Chapter 1

INTRODUCTION

1.0 Background

The major concern of educators is how to enhance the outcome of education. Effective education media used to assist teaching have been constantly sought by the researchers in educational technology. Virtual Reality (VR) has been identified as one of them. One of the reasons that VR is being used in educational settings is because it provides interactive and complex three-dimensional (3-D) structures in a highly realistic manner and gives the users a sense of “being there” (Ausburn & Ausburn, 2004; Ausburn & Ausburn, 2008; Ausburn et al., 2009; Chuah, Chen, & Teh, 2008; Inoue, 2007; Lee & Wong, 2008). VR can range from fully immersive environments where the users interact with the virtual world with complex head-mounted devices (HMDs), voice activation and body suits, to non-immersive desktop environments that are based on realistic PC imagery (Ausburn & Ausburn, 2004; Ausburn & Ausburn, 2008, Ausburn et al., 2009; Beier, 2004). VR technology is believed to be able to help learners to learn better in a less traditional and less structured learning environment.

With VR technology, an open learning environment is possible where learners are given relevant information and resources to support their learning. Furthermore, learners can control their own learning, identify the learning goals and construct their
own knowledge and meanings, thus learning is more student-centered (Cradler, 1997; Hannafin et al., 2008).

Proponents of the VR-based learning environment suggest that VR can help to improve the learning outcomes by engaging students in authentic learning. Many associate VR with science fiction, high-tech industries and computer games but very few with education (Strangman & Hall, 2003). However, not only has VR been used as an educational tool for some time in applied fields such as aviation and medical imaging, it has begun to edge its way into the primary and secondary classrooms (Strangman & Hall, 2003). Furthermore, VR on the Internet, which can be accessed using Virtual Reality Modeling Language (VRML) and eXtensible 3D Graphic (X3D), has changed the potential of web-based learning (Ieronutti & Chittaro, 2007). With the development and maturity of the Web3D technology, it is possible to provide a shared-virtual environment to support and enable collaborative learning through synchronous and/or asynchronous communication (Chen & Teh, 2000; Zhang & Yang, 2009).

VR is a cutting edge technology that allows learners to explore and manipulate 3-D interactive environments (Chen et al., 2004; Strangman & Hall, 2003). The benefits of using VR technology in the teaching and learning process have increasingly gained recognition from researchers and instructional designers (Chen et al., 2004). Pantelidis (1995) has listed some reasons to use VR in education. Among them are that VR provides motivation to learn; VR allows observation from multiple perspectives, which encourages diverse ways of thinking; VR allows learners to
proceed through an experience at their own pace; and VR encourages active participation (Pantelidis, 1995).

Although VR has been recognized as an alternative tool in education, the need for expensive HMDs, gloves, suits and high-end computer systems has somehow restricted its use in schools or colleges. However, a rapid fall in computer prices, a huge leap in the processing power of personal computers, the availability of broadband computer access and the proliferation of the World Wide Web has unleashed new opportunities for educators to use non-immersive VR that runs on a desktop computer as an alternative or a supplement to the traditional way of teaching (Lee, Wong, & Fung, 2009a; McArdle, Monahan, & Mangina, 2004; McLellan, 2004; Yang & Heh, 2007). This non-immersive or desktop VR system can be explored using conventional input devices such as a keyboard and mouse without any additional costly peripheral devices (Chen et al. 2004; Inoue, 2007). This relatively low cost VR system has become increasingly prevalent (Fox, Arena & Bailenson, 2009). According to Youngblut (1998), such non-immersive technology is much more mature and ubiquitously used in many different application areas as compared with the immersive technology. Non-immersive desktop VR is very accessible. It can be easily distributed via the World Wide Web and on compact disc (Allen et al., 2002). In fact, it is the most widely used form of VR in use today (Allen at al., 2002; Fox et al., 2009).

Recent research has shown an encouraging array of positive learning outcomes with VR. Findings include positive effects on students’ learning of geometry topics (Song
& Lee, 2002), better learning in geosciences (Li et al., 2002), a useful training system for astronaut 3-D navigation (Aoki et al., 2008), better spatial understanding of architectural spaces (Youngblut, 1998), and more accurate and complete understanding of engineering concepts (Bell & Fogler, 1995). With 3-D impression of objects and their structures, depth cues are available for learners to construct a mental model of the objects and its component (Huk, 2006). Depth cues can be incorporated into static pictures and dynamic representations of a VR program. Viewing dynamic and 3-D animations is assumed to have a positive effect on changing and improving students’ incomplete mental models (Huk, 2006; Wu & Shah, 2004). Apart from these, research findings have also shown that learners enjoy their VR educational experiences and see the potential of VR in instruction (Barnett, Yamagata-Lynch, Keating, Barab, & Hay, 2005).

Although these new and emerging technologies have significant potential to improve student learning, Barnett et al. (2005) point out the need to examine the aspects of this technology that are best leveraged for improving students’ understanding of mathematical and scientific concepts. Furthermore, as with any other instructional media, VR should not be seen as a panacea that will work for all kinds of learning problems, despite the positive findings of some research (Chen, 2005; Sanchez, Barreiro, & Maojo, 2000; Strangmen & Hall, 2003).

