study (2008) which reports that VFT is useful for simple concepts or in assisting an introductory course. The same was also found by Harrington (2009), where the PFT was shown to be superior to the VFT for learning required in connecting complex concepts, and both the PFT and VFT were similar when the learning was less complex. Since the present study did not measure the learning effectiveness via assessment, it is difficult to compare the finding from the present study with those in the literature. Therefore, the author concludes that participants felt the VFT provided more in-depth learning concepts, because they were not exposed to the restrictions they had on the PFT such as not being able to listen to the guide's explanation and being tired due to the long trip and tight schedule. In addition, the perception that the 'VFT provides more detailed information than the PFT' is due to reasons stated by them relating to the VFT session and the VR application itself; the VFT allows them to learn at their own pace (by asking the guide to go back and forth at certain place (s)he wishes to have a look at), having links that integrate the information in the VR application, easy identification of equipment via the hotspots, videos and the explanation by the guide (see Table 18 and 19, Section 6.3.3.1).

The detailed learning in the VFT could also be due to the information integration features of the VR application, where different sources of information are linked. This provides participants with a comprehensive knowledge of the milk processing (e.g., from the overview of the milk processing via the PFD to the detailed process that occurred inside a lobe pump via the video). The integration features, for example the links between the PFD and the panoramas are something that could not be replicated in a PFT. Even if the participants were given a PFD of the visited process plant, the participants need to make an effort to link the information derived from the PFT to the respective processes or components occurring in the visited plant. In addition, looking into the process that occurred inside a lobe pump is something that could not be experienced in a PFT. This integrated information feature, although not directly assessed in this study, was positively perceived by the participants. The participants stated that they felt the VFT helped them with their learning through relating the concepts and theories learned in class to the process plant portrayed in the VR application.

Although the VFT provided more detailed information, the information gained from the engineers (the guide) in the process plant in the PFT differs from the lecturer because the engineers are more involved in solving real problems and are not just focussed on the theoretical part. One participant also added that the VFT has a lack of operating details (e.g., the temperature of certain processes).

Social aspect. The participants also stated the social activities they had were reasons why they would choose the PFT over the VFT. This was also reflected in the questionnaire where the social aspects rated significantly higher in the PFT than the VFT. The social aspects such as having dinner together, going for karaoke or spending time together on a bus, are not events that can be replicated in a VFT.

People aspect. This refers to interacting with people working in the plant and gaining information related to their job's scope and daily routine in the process plant. In the present study, the people aspect was observed by participants as missing in the VFT. This aspect, however, has not previously been identified in the literature. The reason could be because of differences in the organisation of the PFT where many trips discussed in the literature were in geology and environmental studies (e.g., Garner, 2004; Lewis, 2008), therefore students deal only with specimens or looking at nature, which does not involve much interaction with workers at the site. Conversely, engineering field trips involve explanations by the guide and, therefore, provide interactions between the students and the workers. Other VR applications in engineering such as those discussed in Cameron et al. (2008) and Ou, Dong and Yang (2009) were not evaluated in terms of field trips. In addition, the participants attending the PFT in the present user study were in their final year of study and therefore they did not only see the trip as an exposure to enhance class learning but also as an opportunity to build contacts and gain more knowledge about things outside the classroom such as job scope and daily working routines. These two points suggest that different content and presentation of a VFT is needed for different learning disciplines and year of study.

Interestingly, although a guide was available during the VFT, the participants did not ask questions related to job scope and description or the company's profile, such as were asked during the PFT. This could be explained by the fact that the guide was not an employee of the milk powder processing plant and, therefore, the participants were not interested in asking anything other than about the processes occurring in the plant. In the VFT, all questions were related to the processes occurring in the plant. This suggests that a guide - although knowledgeable about the processes occurring in the plant – ideally is associated with the company portrayed in the VFT, because participants were not only interested in the processes but also other aspects such as company profile, job scope and description. This was also demonstrated when one participant suggested including commentaries by the operators of the process plant in the VR application.

Career aspect. In addition to having the opportunity to interact with the people working in the process plant, the exposure the participants had to different sites was among the reasons the participants opted for PFT over the VFT. The exposure students had during the PFT helped them in choosing their career path, which aligns with findings by Naizer (1993). In the present study, the 'career aspect' was not mentioned by the participants in the VFT group. One reason is because it was based on a single plant and, therefore, the participants were not exposed to other types of plant so there was no prompt for them to state the career aspect as a learning contribution. The emergence of the career aspect for those who attended the PFT may be because they were in their final year of study and therefore exposure to a variety of plants was seen as an opportunity to compare different potential workplaces.

The identification of the 'people' and 'career aspect' features suggests that the PFT was not only seen as a medium for the participants to connect what they learned in class to the process in the physical environment, but also as a medium to expose them to things beyond the curriculum, such as deciding their career path and gaining more information about job routine in a relevant plant. This suggests the development of the VR application used for the VFT needs to include information related to job scope and the workers' role in the plant, as suggested by one participant. This would help to widen the participants' knowledge in terms of careers. However, if this is included, it is still limited because participants were not able to interact with the people in the process plant.

6.4.2 Attitudes towards the VFT

Attitudes towards the VFT can be divided into the VR application used as the medium for VFT and the VFT session.

VR application. One unique feature of the application is integration of information. This allows the VFT to present information in a different way from the PFT. Although this feature was not directly assessed, the participants agreed that the integration of information, including the hotspots and videos, was helpful for learning (Table 19, Section 6.3.3.1). In addition, the participants also stated that they especially liked the integration, together with the interactive PFD and P&ID.

VFT session. Participants found the VFT was enjoyable and engaging, replicating the findings of Poland et al. (2003). Learning engagement, regardless of the type of field trip (physical or virtual) is important to help students learn (Garner, 2004).

The presence of the guide, who provided the participants with information throughout the VFT, was intended to provide a similar experience to PFT. The session with the guide, however, was perceived differently by the participants; some would have liked to use the application by themselves and others would have liked to have an individual session with the guide so that they could ask more questions. Individual differences, where some liked to work individually and some liked to discuss with someone else were also found by Poland et al. (2003).

6.5 Limitations of the study

The first limitation relates to the observation made by the author during the PFT. During the PFT, the students were divided into smaller groups for the site tours and, therefore, the observations in this study covered only the group of which the author was part and therefore not all groups. This limited observations such as tracking the number of questions asked by the students during the PFT. In addition, comparisons to see if the same students were actively asking questions in both the PFT and VFT could not be made.

Second, students were given the questionnaire related to the PFT (Questionnaire-PFT) about two weeks after the PFT (at the beginning of the VFT session) and not immediately after the PFT. For the VFT, the questionnaire was given immediately after the session. The reason for not giving immediately after the PFT was that the students were very tired on the last day and some of them were 'hungover' from the night before, which therefore would not be a suitable time for them to complete the questionnaire. Furthermore, at that stage, no participants had been recruited (voluntarily) for the VFT, which made it difficult to ask the students to voluntarily fill in the questionnaire. This limitation (completing the questionnaire two weeks after the PFT) is considered minimal as PFTs are known to provide students with a long memory (Falk & Dierking, 1997).

Another limitation is that the 360^{o} panoramas in the VR application did not correspond to any of the physical process plants visited by the students during the PFT. The use of only one process plant for the VFT is different from the exposure to the variety of process plants the students had in the PFT. This is considered minimal as the present study focus on attitudes not learning effects; although it was not expected that this would have an effect on the career aspect.

Students who attended the PFT were final year students and both the PFT and VFT were conducted in the final semester. Therefore, a major focus of the PFT is not only to gain knowledge about the processes occurring in the visited plants, but also to know more about career prospects and the experiences of people working there, because the students have started looking for jobs. A different focus of a PFT may be perceived by first year students who may not give as much emphasis to career prospects.

6.6 Lessons learned

The results indicate that students would choose to attend a PFT over a VFT and would attend a VFT only if they did not have the opportunity to attend a PFT. Apart from the physical exposure, the students stated the people, career and social aspects as reasons why they chose the PFT. The physical exposure in the PFT, along with the identification of people and career aspects, need to be considered in organising a VFT. Students, however, agreed that the VFT provides more detailed information than the PFT and that the session was engaging. They suggested that the VFT could be used as a complement to a PFT (e.g., preparation and revision tool for a PFT).

- A VR application should be able to demonstrate or simulate a non-perfect condition (e.g., pump not working, disconnected pipe), so that students can experience what to do when this condition happens.
- Showing physical material, such as samples of the end products during the VFT, may assist students to gain a similar exposure to students in the PFT, in terms of familiarity with the product materials.
- Apart from panoramas representing the physical site of the field trip, a 3D model of the sites with a size indicator (e.g., a human figure) provides students with an idea of the scale and size of the environment. The 3D model also shows the layout of the environment.

- Integration of the information, together with the other features of the application such as easy identification of the equipment (e.g., hotspots) and having a guide explain the process involved in the VFT are features that students found engaging and they felt help with their learning.
- To cater for different individual preferences, the students should be given an individual hands-on session to use the VR application so that they can explore it by themselves.
- Different ways of developing a VR application apply for different disciplines. For disciplines where the PFT involves interaction with workers, the inclusion of information related to job descriptions and what the workers do on a daily basis should be included so students gain knowledge about the working organisation.
- Different ways of organising a VFT apply to different students according to their year of study. Students in the final year do not see the field trip (physical or virtual) only as a means to relate what they learn in the class to the physical environment, but they also see it as a medium to gain information about their career path. Therefore, ideally, the content for the VFT for final year students should include information (e.g., company profile, job routines, etc.), other than just the information related to the processes
- If the VFT was conducted in a session with a guide, the guide would ideally be someone associated with the organisation portrayed in the VFT, as well as being a content expert. This would allow the students to ask questions related to job descriptions or the company profile, like students on the PFT.

Chapter 7

User study 3: The learning assessment comparing the VR application to paper-based learning material

This user study was carried out to answer the research question, "*How do different types of learning materials affect the students' learning?"* This question aims to assess the learning impact of the VR application compared to printed notes and also to assess the students' opinions about the respective learning materials. Another aspect that is investigated in the VR application is using different panels of information linked together, which is not able to be implemented in the printed notes.

This chapter describes the user study conducted to compare the learning effects of using the VR application with the printed notes, the material currently used in class. The students tested were enrolled in ENCH 394 (Process Engineering Design), an introductory course on process engineering design. This course covers heat exchanger design, risk reduction techniques, the basics of material science and an introduction to the UniSim™[20] and SuperPro Designer™[21] process simulation packages. The test during this section of the course was worth 10% of the total marks for the course[22]. The user study was conducted in 2011 and 2012. The results were published in Herritsch et al. (2012) and Herritsch, Abdul Rahim, Fee, Morison and Gostomski (2013), which was co-authored by the thesis author.

This study hypothesised that the participants using the VR application would have higher test marks than participants using the printed notes. This because in the VR application, the text information and pictures are presented and linked together and, according to the *multiple representations principle* (an explanation based on a combination of words and pictures is more effective than an explanation in either words or pictures only) and *contiguity principle* (better learning takes place when the words and pictures are presented together instead of separately), this should be more effective compared to

[20]https://www.honeywellprocess.com/en-US/explore/products/advanced pplications/ simulation/ Pages/ UniSim- Design-Suite.aspx.
[21] http://www.intelligen.com/superpro_overview.html.
[22] Final grade scaling was performed to adjust the marks of both groups to enable fair student outcomes for the course assessment.

information being presented separately (Mayer, 1997). In contrast, the information in the printed notes cannot be linked together in the same way. Examples of the information presented in the VR application and printed notes are shown in Section 7.1.3. Therefore, the hypothesis of this user study is:

$H_{1:}$ The test performance of the participants using the VR application is better than the performance of participants using the printed notes.

The instruments in this user study consist of test questions, the learning materials and questionnaires to measure the students' learning styles, the usability of the learning materials and the students' experiences in using the materials. The author's contributions to this study are the questionnaires and the analysis of the results. The test questions and the learning materials were prepared and marked by CAPE lecturers.

This chapter begins with a description of the learning materials (Section 7.1), followed by the assessments involved in the user study (Section 7.2) and the procedures for the user study (Section 7.3). Section 7.4 then reports on the user study results and Sections 7.5, 7.6 and 7.7 provide a discussion, limitations of the study and lessons learned from this study, respectively.

7.1 Description of the learning materials

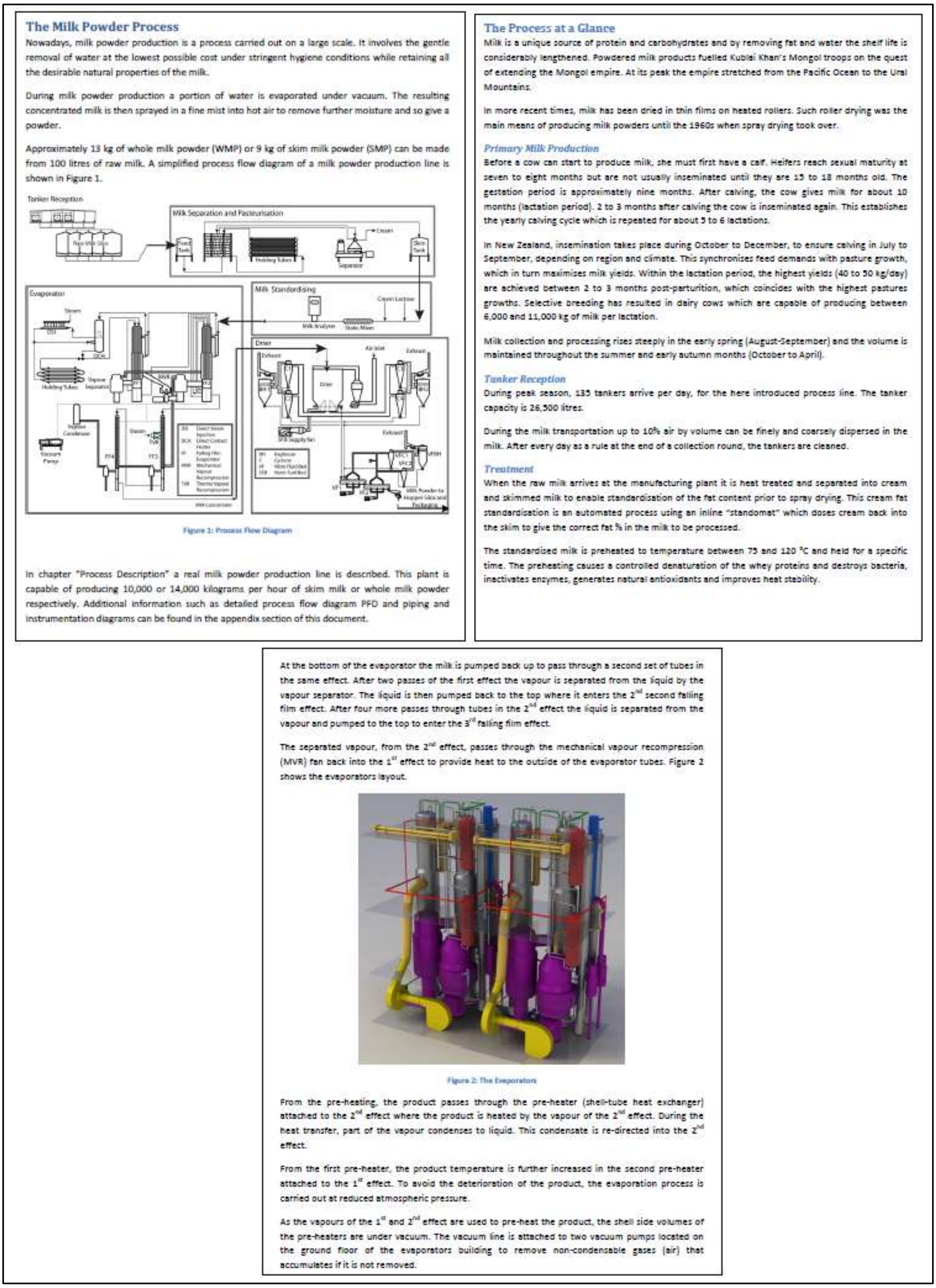
The learning materials are described below.

7.1.1 VR application

The VR application adopted for this study is described in Chapter 5. The application was installed on a server and could be launched only from desktop computers in two computer laboratories in the University of Canterbury. Only students assigned to the VR group were given rights to access the VR application.

7.1.2 Printed notes

The printed notes comprised a 35 page document with similar information to that in the VR application used by the students in the VR group. The information in the printed notes contains the PFD, P&ID, 3D drawings and the text information from the VR application (including the detailed information) from the Info Panel of the VR application.



The Milk Powder Process

Nowadays, milk powder production is a process carried out on a large scale. It involves the gentle removal of water at the lowest possible cost under stringent hygiene conditions while retaining all the desirable natural properties of the milk.

During milk powder production a portion of water is evaporated under vacuum. The resulting concentrated milk is then sprayed in a fine mist into hot air to remove further moisture and so give a powder.

Approximately 13 kg of whole milk powder (WMP) or 9 kg of skim milk powder (SMP) can be made from 100 litres of raw milk. A simplified process flow diagram of a milk powder production line is shown in Figure 1.

Figure 1: Process Flow Diagram

In chapter "Process Description" a real milk powder production line is described. This plant is capable of producing 10,000 or 14,000 kilograms per hour of skim milk or whole milk powder respectively. Additional information such as detailed process flow diagram PFD and piping and instrumentation diagrams can be found in the appendix section of this document.