1.1 Problem Statement

VR is hypothesized to be an excellent educational tool because it offers the opportunity to visualize, explore, manipulate and interact with objects within a
computer generated environment (Crumpton & Harden, 1997), which allows for discovery and self-paced learning. A more student-centered approach of instruction is possible with the use of VR. Nevertheless, VR is just an educational tool which can be used to support learning and it might not work for all kinds of learning. In spite of the positive findings of some research, it would be premature to make broad recommendations regarding the use of VR for curriculum enhancement (Strangman & Hall, 2003), and it should not be used indiscriminately in any educational program (Sanchez et al., 2000). Furthermore, there have been few studies that compare the effectiveness of VR against non-VR teaching practices to support the use of VR in learning (Crosier, Cobb, & Wilson, 2000; Youngblut, 1998). There have also been few studies that investigated the effects of individual differences in VR-based learning (Crosier et al., 2000).

According to Gustafson (2002), the low cost 3-D visualizations and walk-around VR will revolutionize how people of all ages learn and work. These technologies have the potential to facilitate the acquisition of higher-order thinking and problem solving skills (Rieber, 1996). However, they too believe that there is much research and development that needs to be done. These issues include:

- Investigate how the attributes of VR technology are able to support and enhance learning in a way that the conventional instructional methods are not able to, and find whether the use of VR can improve the intended performance and understanding.

- Investigate the impact of VR on learners with different aptitudes.
VR is a learning tool that can support learning as suggested by Jonassen, Peck, & Wilson (1999) who stated that technologies can support and facilitate learning. Moreover, VR can support the constructivist learning model that assumes individuals learn better when they discover things by themselves and when they can control the pace of learning to construct new knowledge (Chen & Teh, 2000; Chen & Toh, 2005, Sung & Ou, 2002). However, if VR technology is to be used to support meaningful and constructivist learning, then the relevant constructs and their relationships that help to achieve this goal need to be examined. To investigate how the attribute of VR technology is able to support and enhance learning in a learning environment that supports the constructivist learning model, the pedagogical benefits of VR as a learning tool need to be examined in a more comprehensive way.

This study focuses on non-immersive desktop VR although there are different types of VR. Though some work on factors that influence the learning outcomes has been done for the immersive VR environment, a broad framework that identifies the theoretical constructs and their causal relationships in this domain has yet to be developed for a desktop VR-based learning environment. Relevant constructs or factors such as student characteristics, interaction experience, and learning experience that could affect the learning outcomes should be considered. Relevant constructs and their relationships need to be examined for the effective use of VR in education because all these constructs play an important role in shaping the learning outcomes (Salzman, Dede, Loftin, & Chen, 1999; Wan, Fang, & Neufeld, 2007). Strangman and Hall (2003) also mentioned that factors influencing computer simulations have not been extensively or systematically examined. Moreover, there
is limited research in the exploration of VR-based learning that addresses the issue of ‘How can VR technology enhance learning outcomes?’ rather than just ‘Does VR technology influence learning outcomes?’

Furthermore, there is a lack of greater depth of research in VR-based learning that investigates the influence of psychological factors on learning. It is a challenge and an outstanding task to study the right and applicable use of VR in education (Sanchez et al., 2000). There is still limited research that addresses the questions posed by Sanchez et al. (2000): How are VR systems capable of improving the quality of student learning? What kinds of student require this technology? According to Ausburn & Ausburn (2008), there are not many studies that explore and explain the effects of desktop VR in terms of theoretical perspectives and models. Indeed, there have been limited attempts to introduce theoretical frameworks and models that consider explicitly the use of desktop VR in education that can help desktop VR practitioners to understand how this technology enhances learning outcomes. This study aims to fill this gap.

In addition, work in VR has focused primarily on refining and improving the technology and developing applications (McLellan, 2004, p. 474). More VR research is needed to investigate the emotional and cognitive dimension of human experience in the virtual world rather than just technical issues such as providing sensory immersion (McLellan, 2004). Research in VR and education is a relatively young field (Adamo-Villani & Wilbur, 2007; Inoue, 2007). More research is needed to justify the benefits of using VR for learning and to investigate VR for different
applications of learning (Inoue, 2007; McLellan, 2004). Ausburn and Ausburn (2008, p. 60) mentioned that “research on the effectiveness of desktop VR has as yet been minimal, and still falls far short of establishing empirical support for instructional uses of desktop environments.” Moreover, it is this PC-based technology that makes VR more accessible to educators in schools and colleges, both technically and economically (Ausburn & Ausburn, 2008; Strangman & Hall 2003; Youngblut, 1998). Thus, this research articulates a research agenda specific to desktop VR and education. The issues investigated include: (1) the learning effectiveness of a desktop VR compared to a traditional learning environment; (2) the impact of desktop VR on learners with different aptitudes; and (3) how desktop VR enhances learning outcomes in a learning environment that supports constructivist learning.

1.2 Purpose of the Study

In view of the fact that effective learning is the ultimate aim of new technology in teaching and learning, it is crucial to perform educational effectiveness evaluation. Hence, the purpose of this study is to investigate the learning effectiveness of a desktop VR-based learning environment and to develop a theoretical model for evaluating how desktop VR enhances learning outcomes that could guide future developmental efforts. A critical step towards achieving an informed design of a VR-based learning environment is the investigation of the interplay among VR affordances and other factors such as the student characteristics, the interaction experiences and learning experiences (Salzman et al., 1999). By understanding how these factors work together to shape learning, instructional designers will be better
able to target learning and visualization problems with the appropriate affordances and to maximize the benefits of VR technology (Salzman et al., 1999, p. 42). Thus, this study aims to do more in-depth research by investigating the various relevant constructs and their relationships that play a vital role in enhancing the learning outcomes in a desktop VR-based learning environment, besides investigating “Does desktop VR influence the learning outcomes?” If desktop VR can facilitate learning, then it is vital to investigate the interaction and learning experiences of the learners unique to the desktop VR-based learning environment. As mentioned by Jones et al. (1996, p. 9), “in judging the effectiveness of computer-assisted learning (CAL), one important problem will be to determine the extent to which desired outcomes are attained and establish the causal link between CAL and the learning that has taken place.” Emphasis is on the process and experience when learning with CAL rather than the product.