The Process at a Glance

Milk is a unique source of protein and carbohydrates and by removing fat and water the shelf life is considerably lengthened. Powdered milk products fuelled Kublai Khan's Mongol troops on the quest of extending the Mongol empire. At its peak the empire stretched from the Pacific Ocean to the Ural Mountains.

In more recent times, milk has been dried in thin films on heated rollers. Such roller drying was the main means of producing milk powders until the 1960s when spray drying took over.

Primary Milk Production

Before a cow can start to produce milk, she must first have a calf. Heifers reach sexual maturity at seven to eight months but are not usually inseminated until they are 15 to 18 months old. The gestation period is approximately nine months. After calving, the cow gives milk for about 10 months (lactation period). 2 to 3 months after calving the cow is inseminated again. This establishes the yearly calving cycle which is repeated for about 5 to 6 lactations.

In New Zealand, insemination takes place during October to December, to ensure calving in July to September, depending on region and climate. This synchronises feed demands with pasture growth, which in turn maximises milk yields. Within the lactation period, the highest yields (40 to 50 kg/day) are achieved between 2 to 3 months post-parturition, which coincides with the highest pastures growths. Selective breeding has resulted in dairy cows which are capable of producing between 6,000 and 11,000 kg of milk per lactation.

Milk collection and processing rises steeply in the early spring (August-September) and the volume is maintained throughout the summer and early autumn months (October to April).

Tanker Reception

During peak season, 135 tankers arrive per day, for the here introduced process line. The tanker capacity is 26,500 litres.

During the milk transportation up to 10% air by volume can be finely and coarsely dispersed in the milk. After every day as a rule at the end of a collection round, the tankers are cleaned.

Treatment

When the raw milk arrives at the manufacturing plant it is heat treated and separated into cream and skimmed milk to enable standardisation of the fat content prior to spray drying. This cream fat standardisation is an automated process using an inline "standomat" which doses cream back into the skim to give the correct fat % in the milk to be processed.

The standardised milk is preheated to temperature between 75 and 120 °C and held for a specific time. The preheating causes a controlled denaturation of the whey proteins and destroys bacteria, inactivates enzymes, generates natural antioxidants and improves heat stability.

At the bottom of the evaporator the milk is pumped back up to pass through a second set of tubes in the same effect. After two passes of the first effect the vapour is separated from the liquid by the vapour separator. The liquid is then pumped back to the top where it enters the 2nd second falling film effect. After four more passes through tubes in the 2nd effect the liquid is separated from the vapour and pumped to the top to enter the 3rd falling film effect.

The separated vapour, from the 2nd effect, passes through the mechanical vapour recompression (MVR) fan back into the 1st effect to provide heat to the outside of the evaporator tubes. Figure 2 shows the evaporators layout.

Figure 2: The Evaporators

From the pre-heating, the product passes through the pre-heater (shell-tube heat exchanger) attached to the 2nd effect where the product is heated by the vapour of the 2nd effect. During the heat transfer, part of the vapour condenses to liquid. This condensate is re-directed into the 2nd effect.

From the first pre-heater, the product temperature is further increased in the second pre-heater attached to the 1st effect. To avoid the deterioration of the product, the evaporation process is carried out at reduced atmospheric pressure.

As the vapours of the 1st and 2nd effect are used to pre-heat the product, the shell side volumes of the pre-heaters are under vacuum. The vacuum line is attached to two vacuum pumps located on the ground floor of the evaporators building to remove non-condensable gases (air) that accumulates if it is not removed.

Figure 7-1 The text information, PFD and the 3D model presented in the printed notes[23].

[23] The examples shown are not in consecutive pages.

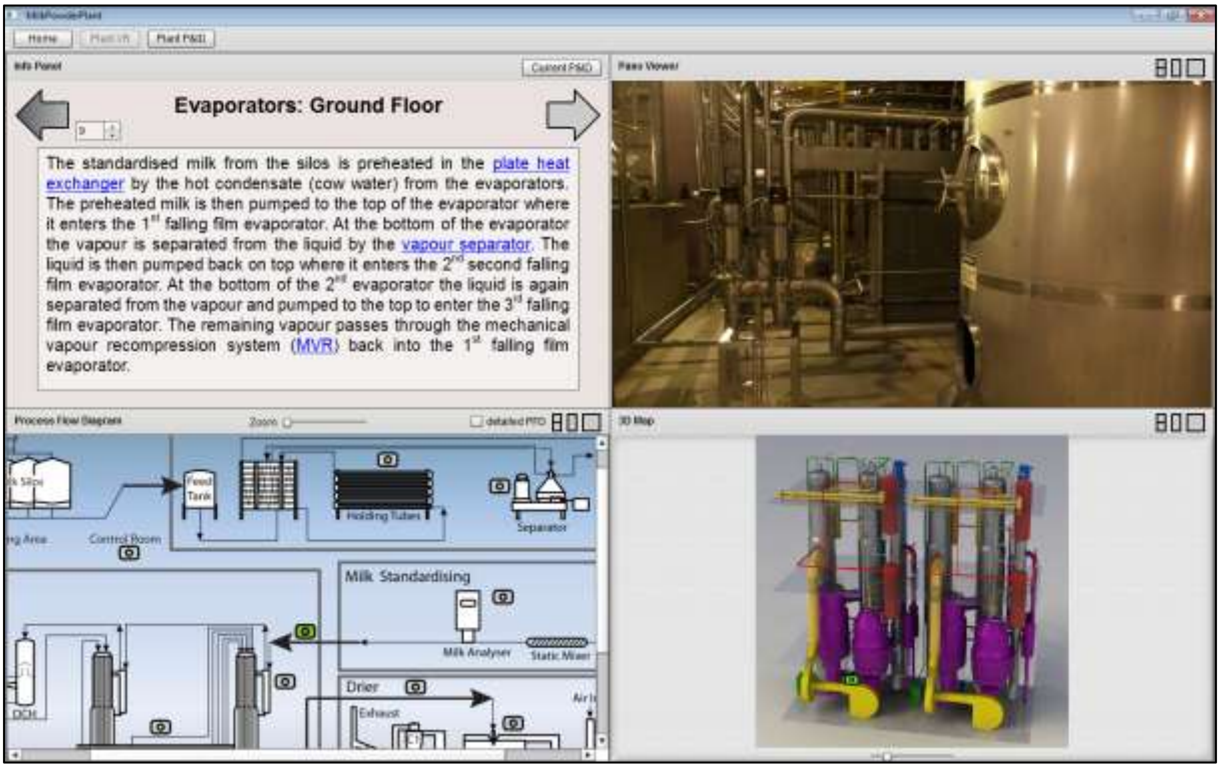


Figure 7-2 The text information, PFD and the 3D model presented in the VR application.

The presentation of the document was similar to the current lecture notes and, therefore, the 360^{o} panoramas and animations were not included in the printed notes because they are in an interactive form. No questions related to the panoramas and animations were asked in the test. In addition to the document, two appendices, comprising the P&ID (18 A4 pages) and the detailed PFD (1 A3 page), were included in the printed notes.

7.1.3 Examples of the information presented in the learning materials

This section shows examples of the information presented in the printed notes and in the VR application. For the printed notes, the simplified version of the PFD and the 3D model of the evaporator were displayed within the text information (Figure 7-1). In the VR application, similar information is presented (see Figure 7-2). The PFD, 3D model and the Info Panel, where the text information is presented, are interactive. The detailed PFD in the printed notes and the VR application are shown in Figure 7-3. The PFD presented in the VR application can be zoomed in/out.

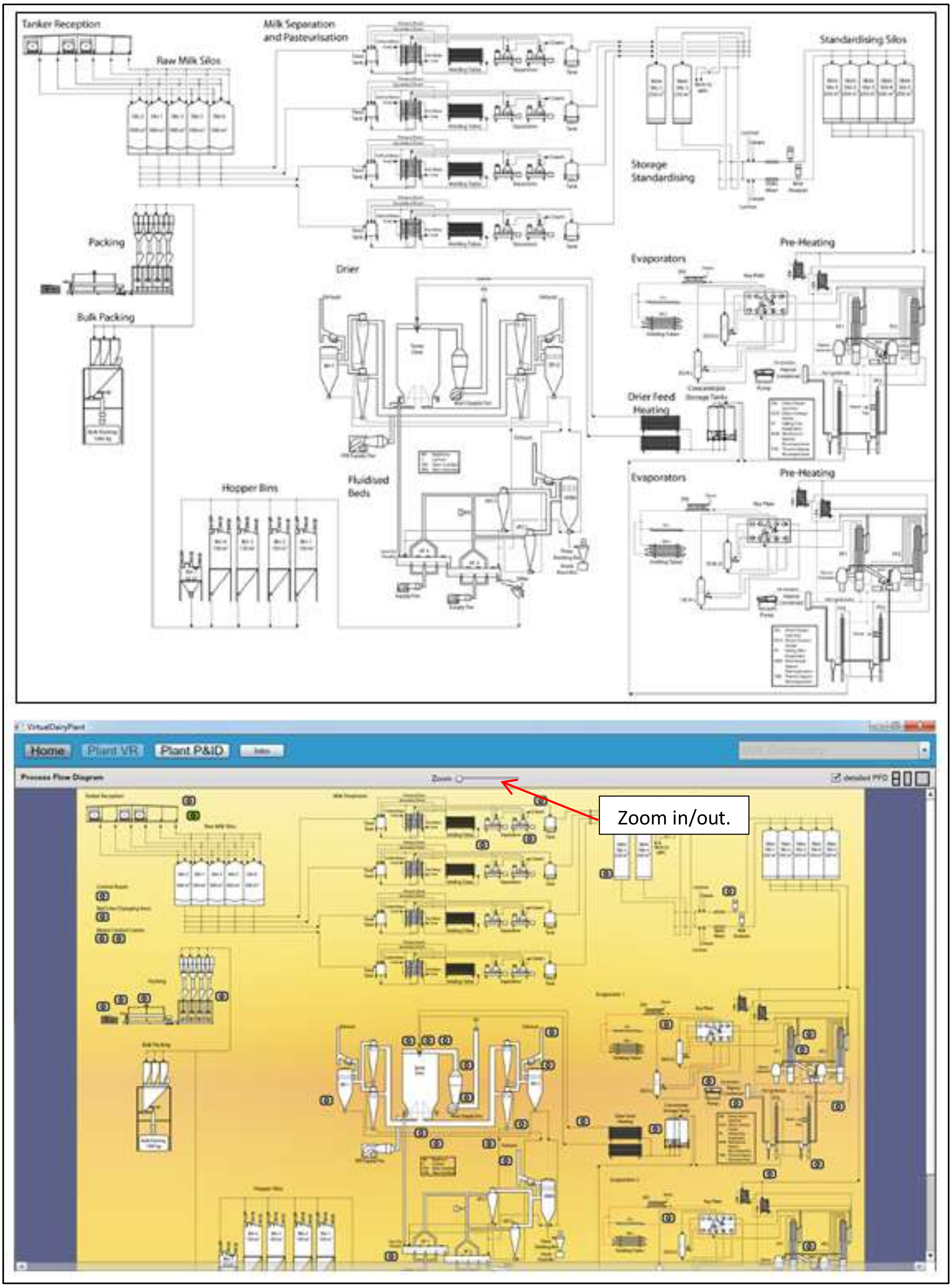


Figure 7-3 The detailed PFD, presented in the printed form (top) and the VR application (bottom).

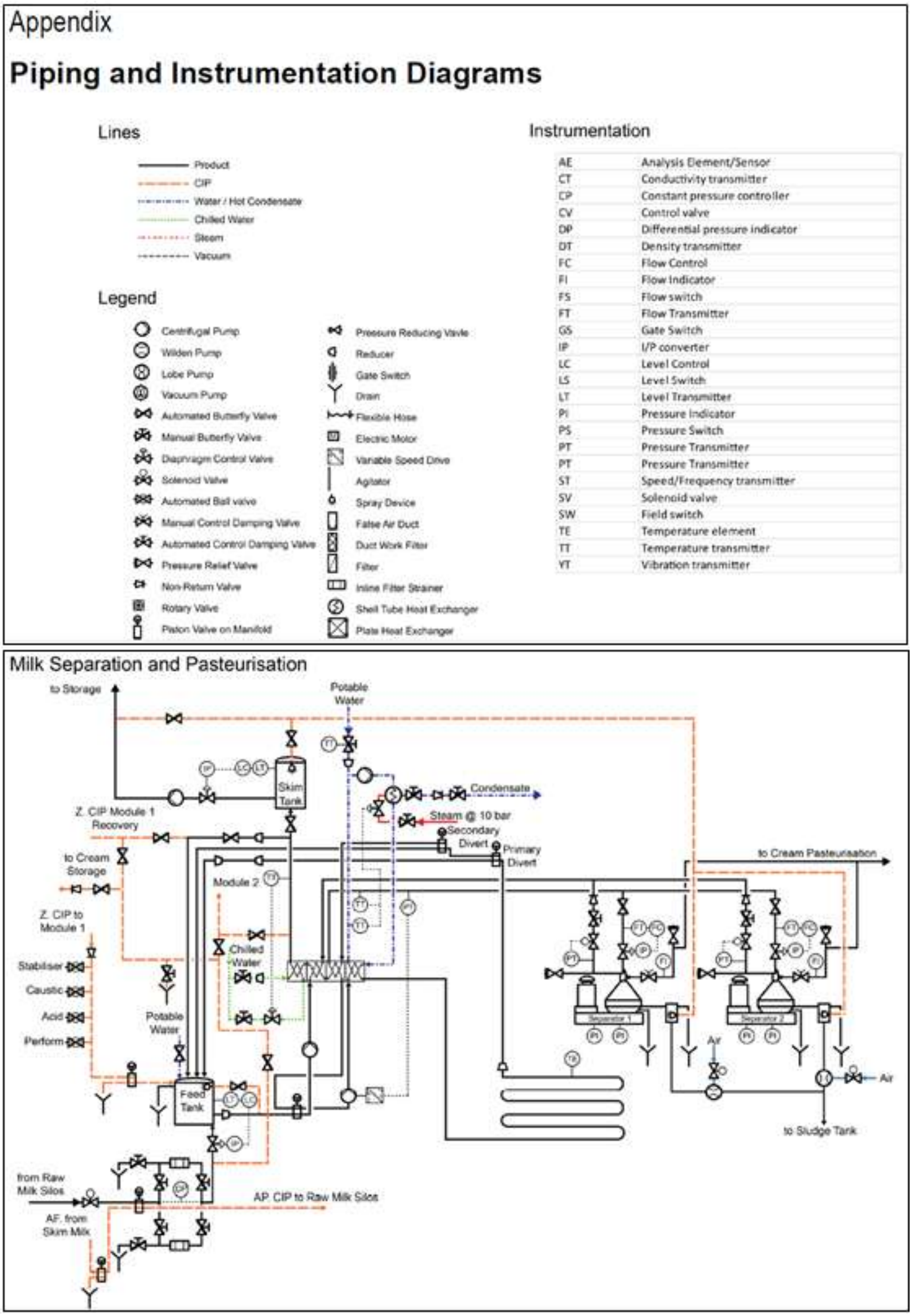


Figure 7-4 The front page of the appendix (top) and one of the P&ID (bottom).

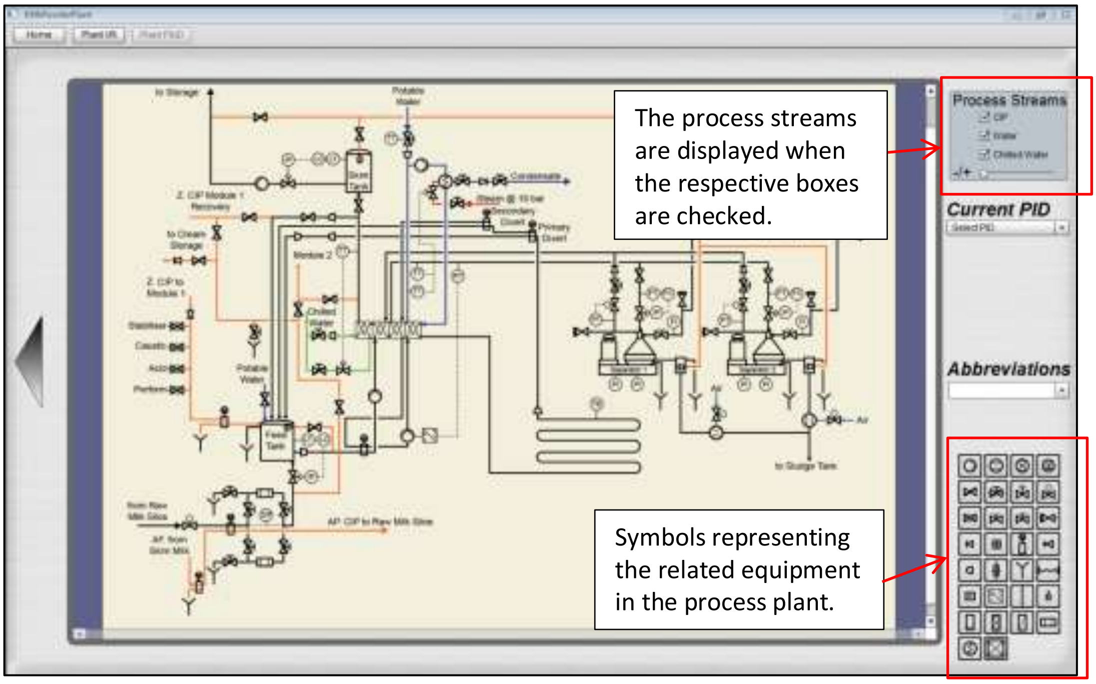


Figure 7-5 The P&ID presented in the VR application.

An example of the P&ID in the printed notes is shown in Figure 7-4. The first page contains information related to the symbols and the process streams (lines) in the P&ID. The same P&ID, as presented in the VR application, is shown in Figure 7-5. The process streams (lines) are presented when the respective boxes are checked.

In addition to the process streams, the bottom right of the P&ID screen contains a set of symbols representing the related equipment in the process plant. Clicking on the symbols shows additional information about the equipment represented by the symbols, e.g., see Figure 7-6. For certain equipment, the pop-up window may also contain a video.

In the printed notes, this information is also included and presented as shown in Figure 7-7. As stated earlier, no animations (e.g., video) could be provided in the printed notes.

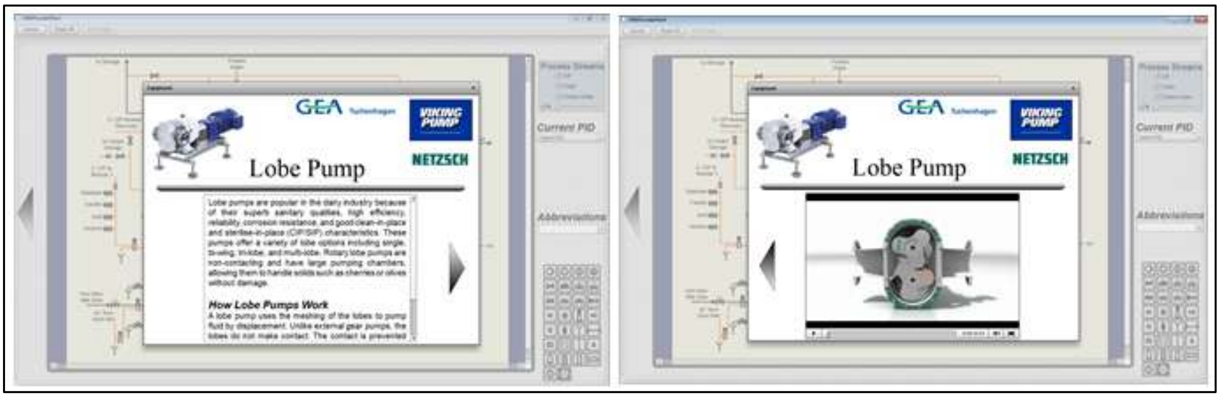


Figure 7-6 Information related to the lobe pump presented in a pop-up window (left); a video of the lobe pump (right).

Lobe Pump

Lobe pumps are popular in the dairy industry because of their superb sanitary qualities, high efficiency, reliability, corrosion resistance, and good clean-in-place and sterilise-in-place (CIP/SIP) characteristics (Figure 6). These pumps offer a variety of lobe options including single, bi-wing, tri-lobe, and multi-lobe. Rotary lobe pumps are non-contacting and have large pumping chambers, allowing them to handle solids such as cherries or olives without damage.

Figure 6: Lobe pump.

How Lobe Pumps Work

A lobe pump uses the meshing of the lobes to pump fluid by displacement. The lobes do not make contact. The contact is prevented by external timing gears located in the gearbox. Pump shaft support bearings are located in the gearbox, and since the bearings are out of the pumped liquid, pressure is limited by bearing location and shaft deflection.

Figure 7: Exploded view of a lobe pump.

Figure 7-7 Information related to the lobe pump presented in the printed notes.

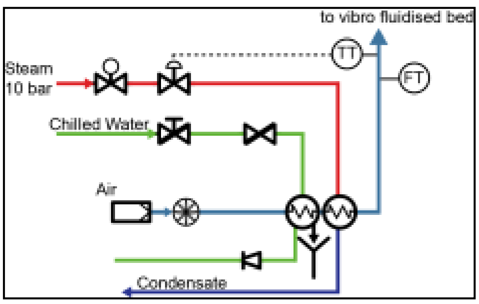
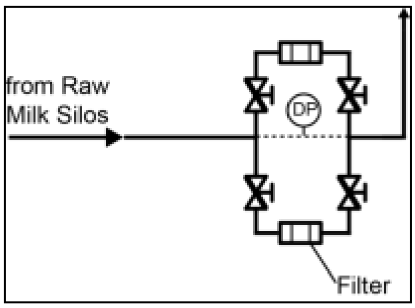
7.2 Assessments

The assessment methods in the user study consisted of test questions and questionnaires, as described below.

7.2.1 Test questions

The test questions were developed by CAPE (as shown in Table 21) and were based on the different levels of Bloom's Taxonomy (Bloom et al., 1956) (as shown in Table 22).

Table 21 The test questions classified into the respective Bloom's taxonomy groups

Levels of Bloom's Taxonomy	Questions
Knowledge	• List the six major areas into which the milk powder production process can be divided. • How much whole or skim milk powder can be produced from 100 litres of raw milk? • What pump types can be found in the dairy plant? • What is the pressure range of the evaporators? • How is the pressure inside the falling film evaporators maintained? • What is "Cow Water"? • Define the abbreviations MVR, TVR, FF. • What is the main material used for the construction of the process equipment? • Name the following components, e.g.,: 
Comprehension	• Describe the milk powder production process (using sketches where appropriate). • Draw a vertical cross-section of the spray dryer and label the components and process streams. • Explain the reasons for the reduced pressure within the falling film evaporators. • Explain the two processes below:  

There are six levels of cognitive learning in Bloom's Taxonomy (Bloom et al., 1956), starting from the lowest level (Level 1: Knowledge) to the highest level (Level 6: Evaluation) (Table 22). Since ENCH 394 is an introductory course on process engineering design, the focus of the questions was more on the lower levels of Bloom's Taxonomy, the knowledge and comprehension levels.

Table 22 The six levels of Bloom's taxonomy of educational objectives.

Level	Definition
Level 1: Knowledge	The basic ability to recall information without requiring any understanding of the material being recalled.
Level 2: Comprehension	The ability to understand and interpret material or situations and to extrapolate that understanding to areas not covered by the original input.
Level 3: Application	The ability to determine which knowledge is relevant to a particular situation and to correctly apply that knowledge to produce a correct solution to the problem at hand.
Level 4: Analysis	The ability to break a complex problem or situation into parts and to recognize the relationships between the parts and the organization of the parts.
Level 5: Synthesis	The ability to create a unique new entity by drawing on different aspects of knowledge and understanding, such that the result is more than simply the sum of its component parts.
Level 6: Evaluation	The ability to judge the value of ideas, solutions, methods, etc. This level is considered to be top of the cognitive hierarchy because the student must employ all five lower levels, plus appropriate evaluation criteria, in order to determine the overall value of the subject being examined.

7.2.2 Questionnaires

The students were asked to complete three questionnaires and were informed that their answers would not impact on their marks for the test. All answers are reported in Section 7.4. These three questionnaires are:

- A questionnaire that asked participants to state their agreement (on a Likert scale) with statements related to the learning materials, see Appendices E.1 and E.2.
- A usability questionnaire (a shortened version of the USE questionnaire (Lund, 2001)). The shortened version contains statements relevant to both the printed notes and the VR application to allow direct comparisons to be made, see Appendices E.3 and E.4.
- A shortened version of the Index of Learning Style (ILS) questionnaire (adapted from (Felder & Solomon, 1991), see Appendix E.5.

The ILS questionnaire is used to assess the learning styles of the participants in order to observe if the VR applications could cater for participants with different learning preferences (i.e., verbal or visual). According to Felder and Brent (2004), most engineering materials are biased towards verbal learners, thus, students with other learning styles (such as visual learners) might be disadvantaged. VR applications are most likely suitable for visual learners as they include visual representations, but it is essential to study if the VR applications disadvantage other types of learners (i.e., verbal).

The ILS was chosen for several reasons: it was created specifically for engineering students (Felder & Silverman, 1988); it has been widely used (e.g., (Broberg, Lin, Griggs, & Steffen, 2008; Morrison, Sweeney, & Heffernan, 2003; Sandman, 2008; Wang, 2007)) and it has been assessed for its validity and reliability (Felder & Spurlin, 2005; Litzinger, Lee, Wise, & Felder, 2007). The ILS consists of 44 multiple choice questions (two options) where each set of 11 questions relates to four different learning styles. The learning styles formulated by (Felder & Silverman, 1988) are:

- **Active/Reflective learners:** Active learners tend to learn by doing things with others. Reflective learners tend to learn by first thinking about it and working alone.
- **Sensing/Intuitive learners:** Sensing learners prefer concrete, practical matters and are oriented towards facts and procedures. Intuitive learners prefer conceptual, innovative matters and are oriented towards theories and meaning.
- **Visual/verbal learners:** Visual learners prefer a visual presentation of the learning material, e.g., pictures, diagrams. Verbal learners prefer written and spoken explanations, e.g., text information.
- **Sequential/Global learners:** Sequential learners tend to learn in an ordered manner and in small sequences of steps. Global learners tend to learn in an holistic manner in large steps.

Since the focus of this user study is on different types of learning material where the VR application has more interactive visuals than the printed notes, the shortened version of the ILS used in this study covered only questions on the visual or verbal learners' scales.

This allows an assessment of how the visual and text based presentations in the learning materials impacted on the visual and verbal learners. Since only the visual and verbal learning styles were included, the results of the present study could not draw any conclusion about the influence of other learning styles to the participants' test marks.

Apart from that, one reason to use a shortened questionnaire was to avoid survey fatigue, as the students were asked to complete the questionnaire after they have completed the 90 minutes test. Furthermore, the questionnaire was completed on a voluntary basis, and therefore having a lengthy questionnaire may discourage students from completing it.

7.3 User study

This section describes the procedures in the user study.

7.3.1 Participants

The test was conducted with two groups of students, one in 2011 and the other in 2012. The procedures, test questions and content material remained the same except for some minor grammatical corrections to the learning materials in 2012. Sixty-two students sat the test in 2011 and 58 sat the test in 2012.

In both years a between-subject design was used where the students were evenly assigned to one of two groups (VR and Paper) according to their grade point average (GPA) based on the students' course grades from the previous year. The GPAs range from 1 to 9, 1 is the minimum passing mark (C-) and 9 is an A+.

7.3.2 Procedure

The procedure for the user study was the same for all participants.

i. The participants of the VR group were given access to the VR application and the participants of the Paper group were given the printed notes. They were asked to use only the learning materials given to them. Only the participants of the VR group had access to the VR application (via their login ID), to ensure that the participants of the Paper group did not use the VR application. Participants in the VR group were also given a brief explanation on how to use the VR application.

ii. A 90-minute closed-book test was conducted one week later.

iii. The participants were asked to record the amount of time spent using the given learning materials in preparation for the test.

iv. During the test, the participants were also asked to complete the questionnaires listed in Section 7.2.2. They were informed that their answers to the questionnaires would not impact on their marks for the test.

7.4 Results

Since the test procedure and questions and the learning materials were the same for both years (2011 and 2012), the data were combined for analysis. Before the data were combined, an independent t-test was conducted to see if there was any significant difference between the total marks of participants in the respective groups for 2011 and 2012 (e.g., Paper group for 2011 and 2012). No significant difference was found between the total marks of participants (Table 23).

Table 23 The mean test marks and the results of the independent t-test of participants using the two different learning materials in 2011 and 2012.

Group	2011 (*n* = 31)	2012 (*n* = 29)	*t*	*df*	*p-value*	*d*
	Mean (SD)	Mean (SD)				
Paper	62.05 (11.49)	63.33 (13.89)	-0.393	58	.696	-0.10
VR	68.63 (12.06)	68.12 (15.44)	0.144	58	.886	0.04

In total, there were 120 participants, 60 were in the VR group and 60 in the Paper group. For the participants' GPA, an independent-samples t-test indicated no significant difference between the GPA of the 60 VR group participants (M = 4.81, SD = 1.85) and that of the Paper group participants (M = 4.65, SD = 1.69), $t(118) = 0.486$, p = .628.

7.4.1 Test marks of the VR and Paper groups

An independent-samples t-test indicated that the mean total mark (maximum 100%) was significantly higher (p = .019) for the VR and, therefore, the null hypothesis is rejected. When the 'Knowledge' and 'Comprehension' marks were analysed separately, the analysis indicated a significant difference for the 'Comprehension' questions (see Table 24).

Table 24 The mean of Total, Knowledge and Comprehension marks and independent t-test results of the the marks of the participants in the VR and Paper learning materials groups.

	VR (n = 60)	Paper (n = 60)	*t*	*df*	*p-value*	*d*
	Mean (SD)	Mean (SD)				
Total mark (max. mark is 100%)	**68.39(13.68)**	**62.67(12.60)**	**2.38**	**118**	**.019***	**0.44**
Knowledge (max. mark is 15)	10.08(2.19)	9.68 (1.88)	1.05	118	.296	0.20
Comprehension (max. mark is 30)	20.69(4.38)	18.53 (4.14)	2.78	118	.006**	0.51

Note: * indicates a significant difference at $p < .05$. ** indicates a significant difference at $p < .025$[24].

For further analysis, the marks were grouped according to the participants' GPAs (see Figure 7-8). Due to the small number of participants in each category of the GPA, no statistical analysis could be done. Therefore, the analysis was done descriptively. The graph shows that independent of the participants' GPA, the mean of total marks of participants in the VR group were higher than the participants in the Paper group.

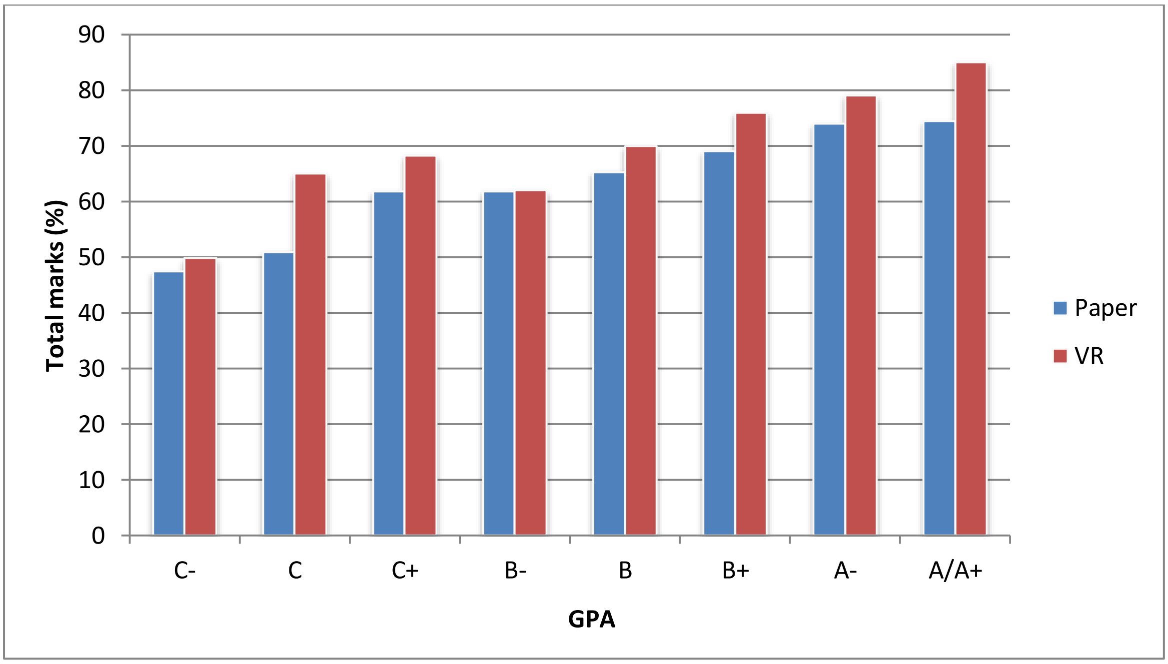


Figure 7-8 The mean total marks of VR and Paper learning materials participants grouped according to their GPA.

[24] To reduce type 1 error risk (the probability of rejecting null hypothesis when in fact it was true), Bonferroni adjusted alpha levels of .025 per test (.05/2) were used.

7.4.2 Participants' learning styles and test marks

The scoring of the ILS test indicates whether students have a 'mild', 'moderate' or 'strong' preference for the visual or verbal dimensions. 'Mild' refers to the learner having a lower preference for the preferred dimension, which suggests that s(he) may switch between visual or verbal dimensions. 'Moderate' and 'strong' refer to medium and higher preferences of the preferred dimension. Nine of the 120 participants' results (six from the Paper group and three from the VR group) were excluded from this analysis because they provided invalid answers, e.g., marked both options as their answer or did not mark either option. Most participants from both the VR and Paper groups showed a preference towards the *visual* dimension rather than the *verbal* dimension (Table 25).

Table 25 The learning style preferences of the participants in each learning materials group.

Group	VISUAL					VERBAL
	Strong	Moderate	Mild	Mild	Moderate	Strong
Paper	16	14	15	5	3	1
VR	13	13	16	10	5	0

Due to the small number of participants in each category of the *verbal* dimension, participants with a 'mild', 'moderate' or 'strong' preference for the *verbal* dimension were grouped as VERBAL and, similarly, participants preferring the *visual* dimension were grouped as VISUAL. There were 24 participants in the VERBAL group (nine from the Paper group and 15 from the VR group) and 87 participants in the VISUAL group (45 from the Paper group and 42 from the VR group).