A desktop VR system is used for the VR-based learning environment in this study. It is a highly interactive 3-D computer generated program in a multimedia environment, which is implemented on a conventional personal computer without introducing any additional peripheral devices such as head-mounted displays, gloves, suits and high-end computer systems (Chen et al. 2004; Inoue, 2007). Users can navigate and manipulate the virtual object in the virtual world and the interaction can be observed by the users in real time.
The research questions addressed in this study are:

1) Is there any difference in the learning outcomes (performance achievement, perceived learning effectiveness and satisfaction) between desktop VR-based learning (VR mode) and conventional classroom learning practice (Non-VR mode)?

2) What are the effects of learners’ aptitudes (spatial ability and learning style) on learning?

3) Is there a difference in the learning outcomes for high and low spatial ability learners in the VR mode?

4) Is there a difference in the overall improvement in performance for high and low spatial ability learners in the VR mode?

5) Is there a difference in the learning outcomes for accommodator learners and assimilator learners in the VR mode?

6) Is there a difference in the overall improvement in performance for accommodator learners and assimilator learners in the VR mode?

7) What are the relevant constructs that play an important role in a desktop VR-based learning environment?

8) How do these constructs interrelate to enhance the VR-based learning effectiveness?

1.3 Research Objectives

The specific objectives of this study are thus:

1) to compare the learning effectiveness between desktop VR-based learning and conventional classroom teaching practice;
2) to investigate the moderating effect of student characteristics on the learning mode with respect to learning outcomes;

3) to investigate the difference in the learning outcomes for students with different characteristics in the VR mode;

4) to investigate the difference in the overall improvement in performance for students with different characteristics in the VR mode;

5) to identify the relevant constructs in a desktop VR-based learning environment; and

6) to determine the relationships of the relevant constructs that influence the learning outcomes in a desktop VR-based learning environment.

1.4 Research Approaches

A research framework as shown in Figure 1.1 is first proposed to guide the evaluation of the desktop VR-based learning environment as compared to the conventional classroom learning method. Based on the model of Salzman et al. (1999) and technology-mediated learning models, a conceptual framework as shown in Figure 1.2 is developed for the purpose of evaluating how desktop VR enhances the learning outcomes. The target population is senior high school science students aged between 15 and 17 years old. An evaluation that employs a quasi-experimental design is conducted to investigate the learning effectiveness of a desktop VR-based learning environment. Through a survey with objective and subjective measurements, the investigation on how desktop VR enhances the learning outcomes is further conducted.
Figure 1.1: Research framework for determining the effects of a desktop VR-based learning environment and aptitude-by-treatment interaction research.

Independent Variable
Learning Mode
VR Mode — VR-based learning environment
Non-VR Mode — Conventional classroom learning method

Dependent Variables (Learning Outcomes)
- Performance Achievement (Posttest Score)
- Perceived Learning Effectiveness
- Satisfaction

Moderator variables (Student Characteristics)
- Spatial Abilities
- Learning Styles

Independent Variable
(VR Features)
- Representational Fidelity
- Immediacy of Control

Mediator Variables (Interaction Experience - Usability)
- Perceived Usefulness
- Perceived Ease of Use

Mediator Variables (Learning Experience - Psychological Factors)
- Presence
- Motivation
- Cognitive Benefits
- Control & Active Learning
- Reflective Thinking

Dependent Variables (Learning Outcomes)
- Performance Achievement
- Perceived Learning Effectiveness
- Satisfaction

Mediator Variables (Interaction Experience - Usability)
- Perceived Usefulness
- Perceived Ease of Use

Moderator Variables (Student Characteristics)
- Spatial Abilities
- Learning Styles

Figure 1.2: Conceptual framework for outcomes and their causal relationships in a desktop VR-based learning environment.
1.5 Significance of Research

The findings of this research would help to verify the learning effectiveness of desktop VR-based learning. For years, student-centered learning has been advocated by educators to improve the learning experience and learning outcomes. VR has the potential to empower student-centered learning, but until its impact on students is studied, it cannot be fully recognized as a curriculum enhancement. Furthermore, VR-based learning has been heralded as providing instruction that accommodates learners’ individual difference, such as learning styles and spatial abilities. While intuitively appealing, empirical research has not confirmed or rejected this assumption. Nor is there compelling evidence to suggest that learners with different learning styles and spatial abilities benefit equally from a desktop VR-based learning environment. Thus, the aptitude-by-treatment interaction (ATI) research conducted in this study would illustrate the effect of a desktop VR-based learning environment and a traditional teaching practice on learning for learners with different spatial abilities and learning styles.

The understanding of how these individual differences interact with different learning environments could help the instructors to identify instructional treatments that facilitate individualized learning, and also to provide evidence that VR could accommodate learners’ individual differences. Furthermore, the findings are important to educational administrators and educational planners at the federal, state, county, city and school levels because the effectiveness and successfulness of VR as an educational tool could have important implications for course planning, budgets,
purchasing of computer hardware and software and also supporting software development.