A 2x2 ANOVA for the test marks, with learning preferences (VISUAL, VERBAL) and learning materials (paper, VR) as between subject factors, revealed no significant main effects for learning preferences, $F(1, 107) = 0.104$, $p = .747$, $\eta p^2 = .001$, and learning material, $F(1,107) = 3.842$, $p = .053$, $\eta p^2 = .035$. The interaction effect was also not significant, $F(1,107) = 0.484$, $p = .488$, $\eta p^2 = .005$.

A possible explanation for the non-significant results may be due to the large number of participants with a 'mild' preference for the *visual* or *verbal* dimensions, which suggests that they are fairly well-balanced between these two dimensions and could learn well given either printed notes or VR application. Therefore, another analysis was conducted where the participants with a 'mild' preference for the *visual* or *verbal* dimensions were removed from the analysis.

With the removal of students with mild preferences for the *visual* or *verbal* dimensions, there were nine participants in the VERBAL group (four from the Paper group and five from the VR group) and 56 participants in the VISUAL group (30 from the Paper group and 26 from the VR group). A 2x2 ANOVA, with learning preferences (VISUAL, VERBAL) and learning materials group (Paper, VR) as between subject factors, revealed no significant main effects for the learning preferences, $F(1,61) = 0.037$, $p = .848$, $\eta p^2 = .001$, and learning material, $F(1,61) = 0.200$, $p = .656$, $\eta p^2 = .003$. The interaction effect was also not significant, $F(1,61) = 0.167$, $p = .684$, $\eta p^2 = .003$.

The average marks for participants using the VR application are higher than participants using the printed notes, independent of the participants' learning preferences (Table 26).

Table 26 Mean marks (and standard deviation) of the students using the VR and Paper learning material, grouped based on their learning preferences

Group	VISUAL	VERBAL	VISUAL (with the removal of 'mild' preferences)	VERBAL (with the removal of 'mild' preferences)
VR	67.36 (14.94)	70.54 (11.09)	68.42 (14.26)	67.35 (18.03)
Paper	63.41 (11.99)	62.25 (13.53)	64.20 (12.31)	67.16 (14.09)

The small difference between the average marks of students using the VR application and the printed notes in the VERBAL group (with the removal of 'mild' preferences) could be explained with the small number of participants (nine) in that group.

7.4.3 The time spent using the learning materials

Of the 120 participants, 96 (52 of the Paper group and 44 of the VR group) reported the time spent using the VR application and the printed notes to prepare for the test. An independent-samples t-test indicated no significant difference (at $p < .05$) for the time, in hours, to prepare for the test between the students in the Paper group ($M = 6.3$, $SD = 3.0$) and VR group ($M = 5.4$, $SD = 2.3$), $t(94) = 1.63$, $p = .107$, $d = 0.34$. Although there was no significant difference, the time taken to prepare for the test was on average approximately one hour more for the Paper group compared to the VR group.

7.4.4 Usability of the learning materials

The participants' agreement with the statements (from 1 = Strongly Disagree to 7 = Strongly Agree) are shown in Figure 7-9.

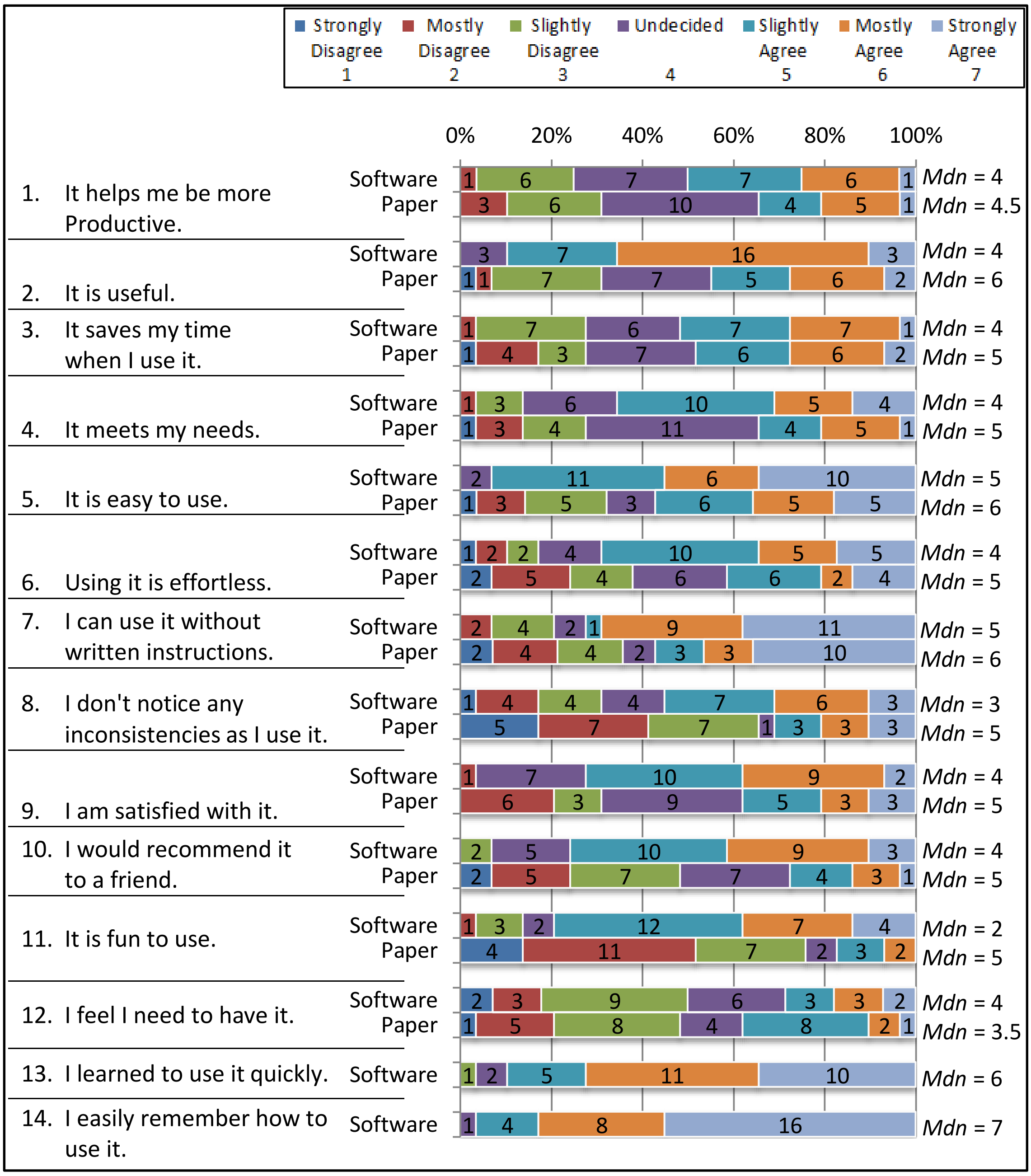


Figure 7-9 Participants' level of agreement with the statements in the USE questionnaire. The length of the bars shows the proportion of participants selecting the corresponding level of agreement. The numerical values give the number of participants who selected that level. Mdn gives the median level of agreement.

The last two statements (statements 13 and 14) were only included in the questionnaire given to the VR group, since they were not relevant to the Paper group. For this analysis, because of minor errors in the USE questionnaires given to the students in 2011, only data from 2012 (29 participants each in the VR and Paper groups) are included.

Figure 7-9 shows that the responses from participants in the VR group incline towards agreement (and are higher than those of the Paper group, except for statement *'I feel I need to have it'*. For this statement, the median is neutral (*Mdn* = 4) for participants in the Paper group and incline towards disagreement (*Mdn* = 3.5) for those in the VR group. This is discussed further in Section 7.5. A Mann-Whitney U Test found significant differences between the VR and Paper groups' agreement with statements 2, 4, 5, 8, 9, 10 and 11, as shown in Table 27.

Table 27 The results of Mann-Whitney U Test of the participants' agreement with the statements

Statement	VR (*Mdn*)	Paper (*Mdn*)	*Z*	*p*-value
1	4.50 (3.25, 5.75)	4.00 (3.00, 5.00)	-.950	.342
2	6.00 (5.00, 6.00)	4.00 (3.00, 5.00)	-3.460	.001*
3	5.00 (3.00, 6.00)	4.00 (3.00, 5.00)	-.301	.763
4	5.00 (4.00, 6.00)	4.00 (3.00, 5.00)	-2.111	.035*
5	6.00 (5.00, 7.00)	5.00 (3.00, 5.00)	-2.592	.010*
6	5.00 (4.00, 6.00)	4.00 (3.00, 5.00)	-1.875	.061
7	6.00 (4.00, 7.00)	5.00 (3.00, 5.00)	-1.171	.241
8	5.00 (3.00, 6.00)	3.00 (3.00, 5.00)	-2.142	.032*
9	5.00 (4.00, 6.00)	4.00 (3.00, 5.00)	-2.512	.012*
10	5.00 (4.50, 6.00)	4.00 (3.00, 5.00)	-3.834	<.001*
11	5.00 (5.00, 6.00)	2.00 (3.00, 5.00)	-4.886	<.001*
12	3.50 (3.00, 5.00)	4.00 (3.00, 5.00)	-.073	.941

Note: Numbers in parentheses are at the 25th and 75th percentiles.* indicates a significant difference at $p < .05$.

For further analysis, the statements were grouped into four categories: 'Usefulness' (Statements 1 to 4), 'Ease of Use' (Statements 5 to 8), 'Satisfaction' (Statements 9 to 12) and 'Ease of Learning' (Statements 13 and 14) as they appear in Lund (2001). The averaged responses for the statements in each category are shown in Table 28 together with the result of the Mann-Whitney U Tests.

Table 28 The median marks of the participants' levels of agreement on the usability of the learning materials.

	VR (*Mdn*)	Paper (*Mdn*)	*Z*	*p*-value
Usefulness	4.75 (4.25, 5.75)	4.25 (3.38, 5.25)	-1.86	.062
Ease of Use	5.00 (4.50, 6.13)	4.00 (3.00, 5.50)	-2.74	.006*
Satisfaction	4.75 (4.25, 5.50)	3.50 (2.88, 4.63)	-3.77	<.001*
Ease of Learning	6.00 (5.75, 7.00)	-	-	-

Note: Numbers in parentheses are at the 25th and 75th percentiles. * indicates a significant difference at $p < .05$.

The results indicate that the usability of the VR application was higher than for the printed notes. The participants' agreement with the 'Ease of Use' of the printed notes is neutral (*Mdn* = 4). In addition, their agreement with the statements related to 'Satisfaction' inclined towards disagreement (*Mdn* = 3.5). Significant differences were found between the VR and Paper groups' level of agreement for 'Ease of Use' and 'Satisfaction'.

7.4.5 Participants' levels of agreement with the presentation of the learning materials

This section presents the participants' agreement levels (1= Completely Disagree to 6 = Completely Agree) with the statements related to the learning materials, such as the layout and presentation of information. Some statements were relevant only to the VR application and some were relevant to the printed notes. The analysis included questionnaires from both 2011 and 2012. Because one participant in the Paper group did not complete the questionnaire, these data were excluded.

Table 29 shows the median value of the participants' levels of agreement with the statements related to the VR application and the printed notes.

The responses for all statements related to the VR application incline towards agreement (*Mdn* ≥ 4) except for *'I often was not aware of my location within the virtual plant'* and *'I knew in which direction I was facing while I was in the plant'* (*Mdn* = 3), suggesting that they knew their position but were unaware of the direction in which they were looking.

A different responses was received regarding the 3D models of the dryer and the evaporators; participants in the VR group agreed that these models helped them with exposure to the actual scale (*Mdn* = 5) whereas participants in the Paper group disagreed (*Mdn* = 2).

Table 29 The median of the participants' responses to the statements related to the 'VR' and Paper' learning methods, from scale of 1= Completely Disagree to 6 = Completely Agree.

Category	Statement	VR (*n* = 60)	Paper (*n* = 59)
Navigation	I often was not aware of my location within the virtual plant.	3 (1,6)	-
	The 3D map was useful in showing me where I am in the virtual environment (VE).	4.5 (1,6)	-
	I knew in which direction I was facing while I was in the plant.	3 (1,6)	-
	I frequently used the buttons on the PFD to move around the plant.	4 (1,6)	-
	I frequently used the arrows in the Info Panel to move through the plant.	5 (1,6)	-
Hotspots	The green hotspots (high-lighted elements) helped me to identify the specific pieces of equipment in the plant.	5 (2,6)	-
	The green hotspots were clearly visible.	5 (2,6)	-
3D model	The 3D models of the dryer and evaporator were useful in showing me the actual scale of the process plant.	5 (1,6)	2 (1,6)
Presentation of the information	The graphics were useful in helping me to understand the various processes in the process plant.	-	3 (1,6)
	The graphics that complement the text information make the hand-out interesting.	-	3 (1,6)
	The hand-outs presented the information clearly.	-	3 (1,6)
	The links between the diagrams, the VE, the 3D model and the additional information (text and graphics) were useful in helping me to understand the various processes in the process plant.	4 (1,6)	-
Layout	I like the layout of the hand-outs	-	4 (1,6)
	I like the layout of the VR application (the location of the Info Panel, 3D map, diagrams, photographs, etc.)	5 (1,6)	-
Diagrams	The simplified PFD was useful in providing me with the overall picture of the milk powder process.	5 (1,6)	5 (1,6)
	The detailed PFD was easy to read.	4 (1,6)	3 (1,6)
	The quality of the P&ID drawings was good.	5 (2,6)	4 (1,6)
	The respective process streams in the P&ID are presented clearly.	4 (1,6)	3 (1,6)
Text information	The text information was easy to read.	5 (1,6)	4 (1,6)
	The text information was easy to understand.	4 (1,6)	3 (1,5)

Note: Numbers in parentheses are the min and max values.

Participants in the Paper group found that the graphics were not interesting and were not useful in assisting them understand the processes in the plant (*Mdn* = 3). In addition, they did not find the detailed PFD easy to read or that the respective process streams in the P&ID are presented clearly. Participants in the VR group agreed that the links between the panels helped them to understand the processes (*Mdn* = 4).

Although participants in both groups liked the layout of their respective learning materials and agreed that the text information was easy to read, those in the Paper group disagreed that the text information was easy to understand.

7.4.6 Results summary

The results of this study are summarised below:

- The total marks for the test were significantly higher for participants using the VR application than for those using the printed notes and, therefore, the null hypothesis was rejected. The better performance of the VR group was mainly due to higher marks in the 'Comprehension' questions.
- The participants using the VR application produced better results compared to the participants using the printed notes, independent of their GPA and learning preferences, based on the descriptive analysis.
- On average, the participants using the printed notes spent approximately one hour more in revision, than those using the VR application, although the difference was not significant.
- The participants' levels of agreement with the statements related to 'usefulness', 'ease of use' and 'satisfaction' of the VR application were higher than for printed notes. In addition, the participants also found the VR application easy to learn.
- Participants had a lower positive response towards the presentation of the 3D models, the graphical presentations and the PFD and P&ID in the printed notes compared with the participants using the VR application.
- Participants using the VR application were generally aware of their location in the virtual plant but were not aware of the direction in which they were facing.

7.5 Discussion

This user study was carried out to answer the research question, "*How do different types of learning materials affect the students' learning?"* This question aims to assess the learning impact of the VR application compared to the printed notes and to assess students' opinions about the respective learning materials. One of the unique features of the VR application is that it has different panels of information linked together, which could not be implemented in the printed notes.

Overall, the results confirmed the study’s hypothesis; namely, that participants using the VR application obtained higher marks than participants using the printed notes. This suggests that the VR application assisted the participants with better learning than the printed notes. The results also reveal that the participants rate the VR application higher in terms of the usability.

The differences in the marks obtained by participants using the VR application and those using the printed notes can be explained from many perspectives, as discussed next.

7.5.1 Presentation of the information

The ability to present the information together, based on the *contiguity principle* (where better learning takes place when the words and pictures are presented together instead of separately) (Mayer, 1997), could be one reason that the participants were able to obtain higher test marks than those using the printed notes.

The presentation of the information received positive responses from the participants, based on the levels of agreement with the statements related to the layout of the application (Table 29, Section 7.4.5). A different response was received regarding the presentation of information in the printed notes (e.g., the graphics that complement the text information).

The differences could be explained by the features of the VR application that allow connection of one piece of information to another (e.g., PFD to the text information and the 3D model), that could help participants to relate each component easily, compared with flipping to different pages of printed notes of information in order to relate them. Although participants in both groups agreed that both sets of learning materials were easy to use, the levels of agreement for the VR application are higher than for the printed notes. Linking information helps students to gain better understanding of the connected information (Schofield, 2012). Similarly, Maynard et al. (2012) also found that links between the panoramas and diagrams were perceived as being useful by students. The fact that the printed notes did not have panoramas may also have contributed to the lower marks obtained by the participants in this group, although no assessments were made regarding the panoramas.

7.5.2 Interactivity

One of the contributing factors to the better performance of the students using the VR application may be due to the interactivity offered by the VR application, although this was not studied specifically in the present study.

Although participants from both the VR and Paper groups agreed that the text information was easy to read, only the participants using the VR application agreed that the information was easy to understand while the participants using the printed notes disagreed. This could possibly be due to the interactive elements, such as the 3D model, PFD and P&ID, which were presented in a static form in the printed notes. Interactive components can support deeper understanding of the subjects compared to static content (Khul, Scheiter, Gerjets, & Edelmann, 2011).

Diagrams (PFD and P&ID). Participants were able to interact with both the PFD and P&ID. For example, when using the P&ID, the participants could select the process streams they wish to see (Figure 7-5, Section 7.1.3), giving them the ability to control the display of items they would like to see on the screen. Conversely, in the printed notes, both the PFD and P&ID are static and all the process streams in the P&ID are displayed at the same time. The flexibility to display only the intended items allows participants to limit the information that has to be processed and stored in their verbal and visual channels which, therefore, reduces the possibility of excess cognitive load. According to Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2003), the verbal and visual channels have limited capacity to process information and, therefore, a careful presentation needs to be considered to avoid excess cognitive load. Hence, the flexibility to select what to learn could help to minimise this. This also aligns with the study by Rasch and Schnotz (2009), who suggest that an ‘enabling function’ (e.g., similar to selecting the respective process streams in the P&ID) is better than static images because it enables the learners to select and store the required information into their working memory, which cannot be done using a static image.

Participants liked the PFD and P&ID in the VR application. In the case of the printed notes, students liked the simplified PFD and the quality of the P&ID drawings, but not the detailed PFD and the process streams presented in the P&ID (Figure 7-5, Section 7.1.3). This suggests that a simple presentation is suitable for paper-based materials but for a complicated presentation, a computer-based application is preferred as it allows control of the items to be displayed, thus making the presentation less complicated.

3D model. The 3D model is also a component with which the students could interact in the VR application. Participants using the VR application agreed that the 3D model is useful in showing them the actual scale of the process plant while the participants using the printed notes disagreed. The main difference between the 3D models presented in both formats is that the one in the VR application could be rotated and, therefore, shows a different view of the 3D model. Also, the panel containing the 3D model could be enlarged. Participants using the printed notes might not have realised the existence of the 'human figure' on the 3D model, which could be used as an indicator to provide a perception of the plant size, since the model itself could not be enlarged or rotated. For the participants of the VR application, the ability to rotate the 3D model may have caused them to spend more time studying the model. Thus, they paid more attention to the details of the model, including the presence of the 'human figure'.

7.5.3 Satisfaction with the learning materials

The VR application and the printed notes were rated by the participants as being useful and easy to use. In addition, the participants agreed that the application was easy to learn. However, the levels of satisfaction differ between the groups; the participants using the VR application had positive responses for satisfaction but the participants using the printed notes had a neutral response (neither positive nor negative).

The participants' satisfaction with the VR application could be one reason why participants obtained higher test marks, since satisfaction is seen as a factor that influences how students learn (Abrantes, Seabra, & Lages, 2007; Liaw, 2008). Students will be less likely to engage in their learning if they are not satisfied with the form of learning delivery (Bradford, 2011). For the printed notes, the participants perceived the material as neither satisfying nor unsatisfying.

7.5.4 Flexibility of the VR application

According to Felder and Brent (2004), most engineering materials are biased towards verbal learners, which may impact the performance of students who do not belong in this group. This could be a difficult situation because most engineering students are visual learners (Broberg et al., 2008; Kolmos & Holgaard, 2008; Rosati, 1998), making it difficult for the students to adapt to the format of the learning materials. The results of the present study demonstrate that the average marks for participants using the VR application were higher than those using the printed notes regardless of their learning preferences. This suggests that the VR application lets both, verbal and visual learners perform better than with printed notes. This fact could be due to the presentation of the information in different formats, allowing the participants to choose what format they like to use for learning.

Not only did the participants with different learning preferences benefit from the VR application but also similar results were found for participants with different GPAs, where the participants who used the VR application obtained higher marks than the participants using the printed notes regardless of their GPA. The benefit of hypermedia learning, regardless of the students' GPAs, aligns with the findings by Żywno (2003). In addition, Zywno also found that low ability students developed better learning at the lower category of Bloom's taxonomy and the high ability learners developed better learning at higher level categories. Since the present study only covers the lower levels of Bloom's taxonomy, the latter could not be analysed.

7.5.5 Time spent with the learning materials

On average, the preparation time spent by the participants using the VR application was approximately one hour less than participants using the printed notes. The shorter time required by the participants using the VR application may be due to limited access to the VR application, because it could be accessed only on campus. However, this did not impact their marks, which were higher than those of participants using the printed notes. This further suggests that the VR application was an efficient tool for learning compared with the printed notes.

The time spent on the learning materials does not align with the results of the study by Evans and Gibbons (2007), who found that students spend a longer time using dynamic interactive learning materials than static learning materials. The explanation given in that study is that the interactive materials contain self-assessment questions, which were not included in the static learning material. In the present study, the VR application does not have any self-assessment and does not require any additional activity by the participants.

7.5.6 Students' need for the learning materials

Interestingly, although positive responses were received by the participants regarding the VR application, the participants disagreed with *'I feel the need to have it'*, in contrast to participants using the printed notes (Figure 7-9, Section 7.4.4). The reason for this could probably be explained by the restrictions in using the VR application. The VR application was accessible only from desktop computers in two computer laboratories at the university. The participants, therefore, needed to be physically on campus to use it, whereas the participants using the printed notes could do so anywhere. This may have restricted VR application students' access to the materials, compared with those using the printed notes.

7.6 Limitations of the study

The first limitation is related to the test questions used, in that they cover only the lower two levels of Bloom's taxonomy (Knowledge and Comprehension), because of the course's syllabus. Therefore, this does not allow analysis of higher levels of cognitive learning.

The second limitation is the restricted access to the VR application; the application could be accessed only in a computer laboratory and, therefore, it did not give the participants the full flexibility to use it at their own pace. This, therefore, may be one of the contributing factors to the shorter time taken by the participants using the VR application for test preparation compared to participants using the printed notes.

Third, existing research demonstrates that most engineering students are visual learners (Broberg et al., 2008; Kolmos & Holgaard, 2008; Rosati, 1998), which therefore suggests that a larger number of participants are needed to have a large number of verbal learners for analysis. The fact that the study was conducted within a university provides a limitation to this, as the number of participants depends on the number of students enrolled for that year; this also affects the distribution and numbers of participants in each GPA group.

Finally, as paper-based materials could not present the interactive content, the panoramas and animations were removed. Although no questions related to these two items were asked, it is assumed that participants using the VR application may have advantages, because the information presented in the application is linked to the interactive panoramas and animations.

7.7 Lessons learned

The results indicate that participants using the VR application obtain higher test marks than students using the printed notes, which demonstrates that the VR application assists participants with better learning than with the printed notes. The test results, including the participants' opinions of the learning materials, lead to a number of considerations when developing similar educational learning material.

- Links between information is useful, particularly when using different formats of information (e.g., diagram, text information), because it minimises the users' efforts to search for, and refer to, the information.
- An interactive application, particularly one that allows users to control (e.g., enable and disable) items they want to display reduces the possibility of having an excess cognitive load since the users can choose what they want to see and learn. This is also useful for complex presentations (e.g., a complex diagram of an electric circuit) because the control function allows users to minimise the complexity by selecting the items to be displayed.
- The interactive function allows users to be more engaged in the exploration of the components and, therefore, may cause them to pay more attention to details.

Chapter 8
Conclusion

This thesis focuses on issues related to using a VR application as a medium to expose students to the real world in the context of learning (relating processes in the real world to the material learned in class) and acquiring spatial knowledge of a site as portrayed in the virtual environment. The issues investigated relate to the design of VR applications from the perspective of integrating different types of information about classroom materials and the real world, and from the perspective of using maps to acquire spatial knowledge in complex multi-level buildings.

The research was carried out in the context of engineering education using a VR application based on a multilevel process plant with integration of the learning content (e.g., Process Flow Diagram (PFD), videos, 3D models). This provides a suitable platform to address the issues raised in this thesis.

Section 8.1 restates the research problem and objectives. The following section (Section 8.2) summarises the findings of each user study. Section 8.3 discusses the lessons learned in the user studies, Section 8.4 discusses the limitations; Section 8.5 describes the threats to the validity; and Section 8.6 discusses the research contributions. The implications for current research and future research possibilities are presented in Sections 8.7 and 8.8, respectively.

8.1 Restatement of the research problems and objectives

Two problems were investigated in this thesis:

Research problem 1: The absence of studies related to the acquisition of spatial knowledge of multilevel buildings with large equipment that does not fit within a single level. An extension of this is that there are not many studies related to using a map as a direct navigation tool (moving from one location to the other location) compared with just using it to provide an overview of the virtual environment.

Research problem 2: Educational VR applications often have different types of information that are not well integrated and linked. Since not much is known about integrating different types of information, the issue is further investigated in this thesis.

A different VR application was used to address each research problem, due to the different requirements of each VR application. The VR application for the acquisition of spatial knowledge needs to include only the necessary components, to avoid excess cognitive load on users (Haik et al., 2003; Witmer et al., 2002). Conversely, the application developed for classroom learning using the virtual environment contained various types of information to assist students with their learning.

The flexibility and capability of computers provide many ways to present information in a computer-based application. One approach, as presented in this thesis, is to present the information through linking and integrating different types of information (for research problem 2). This was chosen because many educational applications focus on displaying information in different locations and therefore the information is not well integrated.

Three user studies were conducted to address research problems 1 and 2. In addition, a usability study was conducted to assess the usability of the application before conducting two of the user studies. The objectives of the user studies were to:

- Investigate the differences in the spatial knowledge acquired by the users with different types of map.
- Provide valuable insights that are useful for the development of similar VR applications.
- Explore the students' attitudes towards virtual field trips and to provide valuable insights that are useful for conducting the trips.
- Assess the learning impact of the VR application compared with a conventional learning resource (paper-based material).

8.2 Summary and findings from each user study

This section summarises the findings of each user study carried out for the research problems and objectives stated in the previous section.

Research problem 1

Objective: To investigate the differences in the spatial knowledge acquired by the users with different types of map.

Spatial knowledge acquisition in a complex large scale virtual environment (Chapter 4). This chapter describes the user study carried out to investigate the differences in spatial knowledge acquired by users of different types of map (2D, 2.5D and 3D). The results indicate that the 2.5D map was the best way to present a complex multilevel building, because it helps users to obtain better survey knowledge than 2D and 3D maps presented in this study. A 2D map is not suitable because it causes confusion when viewed in a top-down manner (especially when cut at the respective levels). An advantage of the 2.5D map over the other maps is the 3D cut-away representation of the objects on the map allows a better presentation of the spatial horizontal and vertical information of objects, since blocking of objects on the map is avoided.

Research problem 2

Objective: To provide valuable insights that are useful for the development of similar VR applications.

A usability study of the milk processing VR application (Chapter 5): This chapter describes a usability study carried out with a milk processing plant VR application to determine the value of its design and how well the problems found with a BP oil refinery application are addressed. The findings suggest that it was easy to use. The link between the panels helped to maintain students' awareness of the information relating to the process in each panel. Other features such as green hotspots, guided and unguided tours and interactive elements, were all perceived positively by the students. In general, the VR application's usability was rated highly by the students and the design issues encountered in the BP oil refinery applications were well addressed.

Objective: To explore students' attitudes towards virtual field trips and to provide valuable insights that are useful for conducting the trips.

Students' attitudes towards virtual field trips (Chapter 6): This chapter attempts to determine the value of VFTs compared with PFTs from the students' perspectives. The results show significant differences only in terms of the social aspects of the PFT and VFT.

No significant difference was found in the students' perceptions of the PFT and VFT as a medium for learning.

The VFT was positively perceived by the students; they found the session was engaging. Students appreciated the presence of the guide but some would have preferred to use the application themselves while others would like to have an individual session with the guide so that they could ask more questions. The features of the VR application (the integration of the information, hotspots, videos, interactive PFD and P&ID) were positively perceived by the students. They felt that these features helped them with their learning.

In general, students stated that a VFT should not be used as a replacement for a PFT but as a complement to a PFT (preparation and revision materials). However, if students did not have the opportunity to attend a PFT, then a VFT may be an adequate replacement rather than no visit at all. The factors contributing to the differences in the preferences for the PFT over the VFT are the physical experiences, different aspects of learning (e.g., health and safety), social activities, the opportunity to interact with the workers in the plant and the exposure to a variety of plants. The latter feature can help them in deciding their career path. Aspects missing in the VFT were social activities, the opportunity to interact with the workers in the visited plant, and exposure to the wide variety of process plants in NZ.

Objective: To assess the learning impact of the VR application compared with a conventional learning resource (paper-based material).

The learning assessment comparing the VR application to paper-based learning material (Chapter 7): This user study compared the learning effects of using the VR application as a learning resource for class assessments compared with conventional printed notes. The results show that students using the VR application obtained higher test marks than students using the 'printed notes', regardless of their GPA level and learning preferences (verbal or visual learners). The usability of the VR application was rated much higher than for the printed notes. In addition, students using the VR application spent one hour less time in revision than those using the printed notes.

8.3 Lessons learned

This section highlights the key lessons learned for designing a VR application to expose students to a process plant and provide them with spatial knowledge about the plant. A complete list of lessons learned is available at the end of each chapter about the respective user study (Section 4.10, Section 5.4.3. Section 6.6 and Section 7.7).

Map development for complex multilevel buildings

- A 3D cut-away presentation of the objects on the map (e.g., a 2.5D map) is most suitable for complex multilevel buildings (e.g., when equipment extends beyond single level), compared with the 2D and 3D maps investigated in this thesis, because the 2.5D map exposes both the spatial *horizontal* and *vertical* information of the objects without blocking other objects on the map.
- A 2D map is not suitable for use in an environment with elements of similar shape (e.g., a processing plant, manufacturing factory) because it causes confusion when viewed in a top-down manner (especially when cut at each level).
- A full 3D presentation (as in the thesis, which provides multiple views of the map from different angles) is not advisable because it causes confusion to the users.

Development of VR applications for learning

- The visibility of information, such as having different panels (with linked information) displayed on a single screen (with the ability to resize each panel), helps to maintain the user's awareness of the information related to the process in each panel.
- Linking information is useful, particularly when different types of information (e.g., diagrams, text information) are involved because it minimises the users' efforts in searching for, and referring to, the related information (i.e., link what has been learned in the class to the actual process shown in the 360^{o} panoramas).
- The interactive elements in the VR application are useful because they allow users to engage with the related content presented in different formats and control

what they want to see and display. This minimises the possibility of having an excess cognitive overload.

- The use of appropriate colours to auto highlight an area of interest of an item referred to in the text information (e.g., hotspots) is engaging and useful for users.

Conducting a virtual field trip (VFT)

- The organisation of a VFT varies according to the year in which the students are studying. Students in their final year do not perceive a field trip (physical or virtual) only as a means to relate what they learn in the class to the physical environment, but they also perceive it as a medium to gain information about their career path. Therefore, the content of the VR application used for a VFT that caters for the final year students' needs to include information other than just the ones related to the processes (e.g., company profile, job routines). Since career choice is one goal, the guide for the VFT ideally should be someone associated with the organisation portrayed in the VFT, as well as being a content expert.

- Showing some physical materials, such as samples of the end products, during the VFT may assist students to gain similar exposure to that of the students in the PFT, in terms of familiarity with the product materials.

- Demonstrating or simulating a non-perfect condition (e.g., pump not working, disconnected pipe) would be useful, so that students can experience what to do when this condition happens, instead of being exposed to a 'perfect' condition.

- A 3D model of the site with a size indicator (e.g., a human figure) should also be included so students can gain an idea of the layout, scale and size of the environment portrayed in the VR application.

- To cater for individual preferences, students should be given a hands-on sessions to use the VR application so that they can explore it by themselves.

8.4 Limitations of the studies

The limitations of the user study related to the acquisition of spatial knowledge (Chapter 4) is the scoring method; where the measurements were based on the point where the stick was inserted, and the measurement of an object's orientation was done manually. For the design of the map, the rotation function of the 3D map is not a free rotation, and participants did not have free navigation in the virtual environment.

For the user study related to the virtual field trip (Chapter 6), the limitations were related to the students being final year students and the panoramas used during the VFT did not correspond to a physical process plant visited during the PFT. In addition, the observations during the PFT were based only on the group in which the thesis author was a part.

For the learning assessment of the VR application (Chapter 7), the limitation was related to the course (ENCH 394) where it was an introductory course on process engineering design. Another limitation was the limited access to the VR application (only via the computer lab) due to confidentiality issues.

8.5 Threats to validity

There are a number of potential threats to the validity of the user studies conducted in this research. These threats have been divided into internal and external sources, as described in the following subsections.

8.5.1 Internal validity

Internal validity refers to the extent to which a causal outcome based on a user study is assured. One possible threat is selection bias. Selection bias refers to the differences that exist in the participants (before performing the tasks in the user study) that may affect the results.

In this research, precautions have been exercised to minimise this effect. The participants for the spatial knowledge acquisition user study (User study 1, Chapter 4) and the virtual field trip user study (User study 2, Chapter 6) were randomised into each condition (2D, 2.5D or 3D map) of the user study. In addition, spatial ability tests were given to the participants in the spatial knowledge acquisition user study (User study 1, Chapter 4) and the results demonstrated no significant differences between the participants exposed to each map condition (2D, 2.5D and 3D maps), further minimising the possibility of differences between the participants before they performed the navigation task and post-task tests (*landmark recognition, landmark sequencing* and *object placement* tests). For the learning assessments (User study 3, Chapter 7), the participants were grouped based on their GPA; no significant differences were found between the participants in each of the learning conditions.