While the interest in using VR in education is growing rapidly, a broad framework and model that identify the theoretical constructs and relationships in this domain for a desktop VR-based learning environment have yet to be developed and realized. This research aims to fill this gap. Relevant constructs and their relationships need to be examined for the effective use of VR in education. All these constructs play an important role in shaping the learning process and learning outcomes (Salzman et al., 1999; Wan et al., 2007).

Through this research, an initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment is contributed. It should bring VR practitioners one step closer to understanding how VR can be used to support and enhance learning. The model shows that the link between VR affordances and learning occurs within a web of other relationships. The research findings will help to identify if authentic learning with multiple representations will enhance learning; which VR features are prominent; which characteristics of the learners require careful attention; and which facets of the constructs play a substantial role in shaping learning outcomes (e.g. which psychological factors play a more significant role in influencing the learning outcomes). In other words, this research not only focuses on “Does VR technology influence learning outcomes?” but also “How does VR technology enhance learning outcomes?” This theoretical
model is relevant for instructors, instructional designers and software developers who are interested in providing students with VR technology for the future.

Educators are constantly looking for new, innovative and, most importantly, effective ways to improve the learning experience of their students (Kaser, 1996). Thus, it is important for instructional designers and VR software developers to know which learning experiences play a substantial role in shaping students’ learning. For the concept of the psychological factors (e.g. presence and motivation) to be useful and applicable in practical situations, it is thus important to understand the results or consequences of the psychological factors in a desktop VR-based learning environment. The findings on the psychological aspect of learning experiences in this study would be beneficial to instructional designers and VR software developers as they would leverage the VR features to enhance the desired learning experiences that play a significant role in improving the learning outcomes.

The findings on the prominence of the VR features would enable the VR software developers to best leverage the VR affordance for learning. An interesting, appealing and engaging learning environment is made possible with the attributes of VR. However, such a learning environment might not be well accepted by all learners. Indeed, according to Dalgarno et al., (2002), a virtual environment with a high degree of fidelity and immediacy of control that is modeled on a real world scenario will not necessarily facilitate learning, and thus may not be accepted by learners. The interaction experience with the learning environment could play a vital role in addressing this issue.
With regard to the interaction experience, this study will look into the usability aspect in terms of the perceived usefulness and perceived ease of use of the VR program based on the technology acceptance model (TAM) theorized by Davis (1989). It is believed that the beliefs and attitudes toward technology are the determinants of whether the technology will be accepted and thus influence the learning experiences and outcomes. The structural equation modeling (SEM) analysis on the interrelationships among VR affordances, interaction experience, learning experience and learning outcomes might enlighten VR software developers about the importance of considering interaction experience while designing and developing a VR-based learning environment.

The SEM analysis on the influence of student characteristics, such as spatial abilities and learning styles, in a VR-based learning environment would help to determine if VR could accommodate individual differences, that is, be able to support learners with different characteristics or if it benefits a certain group of learners. These findings would further enhance the benefit of using VR for learning. With such information, instructors could use VR to facilitate individualized learning.

To summarize, the results from this study could contribute to the limited literature on the theoretical frameworks and models for using desktop VR in learning. It is hoped that the results of this study could create awareness on the potentials and/or weaknesses of the current VR technology for use in teaching and learning. This research will make a significant contribution in enlightening educators and VR practitioners to the potential of desktop VR technology to support and enhance
learning. Furthermore, through this research, a broad framework that identifies the theoretical constructs and their relationship is developed and an initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment is contributed. The framework and model can be used as guidelines in the development of desktop VR-based learning environments.

1.6 Outline of the Thesis

This thesis is presented in eight chapters. Figure 1.3 is a visual overview of the thesis. The thesis initially explores the potential of VR for educational purposes and the overall research questions addressed in this research in Chapter 1.

Chapter 2 reviews the relevant literature on VR-based learning. It explains what VR is, the types of VR and their application in instructional settings and how VR could support the constructivist learning model. Related theories and models that form the theoretical foundation of a desktop VR-based learning environment are also reviewed.

Chapter 3 discusses the research framework to measure the effectiveness of a VR-based learning environment as compared to a conventional classroom learning practice, and the moderating effects of student characteristics on learning. It also elaborates the development of the conceptual framework, model and hypotheses for evaluating how desktop VR enhances the learning outcomes.
Chapter 4 provides a detailed description of the research methodology. It describes the research design, population and sample, instrument development, software, data collection procedures and data analysis techniques. Furthermore, it explains the
approach of using SEM to determine the fit of the hypothesized model. Finally, it presents the results of the pilot study.

Chapter 5 presents the results of this study. Chapter 5 focuses on the answers to “Does VR influence the learning outcomes?” The effects of a VR-based learning environment on the learning outcomes as compared to the conventional classroom learning method are reported. The results of the ATI research are presented, as well as the influence of individual differences on the VR learning mode.

Chapter 6 also presents the results of this study. However, it focuses on the answers to “How does VR enhance the learning outcomes?” This chapter provides the characteristics of the sample, the results of the measurement models and the structural model.

Chapter 7 discusses the results of this study. It first discusses the results of the learning effectiveness of a desktop VR-based learning environment and the ATI research and their implications. It then discusses the results of the model evaluation of how desktop VR enhances the learning outcomes, and their implications.