8.5.2 External validity

External validity refers to the extent to which the results of the research are able to be generalised to other situations. The sample participants in the study are the students from the Department of Chemical and Process Engineering (CAPE), University of Canterbury. Therefore, a number of concerns need to be considered when generalising from the study.

First, for the spatial knowledge acquisition study (User study 1, Chapter 4), the students involved in this study were well exposed to the use of computers for learning. Therefore, if the study was extended to other disciplines, such as fire fighter training, where some might not be familiar with using computers, they may face difficulties in using the application.

Second, the study was conducted with tertiary education students who have plenty of experience with self-learning. Therefore, the results of the learning assessment user study (User study 3, Chapter 7) may be different if it was conducted with secondary education students, because they are not exposed as much to self-learning (Dunbar, 2013). This exposure to self-learning may also affect the students' preference to use the VR application by themselves, as noted in the results of the virtual field trip study (User study 2, Chapter 6).

8.6 Research contributions

In general, the findings of this thesis have contributed new knowledge by reporting valuable results about the use of a VR application in education, from the perspective of spatial knowledge acquisition and the use of a VR application as a learning resource and for a VFT. The unique feature of the VR application, the links and integration of different types of information, adds value to the design and development of educational software, particularly for disciplines involving a lot of information from a variety of formats. Specific contributions of this thesis are:

Spatial knowledge acquisition. This thesis demonstrates that using a 2.5D map (in point-to-point form) compared with the 2D and 3D map (as presented in the thesis) is a good way to assist users to acquire spatial knowledge in a complex multilevel building.

Learning material. This thesis demonstrates that using a VR application as a learning resource improves students' performance and has a positive impact on their engagement. The unique feature of the application - the link and integration between different source of information - including highlighting the important components in the panoramas (hotspots), interactive diagrams, resulted in a higher level of satisfaction than using conventional materials (e.g., printed notes).

Virtual field trip. This thesis demonstrates that the VFT session has a positive impact on students' enjoyment and engagement. The identification of people and career aspects demonstrate that final year students see field trips (physical or virtual) as more than just a medium to relate what they learn in class to the real world.

8.7 Implications of the research

Although the research conducted in this thesis is in the context of engineering education, the lessons learned in this study could be used for education and training elsewhere, such as in architecture, transportation and fire fighting training; all situations where the learners need to gain spatial knowledge and relate the content learned in class to the real world. This generalisation acknowledges the study validity, as discussed in Section 8.5.

The findings of this research have several important implications for *industrial practitioners, academics* and *developers.*

For *industrial practitioners,* the findings of the spatial knowledge acquisition user study suggest that the application could be used as a medium to assist learners to gain an overview of a processing plant. New plant operators, for example, need to be exposed to the layout of the plant and they need to be able to precisely locate the position of the pieces of equipment for trouble shooting purposes. This could be an issue if the plant is huge and complicated and, therefore, they would need to navigate it more than once, which would be tiring and cause fatigue. However, with the use of the VR application and the 2.5D map, navigation could be done at the person's own pace and comfort.

The same applies to *academics.* The research findings suggest that the VR application could be used as a complement to the conventional learning approach; be it in classroom learning or for a PFT. For classroom learning, the learning content with less complicated diagrams or presentations could be provided using conventional paper-based lecture notes. For more complicated diagrams and explanations, the VR application could be used because it lets the students control what they want to learn at one time. The ability to control what to learn minimises the possibility of having an excess cognitive overload, which aligns with the Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2003), where the verbal and visual channels have limited capacity to process information. The features of the information integration, together with the interactive diagrams, hotspots and videos, were positively perceived by the students and they felt that these features were engaging and had helped them with better learning.

Using the VR application as a preparation and revision tool for a PFT is also seen as useful because students can gain an overview of the site(s) to be visited and, therefore, gain an initial insight into what they need to focus on and pay attention to. Using the VR application as a revision tool allows the students to revise and obtain information that may not have been gained during the PFT because of issues such as not being able to listen to the guide’s explanation or the fatigue effect from the long field trip schedule.

The findings about people's interaction (people aspects) and career aspects provide useful insights for conducting a VFT, where a closer integration with the organisation portrayed in the VR application could be included, e.g., include the job description of the workers in the organisation and have a representative from the organisation as the guide.

For *developers,* the findings from the research provide recommendations for future development of educational and training software. The feature of the VR application (the links and integration between the information) could be used as a basis for developing applications that incorporate multiple information sources, such as the microarray data in the area of biotechnology.

The findings of the spatial knowledge acquisition user study demonstrates that a point-to-point map, which is available in most open source code, should not be underestimated in terms of its benefits in aiding the users in acquiring spatial knowledge. Although no direct assessments were made regarding open source applications (e.g., Tourweaver[25], Voyager[26]), the findings provide useful insights for people without detailed technical skills to further explore the applications for any similar development.

8.8 Future studies

The finding that using a cut-away map assisted in the acquisition of spatial knowledge in a complex multilevel building could be further explored by comparing different types of cut-away maps with which users could interact and manipulate. In addition, the study could also be extended into more complex buildings, where different areas do not have the same number of levels. This would provide further understanding on the extent to which the point-to-point map could be used as an aid for acquiring spatial knowledge.

Another interesting area to be explored is combining the cut-away map (of Chapter 4) into the VR application with integrated information (of Chapter 5). During the VFT study, the students stated that the 3D model in the VR application provided them with exposure to the plant layout. This, however, was not explored in terms of the acquisition of spatial knowledge. Although a previous study by Haik et al (2002) suggests that this would have an impact on excessive cognitive overload, the fact that the 2.5D map was well understood by the students may reduce that possibility.

In addition, since the results indicate that the 2.5D map (with cut-away representations of the objects on the map) was the best map, it could be worthwhile to investigate if the different levels of ability needed to identify cross-sections of 3D objects, would affect the users' ability to use the 2.5D map as a medium to acquire spatial knowledge. Assessing the level of ability could be undertaken using a new spatial thinking test (inferring cross-sections of 3D objects) that measures the individual’s ability to identify the 2D cross-sections of a 3D geometric solid (Cohen & Hegarty, 2012). This skill has been identified as important in the science, engineering and mathematics disciplines (Cohen & Hegarty, 2012).

Another possible area of future research is to extend the VR application by incorporating a virtual character into the application. Since the students were interested in interacting

[25] http://www.easypano.com/Virtual-tour-software.html
[26] http://www.voyager360.com/

with workers in the physical plant, and gaining information about their job scope and company profile, it would be interesting to construct a VFT using a virtual character representing workers from the company in the plant, instead of using a real person. This would allow interactive conversations between the students and the virtual character without the need to have a guide physically present during the VFT.

In addition to this, another future possibility is to conduct a study on this aspect such as comparing the VR application with integrated information with another VR application having the same information without integration.

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Appendix A

A usability study of the BP VR application

A.1 The form for the lecturers

Research Information Sheet for Software Evaluations
Lincoln University

Applied Computing Group ESD

You are invited to participate as a subject in a project entitled:

Name of project *Immersive Learning through Virtual Reality*

The aim of this project is to determine the usefulness of software for VR application for Chemical Engineering. This session will take about 45 minutes to 1 hour. Your participation in this project will involve:

> Familiarising yourself with the software with the help of the researcher and then being asked to carry out some tasks. We are not testing you! We are testing the software to see if it meets user requirements and it is easy to use. You do not have to undertake any tasks you do not wish and you may stop at any time.
>
> The researcher will observe and make notes about your use of the software and video/audio record the session for further analysis. Your keyboard and mouse actions will be recorded automatically during the session. In addition, you will also be asked to fill in a questionnaire and a short interview will take place after the questionnaire.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Only the researcher and supervisor will have access to the raw data. To ensure anonymity and confidentiality, individual participants will not be identifiable in any results or publication. We will record the ID number only so that we can withdraw your results from the research if you ask us to.

You may withdraw your participation at any time, including the withdrawal of any information you have provided. However, by signing the consent form attached, it is understood that you have consented to participate in this experiment and to publication of the results, with the understanding that anonymity will be preserved. The project is being carried out by:

Name of principal researcher: *Elin Abdul Rahim*
Contact details: *elineliana.abdulrahim2@lincolnuni.ac.nz*

She will be pleased to discuss any concerns you have about participation in the project.

A template for projects to evaluate software has been reviewed and approved by Lincoln University Human Ethics Committee. This particular project has been confirmed by the Head of the Applied Computing Group as meeting that template. If you have any concerns about this project you are invited to contact the Head of Group.

Head of Applied Computing Group ________________________________
Contact Details ____

Consent Form for Requirements and/or Software Evaluation

Name of Project: ***Immersive Learning through Virtual Reality*** __________

- I have read and understood the research information sheet for the above-named project.
- On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.
- I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.
- I consent to video footage and digital images being used in conference presentations and academic publications.

Signed: ____ Date: ____________

ID: _________

(This number will be recorded with your data only so we can withdraw it at your request)

General Information Form **ID: ___**

Please answer the following questions.

1. Have you **seen** the BP VR application before?

☐ Yes

☐ No

If yes, have you **used** the BP VR application?

☐ Yes, for ☐ month(s) and ☐ days(s).

Reason(s) for using: ☐ As a teaching tool in class

☐ Personal use

☐ Other(s), please state:

____

____

☐ No

2. Other than the BP VR application, have you used any other VR tool as a teaching
tool in your class?

☐ Yes (for ☐ month(s) and ☐ days(s)

Which tool(s):____

☐ No

3. What tools do you use in your teaching practice? You may tick more than one option.

☐ Lecture slides/power point

☐ Static images of plants, equipment, etc.

☐ Animated images of plants, equipment, etc.

☐ Videos

☐ Other(s), please state:_________________________

A.2 The form for the students

Research Information Sheet for Software Evaluations

Lincoln University

Department of Applied Computing, FESD

You are invited to participate as a subject in a project entitled

Name of project *Immersive Learning through Virtual Reality*

The aim of this project is to determine the usefulness of software for VR applications for Chemical Engineering. This session will take about 15-30 minutes.

Your participation in this project will involve:

> Familiarising yourself with the software with the help of the researcher and then being asked to carry out some tasks. We are not testing you! We are testing the software to see if it meets user requirements and it is easy to use. You do not have to undertake any tasks you do not wish and you may stop at any time.
>
> The researcher will observe and make notes about your use of the software and audio record the session for further analysis. Your keyboard and mouse actions will be recorded automatically during the session. In addition, you will also be asked to complete a questionnaire after the session.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Only the researcher and supervisor will have access to the raw data. To ensure anonymity and confidentiality, individual participants will not be identifiable in any results or publication. We will record the ID number only so that we can withdraw your results from the research if you ask us to.

You may withdraw your participation at any time, including the withdrawal of any information you have provided. However, by signing the consent form attached, it is understood that you have consented to participate in this experiment and to publication of the results, with the understanding that anonymity will be preserved.

The project is being carried out by:

Name of principal researcher *Elin Abdul Rahim*

Contact details *elineliana.abdulrahim2@lincolnuni.ac.nz*

She will be pleased to discuss any concerns you have about participation in the project.

A template for projects to evaluate software has been reviewed and approved by the Lincoln University Human Ethics Committee. This particular project has been confirmed by the Head of the Department of Applied Computing as meeting that template. If you have any concerns about this project you are invited to contact the Head of Department.

Head of Department of Applied Computing ________________________________

Contact Details ____

Consent Form for Requirements and/or Software Evaluation

Name of Project: ***Immersive Learning through Virtual Reality***__________

- I have read and understood the research information sheet for the above-named project.
- On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.
- I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.
- I consent to video footage and digital images being used in conference presentations and academic publications.

Signed: ____ Date: ____________

ID: _________

(This number will be recorded with your data only so we can withdraw it at your request)

General Information **ID: ________**

Please answer the following questions.

1. What year are you currently in (1st Pro, 2nd Pro, 3rd Pro)?

____

2. Have you **been** to any chemical plant before?

☐ Yes

☐ No

If yes, how long did you spend there?

☐ Yes, for ☐ month(s) and ☐ days(s).

Reason(s): ☐ Field trip

☐ Industrial training

☐ Other(s), please state:

____

____

3. Have you used any other VR software (game, educational software, etc.)?

☐ Yes, for ☐ month(s) and ☐ days(s).

Which software(s):____

☐ No

A.3 Instruction for the task (lecturers)

Usability testing for BP VR application

Instructions for users:

The first task will be conducted using the think aloud method. You will need to vocalise any action that you perform, the steps you take to find the information, any questions you have and any confusion or issues that you encounter while performing the task.

If you remain silent and forget to vocalise your thoughts, a reminder will be given to you.

The sessions will take about 45 minutes to 1 hour and will be video/audio recorded for analysis purposes.

Perform the specified tasks below.

No	Task
1	Enter the plant. Look for equipment numbered 802-B and go to the nearest node to the equipment.
2	From this position, look for the available hotspots.
3	From the highlighted hotspots, identify equipment 802-B.
4	Show how you can display the available menu associated with the specified equipment. Click on the second item in the menu.
5	Go back to the position you were at before you clicked on the item in the menu.
6	Face east and move forward.
7	You need to shut down an electrically driven pump. Show how this is done.
8	Suppose you want to see the process of how 'crude' works. Show the steps taken to reach the page.

A.4 Questionnaires (lecturers)

To what extend do you agree with the following statements?

Statements	Scale of Agreement					
	Completely Disagree ---	--	-	+	++	Completely Agree +++
I felt lost when I was in the plant.	☐	☐	☐	☐	☐	☐
The map was useful in assisting my navigation around the plant.	☐	☐	☐	☐	☐	☐
I used the nodes on the map to move around the plant.	☐	☐	☐	☐	☐	☐
I knew in which direction I was facing while I was in the plant.	☐	☐	☐	☐	☐	☐
I used the compass to assist my navigation.	☐	☐	☐	☐	☐	☐
The hotspots (highlighted equipment) helped me to identify the specific pieces of equipment in the plant.	☐	☐	☐	☐	☐	☐
The hotspots (highlighted arrow) helped me to identify the path where I can move to in the plant.	☐	☐	☐	☐	☐	☐
I felt dizzy when I was navigating the plant	☐	☐	☐	☐	☐	☐
The ‘tips’ button was useful in assisting me to perform any specific task/activity.	☐	☐	☐	☐	☐	☐
I like the layout of the VR application (the location of the map, button, etc.).	☐	☐	☐	☐	☐	☐
I used the ‘help’ button to assist me with the navigation.	☐	☐	☐	☐	☐	☐
I used the search button when I was trying to find for any equipment or information.	☐	☐	☐	☐	☐	☐

Rate the importance of these items in the VR application.

The page area	Scale of Importance					
	(Extremely Unimportant) ---	--	-	+	++	(Extremely Important) +++
Map	☐	☐	☐	☐	☐	☐
The nodes on the map	☐	☐	☐	☐	☐	☐
The 'Person' on the map	☐	☐	☐	☐	☐	☐
The available equipment shown on the map.	☐	☐	☐	☐	☐	☐
The 'show hotspots' button.	☐	☐	☐	☐	☐	☐
The highlighted hotspots.	☐	☐	☐	☐	☐	☐
The highlighted arrow that shows the direction to move around the plant.	☐	☐	☐	☐	☐	☐
The compass at the bottom of the plant.	☐	☐	☐	☐	☐	☐
The search facility.	☐	☐	☐	☐	☐	☐
The help button.	☐	☐	☐	☐	☐	☐
Task oriented activity						
Finding the equipment in the plant.	☐	☐	☐	☐	☐	☐
Perform pump shutdown.	☐	☐	☐	☐	☐	☐
The step-by-step instruction to perform the pump shutdown.	☐	☐	☐	☐	☐	☐
Animated page						
The 2D interactive/non-interactive page (e.g.,: **Phase Behaviour – Distillation, where** users can change the value of the vapour and gas flows and tray types, the animation of the processes, etc.)	☐	☐	☐	☐	☐	☐
Video						
Example includes the induction, safety and tour video. This includes the quiz/interactive activities following the induction/safety video.	☐	☐	☐	☐	☐	☐

A.5 Instruction for the task (students)

Usability testing for BP VR application

Instructions for users:

The first task will be conducted using the think aloud method. You will need to vocalise any action that you perform, the steps you take to find the information, any questions you have and any confusion or issues that you encounter while performing the task.

If you remain silent and forget to vocalise your thoughts, a reminder will be given to you.

The session will take about 15 to 30 minutes and will be video/audio recorded for analysis purposes.

Perform the specified tasks below.

No	Task
1	Enter the plant. Look for equipment numbered 802-B and go to the nearest node to the equipment.
2	From this position, look for the available hotspots.
3	From the highlighted hotspots, identify equipment 802-B.
4	Show how you can display the available menu associated with the specified equipment. Click on the second item in the menu.
5	Go back to the position you were at before you clicked on the item in the menu.
6	Face east and move forward.
7	Suppose you want to see the process of how 'crude' works. Show the steps taken to reach the page.

A.6 Questionnaires (students)

To what extend do you agree with the following statements?