The final chapter, Chapter 8, provides a summary of the research and its contributions. Limitations of the research and future directions are explained as well as the implications of this study.
2.0 Overview

The purpose of the literature review is to set the foundation for the specific objectives of this study as described in Section 1.3. In a nutshell, this study aims to determine the learning effectiveness of a desktop VR-based learning environment and how a desktop VR-based learning environment could enhance the learning outcomes. This chapter explains what VR is and the different types of VR. It then provides a description of VR application in instructional settings and is followed by the learning model supported by VR, that is, the constructivist learning model. Next, the role of aptitude-by-treatment interaction with respect to learners’ spatial abilities and learning styles is discussed. Finally, the related models and frameworks that form the theoretical foundation of how a desktop VR-based learning environment could enhance the learning outcomes are presented.

2.1 What is VR?

VR can be described as a 3-D synthetic environment that allows users to interact intuitively in real time with the virtual world and provides a feeling of immersion for the users (Allen et al., 2002; Auld, 1995; Ausburn & Ausburn, 2004; Ausburn & Ausburn, 2008; Beier, 2004; Burdea & Coiffet, 2003; Pan et al., 2006; Roussou, 2004; Strangman & Hall, 2003). VR can range from simple environments presented on a desktop computer to fully immersive multisensory environments (Auld, 1995;
Ausburn & Ausburn, 2004; Ausburn & Ausburn, 2008; Inoue, 2007; Strangman & Hall, 2003). The power of VR lies in its possibility to simulate real or imaginary environments, it can be represented with text or with graphic, and there is an implicit element of interaction between the users and the computer-generated world (Allen et al., 2002; Auld, 1995; Burdea & Coiffet, 2003). In the VR world, one or many people can interact with the computer-generated environments in the way that they would interact with the real-world equivalents (Allen et al., 2002). The degree of interaction that users have in the VR world depends on the engineering within the world itself and the hardware that they use to interact with it (Allen et al., 2002). Interactivity contributes to the feeling of immersion that the user experiences (Allen et al., 2002; Burdea & Coiffet, 2003). The level of immersion is dependent upon the devices that are used and the kind of interactivity that is designed into the virtual world (Allen et al., 2002). In fact, interactivity and immersion are the core elements of VR that set it apart from other two- and three-dimensional graphics media (Allen et al., 2002; Burdea & Coiffet, 2003; Jayaram, 1997).

In brief, what makes VR an impressive tool for learning is, in addition to multimedia, VR allows learners to immerse in a 3-D environment and feel ‘in the middle of another environment’ that closely resembles reality (Chen et al., 2004; Inoue, 1999, 2007). As stated by Inoue (2007, p. 2), “In the VR world, the users believe that what they are doing is real, even though it is an artificially simulated phenomenon.” With other computer-based learning, learners are often distanced from the environments and objects.
2.2 Types of VR

Basically, VR can be classified into two major types based on the level of interaction and immersive environment (Ausburn & Ausburn, 2004; Beier, 2004; Inoue, 2007; Strangman & Hall, 2003). Immersive VR environments are presented on multiple, room-size screens or through a stereoscopic, head-mounted display unit (Chen et al., 2004; Dalgarno et al., 2002; Strangman & Hall, 2003). Special hardware such as gloves, suits and high-end computer systems might be needed in an immersive VR environment.

Allen et al. (2002) have classified three levels of immersive VR:

- **partial or semi-immersive VR**, a system that gives the users a feeling of being there at least slightly immersed by a virtual environment where users remain aware of their real world (Allen et al., 2002; Fällman, 2000), for instance, a workbench that uses a table-top metaphor where special goggles are used to view the 3-D object on a table-top;

- **fully immersive VR**, a system that uses special hardware where users are completely isolated from the physical world outside and are fully immersed in the virtual environment (Fällman, 2000), for instance, CAVE, a projection-based VR system which is a room with multi walls where the stereoscopic view of the virtual world is generated according to the user’s head position and orientation, and users can move around the room; and

- **augmented reality or mixed reality**, a system where users can have access to a combination of VR and real-world attributes by incorporating computer graphics objects into real world scenes (Allen et al., 2002; Pan et al., 2006),
for instance, where a user dissects a virtual dummy frog using a head-mounted device and a real scalpel.

On the other hand, in a non-immersive virtual environment, computer simulation is presented on a conventional personal computer and users can interact with the computer images with a keyboard, mouse, joystick or touch screen (Chen et al., 2004; Inoue, 2007; Neale & Nichols, 2001; Strangman & Hall, 2003). This type of VR is known as non-immersive or desktop VR (Aoki et al., 2008; Ausburn & Ausburn, 2004; Chen et al., 2004; Inoue, 2007; Youngblut, 1998). According to Inoue (2007, p. 2), although the user is not technically immersed in desktop VR, it is considered as a VR system because it is comparable to viewing a real world through a window. Allen et al. (2002) mentioned that desktop VR relies on interactive features built into the virtual world to provide a degree of immersion for users. Desktop VR may be considered less immersive; however, Dalgarno et al. (2002) argued that “the sense of presence or immersion in a 3-D environment occurs as a consequence of the fidelity of representation and the high degree of interaction or user control, rather than just a unique attribute of the environment.”

Silva, Cardoso, Mendes, Takahashi & Martins (2006) have classified two types of VR based on the level of interaction and the complexity of the ambience: VR online and VR offline. With VR offline, more complex simulation and perfect modeling of objects in terms of textures, materials and animations are possible. However, for VR online, there are more limitations in their multimedia aspects because care needs to be taken for the size of files transmitted through the Internet. VR online and VR
offline as discussed by Silva et al. (2006) are in some ways parallel to immersive and non-immersive VR respectively.

Due to the high cost of immersive VR systems and the inherent problems associated with them, such as motion sickness, desktop VR provides an alternative to immersive VR systems because it retains the benefits of real time visualization and interaction within a virtual world (Chen et al., 2004; Chuah et al., 2008; Crosier et al., 2000).

2.3 Virtual Reality Applications in Instructional Settings

VR is becoming increasingly popular for a variety of applications in today’s society. It has become a well-suited medium for use in schools and colleges for science and mathematics subjects as well as arts and humanities studies (Burdea & Coiffet, 2003; Dalgarno et al., 2002; Roussou, 2004). This is due to the ability of VR to engage learners in the exploration, construction and manipulation of virtual objects, structures and metaphorical representations of ideas (Dalgarno, Bishop, Adlong, & Bedgood Jr, 2009, p. 853). Strangman and Hall (2003) have also mentioned that VR technology could make what is abstract and intangible become concrete and manipulable, and this facilitates learning.

The virtual world used in learning could be of two types: a virtual world that mimics the real world scenario (e.g. a virtual museum is created to study the history, art and heritage of a place, or a virtual scene shows how bacteria enters the human body) or computer simulation with 3-D geometric objects in an interactive multimedia
environment (e.g. ripping and unfolding a cube or generating a bottle design from a 2-D diagram) (Lee & Wong, 2008). These simulations could take many forms, ranging from computer renderings of 3-D geometric shapes to highly interactive, computerized laboratory experiments (Strangman & Hall, 2003).

There are quite a number of research reports mentioning VR computer simulations to be an effective approach for improving students’ learning in both non-immersive and immersive virtual environments as discussed below.

A. Non-Immersive VR Applications

Song and Lee (2002) from the Korea National University have used a web-based VR to teach middle school geometry classes in Korea. The Virtual Reality Modeling Language-based 3-D illustration technique was used to provide VR figures and solids for geometric subject in the middle school. The client-server environment was used where the students were allowed to access and explore the geometric objects on the teachers’ server via the World Wide Web. Two-dimensional (2-D) objects or drawings from the textbooks were modeled and implemented in 3-D with the VRML format. By using VRML browsers, students were not only able to access specific figures but also to observe the figures from many different angles. Thus, students could vividly observe and ‘feel’ the figures as if they were real objects. The test results showed that the application of VRML-based 3-D objects had a positive effect on students’ learning of geometric topics, if the visual experience was crucial.
Kim, Park, Lee, Yuk, & Lee (2001) have created a computer-based VR simulation, the Virtual Reality Physics Simulation (VRPS) that helps students to learn physics concepts such as wave propagation, ray optics, and relative velocity at the level of high school or college physics. The VRPS provides a sensory-rich interactive learning environment which enhances students’ understanding by providing a degree of reality which is unable to be achieved in a traditional 2-D interface (Kim et al., 2001). Realistic hands-on experimentation is made possible for the students and physical phenomena can be viewed in many different perspectives in a VR laboratory. Their study findings showed that the students were more satisfied with their instruction through the use of VRPS and they understood the subject matter better. This implies that VRPS is a useful teaching tool for highly interactive visualization of abstract concepts in physics education (Kim et al., 2001).

Dalgarno et al. (2009) have developed a 3-D simulated virtual environment called the Virtual Chemistry Laboratory using VRML as a tool to help prepare distance university chemistry students for their on-campus laboratory sessions. The Virtual Chemistry Laboratory is provided to students on CD-ROM. It is a tool to help prepare students to gain familiarity with the real laboratory environment and to undertake laboratory tasks. Studies were conducted to test the degree to which learning about the laboratory and its apparatus using the virtual laboratory was equivalent to face-to-face learning in the actual laboratory. There was no significant difference in the apparatus identification test, the view position test and the apparatus location test between the virtual laboratory group and the real laboratory group. The
study results indicated that the Virtual Chemistry Laboratory is an effective tool for gaining familiarity with the laboratory environment.

**B. Immersive VR Applications**

Construct3D is a 3-D geometric construction tool based on the collaborative augmented reality system “Studierstube” developed by Kaufmann, Schmalstieg and Wagner (2000). The setup uses a stereoscopic HMD and a Personal Interaction Panel (PIP), a two-handed 3-D interaction tool. It is used in mathematics and geometry education at high school and university level. Complex 3-D objects and scenes are provided by Construct3D to enhance, enrich and complement the mental pictures that students form in their mind when working with 3-D objects (Kaufmann et al., 2000). Thus, complex spatial problems and relationships can be comprehended better and faster than with traditional methods (Kaufmann et al., 2000).

ScienceSpace project consists of three immersive virtual environments for science instruction: NewtonWorld, MaxwellWorld and PaulingWorld. The VR features that are central to the design of ScienceSpace learning environments are: immersive 3-D representation; multiple perspectives and frames of reference; and multisensory cues (Salzman & Loftin, 1996). In NewtonWorld, learners can become a ball that is moving along an alley to learn Newton’s laws of motion. Multisensory cues are used to direct users’ attention to important variables such as mass, velocity and energy (Salzman et al., 1999). In MaxwellWorld, learners can build and explore electric fields. They can directly experience the field by becoming a test charge and be propelled through the field by the electric forces (Salzman & Loftin, 1996).
PaulingWorld, learners explore the atoms and bonds of a simple and complex molecule for a lesson in chemistry (Salzman et al., 1999). The evaluation with respect to usability and learnability of all three virtual learning environments were conducted. From the ScienceSpace research, there was substantial evidence to suggest that multiple viewpoints and frames of reference, multimodal interaction and multisensory cues had enhanced the learning experience and had assisted learners in developing correct mental models of the abstract and complex material.