Statements	Scale of Agreement					
	Completely Disagree ---	--	-	+	++	Completely Agree +++
I felt lost when I was in the plant.	☐	☐	☐	☐	☐	☐
The map was useful in assisting my navigation around the plant.	☐	☐	☐	☐	☐	☐
I used the nodes on the map to move around the plant.	☐	☐	☐	☐	☐	☐
I knew in which direction I was facing while I was in the plant.	☐	☐	☐	☐	☐	☐
I used the compass to assist my navigation.	☐	☐	☐	☐	☐	☐
The hotspots (highlighted equipment) helped me to identify the specific pieces of equipment in the plant.	☐	☐	☐	☐	☐	☐
The hotspots (highlighted arrow) helped me to identify the path where I can move to in the plant.	☐	☐	☐	☐	☐	☐
I felt dizzy when I was navigating the plant	☐	☐	☐	☐	☐	☐
I like the layout of the VR application (the location of the map, button, etc.).	☐	☐	☐	☐	☐	☐
I used the ‘help’ button to assist me with the navigation.	☐	☐	☐	☐	☐	☐
I used the search button when I was trying to find for any equipment or information.	☐	☐	☐	☐	☐	☐

Rate the importance of these items in the VR application.

The page area	Scale of Importance					
	(Extremely Unimportant) ---	--	-	+	++	(Extremely Important) +++
Map	☐	☐	☐	☐	☐	☐
The nodes on the map	☐	☐	☐	☐	☐	☐
The ‘Person’ on the map	☐	☐	☐	☐	☐	☐
The available equipment shown on the map.	☐	☐	☐	☐	☐	☐
The ‘show hotspots’ button.	☐	☐	☐	☐	☐	☐
The highlighted hotspots.	☐	☐	☐	☐	☐	☐
The highlighted arrow that shows the direction to move around the plant.	☐	☐	☐	☐	☐	☐
The compass at the bottom of the plant.	☐	☐	☐	☐	☐	☐
The search facility.	☐	☐	☐	☐	☐	☐
The help button.	☐	☐	☐	☐	☐	☐

Appendix B

Spatial knowledge acquisition in a complex large scale virtual environment

B.1 Consent form

Research Information Sheet for Software Evaluations
Lincoln University

Department of Applied Computing, FESD

You are invited to participate as a subject in a project entitled Immersive Learning through Virtual Reality. The aim of this project is to investigate the effects of different types of maps (2D, 2.5D and the 3D map) in assisting users with the acquisition of spatial knowledge in a large-scale virtual environment. This session will take about 35-45 minutes. If you participate in this project:

> You will be asked to navigate the VR application according to the sequence of numbers shown on the map. You will be given a demonstration beforehand and will be allowed to practise to familiarise yourself with the VR application before performing the navigation task.
>
> You will be asked to complete a spatial orientation test and a mental rotation test before performing the navigation task and upon the completion of the navigation task, you will be asked to complete the landmark recognition test, landmark sequencing test and object placement test. A video recorder will be used while you carry out the tasks. The recorded video will be used for data analysis purposes only.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Only the researcher and supervisor will have access to the raw data. To ensure anonymity and confidentiality, individual participants will not be identifiable in any results or publication. We will record the ID number only so that we can withdraw your results from the research if you ask us to.

You may withdraw your participation at any time prior to publication, including the withdrawal of any information you have provided. However, by signing the consent form attached, it is understood that you have consented to participate in this experiment and to publication of the results, with the understanding that anonymity will be preserved. The project is being carried out by:

Name of principal researcher Elin Abdul Rahim
Contact details elineliana.abdulrahim2@lincolnuni.ac.nz

She will be pleased to discuss any concerns you have about participation in the project.

A template for projects to evaluate software has been reviewed and approved by the Lincoln University Human Ethics Committee. This particular project has been confirmed by the Head of the Department of Applied Computing as meeting that template. If you have any concerns about this project you are invited to contact the Head of Department.

Head of Department of Applied Computing ______________________
Contact Details ______________________

B.2 General information form

General Information **ID: _______**

Please answer the following questions.

1. ☐ Male ☐ Female

2. Year of study:
   ☐ 1st Pro ☐ 3rd Pro

3. Have you been to a process plant before?
   ☐ Yes ☐ No

   If **yes**, please provide the following details:

Reasons (e.g: field trip, internship)	Type of process plants (e.g: milk processing plant, oil refinery)	Durations (e.g: 1 month, 1 hour)
E.g: Field trip	*Milk processing plant*	*1.5 hours*

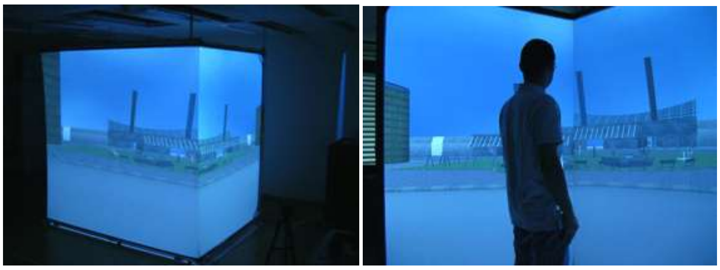
4. Have you used any other virtual reality (VR) software before?

☐ Yes ☐ No

If **yes**, please provide the following details:

☐ Immersive VR, please state (e.g: Cave Automatic Virtual Environment (CAVE), Head Mounted Display (HMD), etc.)

Example of a CAVE:



(Source: (http://archiveweb.epfl.ch/vrlab.epfl.ch/infrastructure/infrastructure_index.html)

Frequency of use:

☐ Never
☐ Less than once a month
☐ Once a month
☐ A few times a month
☐ A few times a week
☐ About once a day
☐ Several times a day

☐ Non immersive VR (desktop VR), please state (e.g: computer games, education software):

Example of a desktop VR:

(Source: http://www.panoramas.dk/2011/salt-lake-city.html)

Frequency of use:

- ☐ Never
- ☐ Less than once a month
- ☐ Once a month
- ☐ A few times a month
- ☐ A few times a week
- ☐ About once a day
- ☐ Several times a day

B.3 Landmark recognition test[27]

Landmark Recognition Test

You will be shown a set of images of the equipment (landmarks). You need to indicate whether the equipment in the images was IN the process plant or NOT. If you are unsure about it, you may choose NOT SURE.

You need to be as accurate as possible. Points will be given if the CORRECT option is selected and points will be deducted if the INCORRECT option is selected. Points will not be given or deducted when the images are stated as NOT SURE.

Example:

[X] In the process plant. [ ] Not in the process plant. [ ] Not sure.

Image source: www.minergy.com

In this example, the equipment shown in the image is IN the process plant. Hence, the first option is selected.

(Note: The image used in this example is not captured in the process plant portrayed in the VR application).

[27] The size of the images has been scaled to minimise the number of pages

*Question 1:

*Question 2:

Question 3:

** Question 4:

[Copyright clearance to reproduce image not obtained]

Question 5:

Question 6:

The images for questions marked with '*' are from www.minergy.com.
The image marked with '**' is from http://drycake.com/equipment/drying/company.php

***Question 7:

[Copyright clearance to reproduce image not obtained]

*Question 9:

Question 10:

The images for questions marked with '*' are from www.minergy.com.
The image marked with '***' is from http://www.es-edelstahl.de/.

Question 11:

*Question 12:

Question 13:

*Question 14:

*Question 15:

Question 16:

The images for questions marked with '*' are from www.minergy.com.

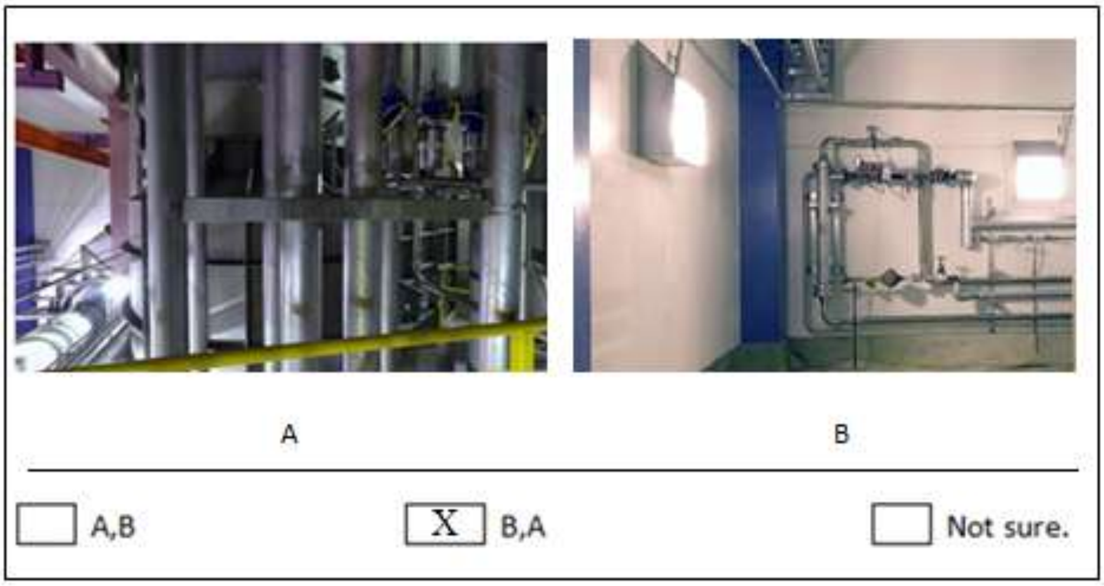
B.4 Landmark sequencing test[28]

Landmark sequencing test

You will be shown 7 pairs of images of the equipment in the process plant. You need to indicate which of the two pieces of equipment (in each pair) that you encountered first during the navigation.

You need to be as accurate as possible. Points will be given if the CORRECT option is selected and points will be deducted if the INCORRECT option is selected. Points will not be given or deducted when the images are stated as NOT SURE.

Example:



In this example, B is encountered first before A. Hence, the second option (B, A) is selected.

(Note: The image used in this example is not captured in the process plant portrayed in the VR application).

[28] The size of the images has been scaled to minimise the number of pages.

Question 1:

A

B

Question 2:

A

B

Question 3:

A

B

Question 4:

A

B

Question 5:

A

B

Question 6:

A

B

Question 7:

A

B

B.5 Participants' scores

B.5.1 Landmark recognition test

Participant ID	2D map	Participant ID	2.5D map	Participant ID	3D map
P1	12.5	**P2**	11	**P3**	14.5
P4	13	**P5**	15	**P6**	10.5
P7	12	**P8**	8.5	**P9**	12
P10	12.5	**P11**	10.5	**P12**	12
P13	10.5	**P14**	14	**P15**	12
P16	15	**P17**	12	**P18**	13.5
P19	12	**P20**	10.5	**P21**	16
P22	11.5	**P23**	11.5	**P24**	14
P25	11.5	**P26**	12	**P27**	11.5
P28	14	**P29**	13	**P30**	12
Mean	**12.45**	**Mean**	**11.8**	**Mean**	**12.8**
SD	**1.30**	**SD**	**1.87**	**SD**	**1.65**

B.5.2 Landmark sequencing test

Participant ID	2D map	Participant ID	2.5D map	Participant ID	3D map
P1	5	**P2**	4	**P3**	3
P4	4.5	**P5**	3	**P6**	4.5
P7	5	**P8**	4	**P9**	1.5
P10	4	**P11**	3	**P12**	3
P13	4	**P14**	5.5	**P15**	4.5
P16	6	**P17**	2	**P18**	5
P19	5	**P20**	2	**P21**	4.5
P22	3.5	**P23**	4.5	**P24**	4.5
P25	4.5	**P26**	3	**P27**	4.5
P28	3.5	**P29**	5	**P30**	6
Mean	**4.5**	**Mean**	**3.6**	**Mean**	**4.1**
SD	**0.78**	**SD**	**1.20**	**SD**	**1.26**

B.5.3 Object placement test

2D map

2D map		Correct vertical level				Correct Horizontal level				Correct Orientation			
Participant ID	**Gender**	**Cyclone**	**Bag Filter**	**Air blower**	**Mean**	**Cyclone**	**Bag Filter**	**Air blower**	**Mean**	**Cyclone**	**Air blower**	**Mean**	**Total Mean (Vertical + Horizontal + Orientation)**
P1	M		1		0.333		1		0.333	1		0.500	1.167
P4	F	1			0.333	1		1	0.667	1		0.500	1.500
P7	M		1	1	0.667		1		0.333		1	0.500	1.500
P10	M	1			0.333				0.000			0.000	0.333
P13	F	1			0.333	1			0.333			0.000	0.667
P16	M		1		0.333	1			0.333	1		0.500	1.167
P19	M	1			0.333	1	1	1	1.000	1		0.500	1.833
P22	M			1	0.333		1		0.333	1		0.500	1.167
P25	F	1	1		0.667				0.000		1	0.500	1.167
P28	M				0.000	1			0.333	1		0.500	0.833
				Mean	**0.367**				**0.367**			**0.389**	**1.133**
				SD	**0.189**				**0.292**			**0.211**	**0.436**

2.5D map

2.5D map		Correct vertical level				Correct Horizontal level				Correct Orientation			
Participant ID	**Gender**	**Cyclone**	**Bag Filter**	**Air blower**	**Mean**	**Cyclone**	**Bag Filter**	**Air blower**	**Mean**	**Cyclone**	**Air blower**	**Mean**	**Total Mean (Vertical + Horizontal + Orientation)**
P2	F	1			0.333	1	1	1	1.000	1		0.500	1.833
P5	M		1	1	0.667	1		1	0.667	1		0.500	1.833
P8	F	1			0.333	1	1	1	1.000	1		0.500	1.833
P11	M				0.000	1	1	1	1.000	1		0.500	1.500
P14	M	1			0.333	1			0.333	1		0.500	1.167
P17	F				0.000	1	1	1	1.000	1		0.500	1.500
P20	F				0.000				0.000	1		0.500	0.500
P23	F	1			0.333	1			0.333	1		0.500	1.167
P26	F	1			0.333	1			0.333	1	1	1.000	1.667
P29	F	1		1	0.667			1	0.333	1		0.500	1.500
				Mean	**0.300**				**0.600**			**0.550**	**1.450**
				SD	**0.246**				**0.378**			**0.158**	**0.416**

3D map

3D map		Correct vertical level				Correct Horizontal level				Correct Orientation			
Participant ID	**Gender**	**Cyclone**	**Bag Filter**	**Air blower**	**Mean**	**Cyclone**	**Bag Filter**	**Air blower**	**Mean**	**Cyclone**	**Air blower**	**Mean**	**Total Mean (Vertical + Horizontal + Orientation)**
P3	F				0.000	1			0.333	1		0.500	0.833
P6	F	1			0.333			1	0.333		1	0.500	1.167
P9	M		1		0.333	1			0.333	1		0.500	1.167
P12	M		1		0.333			1	0.333			0.000	0.667
P15	M		1	1	0.667				0.000			0.000	0.667
P18	M			1	0.333				0.000			0.000	0.333
P21	M		1		0.333	1		1	0.667	1		0.500	1.500
P24	F				0.000	1		1	0.667	1		0.500	1.167
P27	M		1		0.333				0.000			0.000	0.333
P30	M				0.000	1	1	1	1.000	1		0.500	1.500
				Mean	**0.267**				**0.367**			**0.300**	**0.933**
				SD	**0.211**				**0.331**			**0.258**	**0.432**

Appendix C

A usability study of the milk processing VR application

C.1 Related forms

Research Information Sheet for Software Evaluations
Lincoln University

Department of Applied Computing, FESD

You are invited to participate as a subject in a project entitled Immersive Learning through Virtual Reality. The aim of this project is to investigate the usability issues of the Virtual Reality (VR) application for exploring a process plant. This session will take about 20-25 minutes. If you participate in this project:

You will be asked to navigate the Fonterra VR application according to a set of prescribed tasks. You will be given a demonstration beforehand and will be allowed to practise to familiarise yourself with the VR application before performing a list of tasks. You need to 'think aloud' while performing the tasks.

Upon the completion of the tasks, you will be asked to complete a questionnaire and answer some questions at the end of the session.

A video recorder will be used while you carry out the tasks and also during the question and answer session. The recorded video will be used for data analysis purposes only. The researcher will observe and make notes about your use of the software.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Only the researcher and supervisor will have access to the raw data. To ensure anonymity and confidentiality, individual participants will not be identifiable in any results or publication. We will record the ID number only so that we can withdraw your results from the research if you ask us to.

You may withdraw your participation at any time prior to publication, including the withdrawal of any information you have provided. However, by signing the consent form attached, it is understood that you have consented to participate in this experiment and to publication of the results, with the understanding that anonymity will be preserved. The project is being carried out by:

Name of principal researcher Elin Abdul Rahim

Contact details elineliana.abdulrahim2@lincolnuni.ac.nz

She will be pleased to discuss any concerns you have about participation in the project.

A template for projects to evaluate software has been reviewed and approved by the Lincoln University Human Ethics Committee. This particular project has been confirmed by the Head of the Department of Applied Computing as meeting that template. If you have any concerns about this project you are invited to contact the Head of Department.

Head of Department of Applied Computing ______________________________

Contact Details ____

Consent Form for Requirements and/or Software Evaluation

Name of Project: **Immersive Learning through Virtual Reality**

- I have read and understood the research information sheet for the above-named project.
- On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.
- I understand also that I may at any time prior to publication withdraw from the project, including withdrawal of any information I have provided.

Signed: ____ Date: _____________

ID: _________

(This number will be recorded with your data only so we can withdraw it at your request)

General information form **ID:___**

Please answer the following questions.