NICE (Narrative-based, Immersive, Constructionist/Collaborative Environments) is one of the first educational VR applications designed and developed for CAVE by the Electronic Visualization Lab (EVL) at the University of Illinois at Chicago. NICE is a system that supports real-time distributed collaboration. The children can collaboratively construct, plant and tend a healthy virtual garden, learn about gardening and work together (Allison & Hodges, 2000). They can also modify the parameters of the ecosystem to see how it affects the health of the garden.

The Virtual Gorilla Exhibit was developed at the Georgia Institute of Technology for Zoo Atlanta to educate students about gorillas, their lifestyle and their plight as an endangered species (Allison & Hodges, 2000). Students can adopt the role of the gorilla and experience how a gorilla would react to various stimuli and events (Allison & Hodges, 2000). They can explore areas that were usually off limits to casual visitors. The positive reactions from the students imply that it is possible to use VR as a more general educational tool to teach middle school students the
concepts about gorilla behaviors and social interactions which they do not seem to be learning just by visiting the zoo (Allison & Hodges, 2000).

Liu, Cheok, Lim and Theng (2007) have created a mixed reality classroom. Two systems were developed: the solar system and the plant system. In the solar system, users sit around an operation table and use a head-mounted device to view the virtual solar system. Cups are used for the interactions between the users and the virtual objects. For instance, users can use the cup to pick up part of the earth to observe its inner structure. As for the plant system, four topics regarding plants were created: Reproductive, Seeds Dispersal, Seeds Germination and Photosynthesis. For example, in seeds germination, users have to set the right conditions to see a bug growing. The preliminary study conducted by Liu et al. (2007, p. 65) indicated that the participants’ intention to use mixed reality for learning was influenced directly by perceived usefulness and indirectly through perceived ease of use and social influence.

In spite of the positive learning effects, VR might not work for all kinds of learning and it should not be used indiscriminately in any educational program (Sanchez et al., 2000). Research by Song and Lee (2002) found that there was no significant difference in the scores for non-visual aid critical questions in the VRML-based class (using networked VRML material) and the traditional class (chalk and blackboard). This implies that VR may not be useful in a geometry class when visual aids are not crucial. In the study of Crosier et al (2000), comparison was made between desktop VR (virtual laboratory) and traditional teaching methods (using video and
blackboard) for teaching radioactivity to secondary school students aged between 15 and 16 years old. No obvious benefits were found for the use of VR over traditional teaching methods in terms of test scores and attitude rating.

Research in VR and education is a relatively young field (Adamo-Villani & Wilbur, 2007; Inoue, 2007). Thus, more VR research is needed to establish the empirical support for using VR for instructional purposes (Inoue, 2007; McLellan, 2004). In this study, desktop VR is used to determine not only the answer to “Does VR bring benefits to the learners?”, but also to “How does it benefit the learners in a secondary classroom setting?”

2.4 VR and the Constructivist Learning Model

One of the objectives of this study is to examine the learning effectiveness of a desktop VR-based learning environment, which is a student-centered approach that follows the constructivist learning model as compared to the traditional learning method, which is a teacher-centered approach that follows the objectivist learning model. Objectivists believe knowledge exists outside the human mind (Moallem, 2001; Roblyer, 2003). Learning happens when this knowledge is transmitted to people and they store it in their minds (Roblyer, 2003, p. 53). Constructivists, on the other hand, believe that knowledge is constructed by humans in their mind by participating in certain experiences and does not exist outside of their mind (Jonassen, 1994; Jonassen et al., 1999; Martens, Bastiaens, & Kirschner, 2007; Reigeluth, 1999; Roblyer, 2003). Table 2.1 shows the differences between the constructivist and traditional learning methods.
VR is capable of affording constructivist learning because it provides a highly interactive environment in which learners are active participants in a computer-generated world (Kim et al., 2001). As mentioned above, constructivism is a philosophy of learning that believes learners construct their own knowledge and reality. Constructivist learning is student-centric and focuses on meeting the learners’ needs and helping the learners to construct and build on their own new knowledge based on their prior experiences and knowledge (Mergel, 1998; Roblyer, 2003). Learners actively participate in the learning activities to construct meaningful tasks and to achieve meaningful learning. Constructivists believe knowledge and reality are constructed either socially or by individuals (Jonassen, 1994).

<table>
<thead>
<tr>
<th>Constructivist</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Constructed, emergent, situated in action or experience, distributed</td>
</tr>
<tr>
<td>Reality</td>
<td>Product of mind</td>
</tr>
<tr>
<td>Meaning</td>
<td>Reflects perceptions and understanding of experiences</td>
</tr>
<tr>
<td>Learning</td>
<td>Knowledge construction, interpreting world, constructing meaning, authentic-experiential, articulation-reflection, process-oriented</td>
</tr>
<tr>
<td>Instruction</td>
<td>Reflecting multiple perspectives, diversity, modeling, coaching, exploration</td>
</tr>
</tbody>
</table>

Chen and Teh (2000) have pointed out how the various capabilities of VR technology can support the constructivist learning principles as presented in Table 2.2. The constructivist learning principles pointed out by Chen and Teh (2000) are congruent with those posited by Dalgarno (1998) which focus on active learning and
learner control over content, sequence and learning strategy to construct one’s own knowledge; authentic, contextual and discovery activity to encourage diverse ways of thinking and to apply what is learned in realistic contexts; interesting, appealing and engaging problem representation to provide intrinsic motivation; and articulation and discussion to share knowledge built.