1. ☐ Male ☐ Female

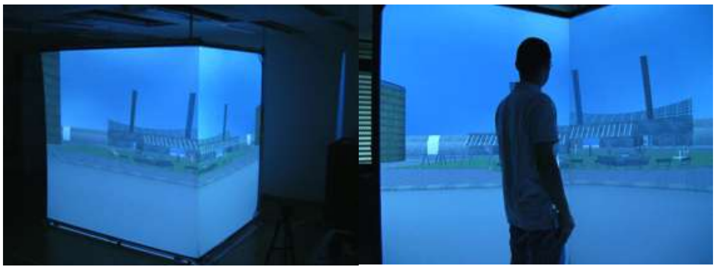
2. Have you used any other virtual reality (VR) software before?

☐ Yes ☐ No

If **yes**, please provide the following details:

☐ Immersive VR, please state (e.g: Cave Automatic Virtual Environment (CAVE), Head Mounted Display (HMD), etc.)

Example of a CAVE:



(Source: (http://archiveweb.epfl.ch/vrlab.epfl.ch/infrastructure/infrastructure_index.html)

Frequency of use:

☐ Never

☐ Less than once a month

☐ Once a month

☐ A few times a month

☐ A few times a week

☐ About once a day

☐ Several times a day

☐ Non immersive VR (desktop VR), please state (e.g: computer games, education software):

Example of a desktop VR:

(Source: http://www.panoramas.dk/2011/salt-lake-city.html)

Frequency of use:

- ☐ Never
- ☐ Less than once a month
- ☐ Once a month
- ☐ A few times a month
- ☐ A few times a week
- ☐ About once a day
- ☐ Several times a day

C.2 General usability questionnaire

Please rate your agreement with the following statements on a scale of 1 to 6, where: 1 = "Completely disagree" and 6 = "Completely agree".

Statements	Scale of Agreement					
	Completely Disagree ---	--	-	+	++	Completely Agree +++
I felt lost when I was in the virtual environment (VE) of the plant.	☐	☐	☐	☐	☐	☐
The 3D map was useful in assisting my navigation around the plant.	☐	☐	☐	☐	☐	☐
The 3D map was useful in showing me where I am in the virtual environment (VE).	☐	☐	☐	☐	☐	☐
The figure on the 3D map was useful in showing me the actual scale of the process plant.	☐	☐	☐	☐	☐	☐
The 3D map was useful in showing me the actual scale of the process plant.	☐	☐	☐	☐	☐	☐
The colour coordination in the 3D map (e.g., different colours used to highlight the equipment involved in the same processes) helps me to understand the various processes involved in the area.	☐	☐	☐	☐	☐	☐
I used the nodes on the PFD to move around the plant.	☐	☐	☐	☐	☐	☐
I used the arrows in the Info Panel to move around the plant.	☐	☐	☐	☐	☐	☐
The nodes on the PFD provide me with an understanding of the process related in the milk processing.	☐	☐	☐	☐	☐	☐
The navigation sequence was useful in assisting me to understand the processes involved in milk processing.	☐	☐	☐	☐	☐	☐
Displaying additional info (e.g., videos) was easy.	☐	☐	☐	☐	☐	☐
I knew in which direction I was facing while I was in the plant.	☐	☐	☐	☐	☐	☐
The green hotspots (highlighted equipment) helped me to identify the specific pieces of equipment in the plant.	☐	☐	☐	☐	☐	☐
The hotspots (highlighted in green) were clearly highlighted.	☐	☐	☐	☐	☐	☐
I felt dizzy when I was navigating the plant.	☐	☐	☐	☐	☐	☐
I like the layout of the VR application (the location of the Info Panel, 3D map, diagrams, VE, etc.).	☐	☐	☐	☐	☐	☐
The links between the diagrams, the VE, the 3D model and the additional information (text and graphics) were useful in helping me to understand the various processes in the process plant	☐	☐	☐	☐	☐	☐

C.3 USE questionnaire

Please rate your agreement with the following statements about the VR application on a scale of 1 to 7, where: 1 = "Strongly disagree" and 7 = "Strongly agree".

Statements	Strongly disagree 1	2	3	4	5	6	Strongly agree 7
It is easy to use.	1	2	3	4	5	6	7
I can use it without written instructions.	1	2	3	4	5	6	7
I don't notice any inconsistencies as I use it.	1	2	3	4	5	6	7
I can recover from mistakes quickly and easily.	1	2	3	4	5	6	7
I learned to use it quickly.	1	2	3	4	5	6	7
I easily remember how to use it.	1	2	3	4	5	6	7
I am satisfied with it.	1	2	3	4	5	6	7
It is fun to use.	1	2	3	4	5	6	7
It works the way I want it to work.	1	2	3	4	5	6	7

Appendix D

Students' attitudes towards virtual field trips

D.1 Questionnaire related to the physical field trip (Questionnaire-PFT)

Statements	Strongly disagree 1	2	3	Strongly Agree 4
The field trip helps in understanding the materials learned in class.	1	2	3	4
What I like best about field trips are the jokes told by my friends.	1	2	3	4
The field trip is a waste of time.	1	2	3	4
I would like to participate in more field trips since this is a good way to learn the subject.	1	2	3	4
I would like to have more field trips since they are a lot of fun.	1	2	3	4
The things I observe in the field trip do not help me to understanding the material taught in class.	1	2	3	4
It is a pity that we do not have more field trips, since this is an enjoyable way to learn.	1	2	3	4
I return from field trips with a lot of experiences.	1	2	3	4
After a field trip, I do not remember the explanations given by the guide.	1	2	3	4
The field trip is important since it demonstrates and illustrates the concepts learned in class.	1	2	3	4
In the field trip, working with paper-based materials (e.g: diagrams, notes) interferes with my enjoyment of the event.	1	2	3	4
The material learned during a field trip will remain in my memory for a long time.	1	2	3	4
The good atmosphere with my friends during a field trip is the main reason for me enjoying the event.	1	2	3	4
Working individually during a field trip is important for understanding the learning material.	1	2	3	4
I would like to have more field trips, since they help in building class spirit.	1	2	3	4
Learning in the classroom is more effective than learning during a field trip.	1	2	3	4
The field trip increases my enjoyment of the subject matter.	1	2	3	4
The field trip does not increase my interest in the learning material.	1	2	3	4
For me, the field trip is important, since it helps in getting to know more friends.	1	2	3	4
I understand the process involved in the process plant better after observing them in a field trip.	1	2	3	4
Field trips make me take an interest in and search for additional information in the literature.	1	2	3	4
The comments and jokes made by my classmates during a field trip interfere with my ability to concentrate on learning.	1	2	3	4

Q1. In what way(s) has your field trip experience contributed to your learning of process engineering?

Q2. State the parts you enjoyed in the field trip and why you enjoyed them. Please be specific. You may provide more than one items.

Q3. State the parts you did not enjoy in the field trip and why. Please be specific. You may provide more than one items.

D.2 Questionnaire related to the virtual field trip (Questionnaire-VFT)

Statements	Strongly disagree 1	2	3	Strongly Agree 4
The virtual field trip helps in understanding the materials learned in class.	1	2	3	4
The virtual field trip is a waste of time.	1	2	3	4
I would like to participate in more virtual field trips since this is a good way to learn the subject.	1	2	3	4
I would like to have more virtual field trips since they are a lot of fun.	1	2	3	4
The things I observe in the virtual field trip do not help me to understanding the material taught in class.	1	2	3	4
It is a pity that we do not have more virtual field trips, since this is an enjoyable way to learn.	1	2	3	4
I return from virtual field trips with a lot of experiences.	1	2	3	4
After a virtual field trip, I do not remember the explanations given by the guide.	1	2	3	4
The virtual field trip is important since it demonstrates and illustrates the concepts learned in class.	1	2	3	4
The material learned during a virtual field trip will remain in my memory for a long time.	1	2	3	4
The good atmosphere with my friends during a virtual field trip is the main reason for me enjoying the event.	1	2	3	4
Working individually during a virtual field trip is important for understanding the learning material.	1	2	3	4
I would like to have more virtual field trips, since they help in building class spirit.	1	2	3	4
Learning in the classroom is more effective than learning during a virtual field trip.	1	2	3	4
The virtual field trip increases my enjoyment of the subject matter.	1	2	3	4
The virtual field trip does not increase my interest in the learning material.	1	2	3	4
For me, the virtual field trip is important, since it helps in getting to know more friends.	1	2	3	4
I understand the process involved in the process plant better after observing them in a virtual field trip.	1	2	3	4
Virtual field trips make me take an interest in and search for additional information in the literature.	1	2	3	4

Statements	Strongly disagree 1	2	3	4	Strongly Agree 5
1. I learned a lot from the VR application.	1	2	3	4	5
2. The VR application covers the same sorts of things as one would encounter during a field trip.	1	2	3	4	5
3. The VR application could be used in place of a physical field trip.	1	2	3	4	5
4. It would be good to use the VR application as a way of preparing me for a physical field trip.	1	2	3	4	5
5. It would be good to use the VR application as a revision tool after the physical field trip.	1	2	3	4	5
6. I would like to see more use of VR in university teaching.	1	2	3	4	5

Note: Statement 2 was only included in the questionnaire given to the students who attended the physical field trip.

Q1. In what way(s) has your virtual field trip experience contributed to your learning of process engineering?

Q2. State the parts you enjoyed in this virtual field trip and why you enjoyed them. Please be specific. You may provide more than one items.

Q3. State the parts you did not enjoy in this virtual field trip and why. Please be specific. You may provide more than one items.

Q4. What suggestions do you have for improving the virtual field trip experiences if this study were replicated?

D.3 Group interviews

The outline of the questions is:

- What do you think about the recent field trips?
- What do you like/did not like about the trip?
- From the answer, where appropriate :

  Please tell me more about ….?

  Could you explain what do you mean by ….?

  Could you give an example of…?

D.4 Consent form

Research Information Sheet for Software Evaluations
Lincoln University

Department of Applied Computing, FESD

You are invited to participate as a subject in a project entitled

Name of project Students' attitudes towards virtual field trips

The aim of this project is to investigate the students' attitudes towards virtual field trips. This session will take about 1.5 hour.

When you participate in this study:

You will be asked to answer some tests/questions (e.g: questionnaires, discussion, etc.) before and after the virtual field trip session.

The researcher will observe and make notes about your use of the software. Your session will be recorded for analysis purposes.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Only the researcher and supervisor will have access to the raw data. To ensure anonymity and confidentiality, individual participants will not be identifiable in any results or publication. We will record the ID number only so that we can withdraw your results from the research if you ask us to.

You may withdraw your participation at any time, including the withdrawal of any information you have provided. However, by signing the consent form attached, it is understood that you have consented to participate in this experiment and to publication of the results, with the understanding that anonymity will be preserved.

The project is being carried out by:

Name of principal researcher *Elin Eliana Abdul Rahim*

Contact details *elineliana.abdulrahim2@lincolnuni.ac.nz*

She will be pleased to discuss any concerns you have about participation in the project.

A template for projects to evaluate software has been reviewed and approved by the Lincoln University Human Ethics Committee. This particular project has been confirmed by the Head of the Department of Applied Computing as meeting that template. If you have any concerns about this project you are invited to contact the Head of Department.

Head of Department of Applied Computing ______________________________

Contact Details ____

Consent Form for Requirements and/or Software Evaluation

Name of Project: Students' attitudes towards virtual field trips

- I have read and understood the research information sheet for the above-named project.
- On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.
- I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.

Signed: ____ Date: ____________

ID: _________

(This number will be recorded with your data only so we can withdraw it at your request)

Appendix E

The learning assessment comparing the VR application to paper-based learning material

E.1 Questionnaire (VR group)

Please rate your agreement with the following statements on a scale of 1 to 6, where: 1 = "Completely disagree" and 6 = "Completely agree".

Statements	Scale of Agreement					
	Completely disagree 1	2	3	4	5	Completely agree 6
I often was not aware of my location within the virtual plant.	1	2	3	4	5	6
The 3D map was useful in showing me where I am in the virtual environment (VE).	1	2	3	4	5	6
The 3D models of the dryer and evaporators were useful in showing me the actual scale of the process plant.	1	2	3	4	5	6
I knew in which direction I was facing while I was in the plant.	1	2	3	4	5	6
I frequently used the buttons on the PFD to move around the plant.	1	2	3	4	5	6
I frequently used the arrows in the Info Panel to move through the plant.	1	2	3	4	5	6
The green hotspots (high-lighted elements) helped me to identify the specific pieces of equipment in the plant.	1	2	3	4	5	6
The green hotspots were clearly visible.	1	2	3	4	5	6
I like the layout of the VR application (the location of the Info Panel, 3D map, diagrams, Photographs, etc.).	1	2	3	4	5	6
The links between the diagrams, the VE, the 3D model and the additional information (text and graphics) were useful in helping me to understand the various processes in the process plant	1	2	3	4	5	6
The quality of the P&ID drawings was good.	1	2	3	4	5	6
The detailed PFD was easy to read.	1	2	3	4	5	6
The simplified PFD was useful in providing me with the overall picture of the milk powder process.	1	2	3	4	5	6
The respective process streams in the P&ID are presented clearly.	1	2	3	4	5	6
The text information was easy to read.	1	2	3	4	5	6
The text information was easy to understand.	1	2	3	4	5	6

E.2 Questionnaire (Paper group)

Please rate your agreement with the following statements on a scale of 1 to 6, where: 1 = "Completely disagree" and 6 = "Completely agree".

Statements	Scale of Agreement					
	Completely disagree 1	2	3	4	5	Completely agree 6
The 3D models of the dryer and evaporators were useful in showing me the actual scale of the process plant.	1	2	3	4	5	6
The handouts presented the information clearly .	1	2	3	4	5	6
I like the layout of the handouts.	1	2	3	4	5	6
The graphics were useful in helping me to understand the various processes in the process plant.	1	2	3	4	5	6
The graphics that complement the text information make the handout interesting.	1	2	3	4	5	6
The simplified PFD was useful in providing me with the overall picture of the milk powder process.	1	2	3	4	5	6
The detailed PFD was easy to read.	1	2	3	4	5	6
The quality of the P&ID drawings was good.	1	2	3	4	5	6
The respective process streams in the P&ID are presented clearly.	1	2	3	4	5	6
The text information was easy to read.	1	2	3	4	5	6
The text information was easy to understand.	1	2	3	4	5	6

E.3 USE Questionnaire (VR group)

Please rate your agreement with the following statements about the hand-out on a scale of 1 to 7, where: 1 = "Strongly disagree" and 7 = "Strongly agree".

Ease of Use	Strongly disagree 1	2	3	4	5	6	Strongly agree 7
It helps me be more productive.	1	2	3	4	5	6	7
It is useful.	1	2	3	4	5	6	7
It saves my time when I use it.	1	2	3	4	5	6	7
It meets my needs.	1	2	3	4	5	6	7
It is easy to use.	1	2	3	4	5	6	7
Using it is effortless.	1	2	3	4	5	6	7
I can use it without written instructions.	1	2	3	4	5	6	7
I don't notice any inconsistencies as I use it.	1	2	3	4	5	6	7
I learned to use it quickly.	1	2	3	4	5	6	7
I easily remember how to use it.	1	2	3	4	5	6	7
I am satisfied with it.	1	2	3	4	5	6	7
I would recommend it to a friend.							
It is fun to use.	1	2	3	4	5	6	7
I feel I need to have it.	1	2	3	4	5	6	7
It works the way I want it to work.	1	2	3	4	5	6	7

E.4 USE Questionnaire (Paper group)

Please rate your agreement with the following statements about the hand-out on a scale of 1 to 7, where: 1 = "Strongly disagree" and 7 = "Strongly agree".

Ease of Use	Strongly disagree 1	2	3	4	5	6	Strongly agree 7
It helps me be more productive.	1	2	3	4	5	6	7
It is useful.	1	2	3	4	5	6	7
It saves my time when I use it.	1	2	3	4	5	6	7
It meets my needs.	1	2	3	4	5	6	7
It is easy to use.	1	2	3	4	5	6	7
Using it is effortless.	1	2	3	4	5	6	7
I can use it without written instructions.	1	2	3	4	5	6	7
I don't notice any inconsistencies as I use it.	1	2	3	4	5	6	7
I am satisfied with it.	1	2	3	4	5	6	7
I would recommend it to a friend.	1	2	3	4	5	6	7
It is fun to use.	1	2	3	4	5	6	7
I feel I need to have it.	1	2	3	4	5	6	7

E.5 A shortened version of the Index of Learning Style (ILS) questionnaire (adapted from Felder & Solomon, 1991)

Please **ANSWER ALL QUESTIONS.** Please choose **ONLY ONE ANSWER** for each question. If both “a” and “b” seem to apply to you, choose the one that applies more frequently.

1. When I think about what I did yesterday, I am most likely to get
   a) a picture.
   b) words.
2. I prefer to get new information in
   a) pictures, diagrams, graphs, or maps.
   b) written directions or verbal information.
3. In a book with lots of pictures and charts, I am likely to
   a) look over the pictures and charts carefully.
   b) focus on the written text.
4. I like teachers
   a) who put a lot of diagrams on the board.
   b) who spend a lot of time explaining.
5. I remember best
   a) what I see.
   b) what I hear.
6. When I get directions to a new place, I prefer
   a) a map.
   b) written instructions.
7. When I see a diagram or sketch in class, I am most likely to remember
   a) the picture.
   b) what the instructor said about it.
8. When someone is showing me data, I prefer
   a) charts or graphs.
   b) text summarizing the results.
9. When I meet people at a party, I am more likely to remember
   a) what they looked like.
   b) what they said about themselves.
10. For entertainment, I would rather
    a) watch television.
    b) read a book.
11. I tend to picture places I have been
    a) easily and fairly accurately.
    b) with difficulty and without much detail. 25