The VR program used in this study is consistent with the constructivist-oriented approach of learning. In the learning environment, students are active learners and have control over content, sequence and pace of learning. They explore the authentic learning environment and construct their own knowledge. Moreover, they need to reflect upon their understanding of the new knowledge to engage in the learning activities and to complete the lab report. The virtual experiment would enhance their procedural knowledge, and this new knowledge and skills can be put forward into practice in realistic contexts. In fact, the 3-D simulations in the VR-based learning environment is consistent with the endogenous interpretation of constructivism, which emphasizes learners’ discovery of knowledge through their interaction with the learning environment rather than from direct instruction (Dalgarno, 2002).
Table 2.2: The technical capabilities of VR in supporting the constructivist learning principles (Chen & Teh, 2000)

<table>
<thead>
<tr>
<th>Constructivist Learning Principles</th>
<th>VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interesting, appealing, and engaging problem representation, which describes the contextual factors that surround the problem</td>
<td>▪ Can present problem in a 3-D environment that simulates aspects of the real world</td>
</tr>
<tr>
<td>Multiple perspectives, themes, or interpretations of a problem to encourage diverse ways of thinking</td>
<td>▪ Can provide unlimited number of viewpoints of the 3-D environment</td>
</tr>
<tr>
<td></td>
<td>▪ Can provide an independent controlled viewpoint for each learner</td>
</tr>
<tr>
<td></td>
<td>▪ Can exclude secondary elements in the virtual environments that may divert the learner’s attention from the elements of primary importance</td>
</tr>
<tr>
<td>Active learning—learners use sensory input and construct meaning out of it</td>
<td>▪ Can provide a problem manipulation space that allows free exploration and manipulation. Feedback/interaction can be observed (either through visual, auditory, tactile, and/or kinesthetic cues) by other participant learners</td>
</tr>
<tr>
<td>Understanding is tracked by experience, gradually built up step-by-step</td>
<td>▪ Can provide virtual experience instead of words or pictures. Virtual experience has natural semantics that provide meaning to the learner without any explanation</td>
</tr>
<tr>
<td>Instruction cannot be designed—learners construct their own knowledge</td>
<td>▪ VR is designed without a specific sequence—permits any kind of interaction the system is capable of</td>
</tr>
<tr>
<td>Rich sources of information</td>
<td>▪ VR in itself naturally contains needed information</td>
</tr>
<tr>
<td></td>
<td>▪ Can also be complemented with other computer-supported collaborative learning tools to provide other relevant information (e.g. World Wide Web)</td>
</tr>
<tr>
<td>Cognitive tools—intellectual devices used to visualize, organize, automate, and or supplant information processing</td>
<td>▪ Can act as visualization tool, modeling and design tool, dynamic modeling tool, and automation tool</td>
</tr>
<tr>
<td>Conversation and collaboration tools—Access to shared information and knowledge building tools to help learners collaboratively construct socially shared knowledge</td>
<td>▪ Can provide a shared space for a group of learners, either co-located or at a distance, to collaboratively construct knowledge through synchronous and/or asynchronous communication</td>
</tr>
<tr>
<td></td>
<td>▪ Can incorporate virtual bodies (embodiments) to improve the realism of the collaboration process</td>
</tr>
</tbody>
</table>
2.5 Aptitude-by-Treatment Interactions (ATI)

Ausburn and Ausburn (2004) have called for the application of the ATI model in new studies on VR in education because the ATI model is more multi-factor in concept. In this model, the interest is not on the effect of an instructional method, if it works or is better, but on the interactions between various instructional methods and learners’ aptitudes or characteristics. Interaction between aptitude and treatment occurs when the effect of treatment differs depending on the level of aptitude measure. Such a research model will enlighten educators for what purposes and for whom an instructional method may be effective (Ausburn & Ausburn, 2004).

In essence, ATI research investigates the effect of individual differences on learning outcomes from different forms of treatment or instruction (Cronbach & Snow, 1969). The concept of ATI begins when Cronbach (1957) uses a correlational approach to relate individual differences and achievement to different experimental treatments (Jonassen & Grabowski, 1993, p. 23). Aptitudes refer to any of the personological variables such as mental abilities, personality, or cognitive styles, whereas treatment comprises the structural and presentational properties of instructional methods (Jonassen & Grabowski, 1993).

Two types of interaction are possible: disordinal interaction and ordinal interaction (Jonassen & Grabowski, 1993). Figure 2.1 shows disordinal interaction. Learners with low scores on the aptitude measure perform poorly on the instructional outcome measure under treatment A. However, learners with similar scores on the aptitude measure do better on the outcome measure under treatment B. Conversely, learners
with high scores on the aptitude measure perform poorly in treatment B but better in treatment A. The regression slopes are different and they are intersected (Jonassen & Grabowski, 1993).

![Disordinal interaction](image1)

**Figure 2.1: Disordinal interaction**

On the other hand, in ordinal interaction, one treatment produces better results for all learners within the range of aptitude studied as shown in Figure 2.2. The two slopes are different and do not intersect (Jonassen & Grabowski, 1993; Tobias, 1980). This means that all learners within the range of aptitude studied perform better under treatment B. The learners with high scores on the aptitude measure perform better than the learners with low scores on the aptitude measure for both treatments.

![Ordinal interaction](image2)

**Figure 2.2: Ordinal interaction**
Results from ATI research can serve as a guide on how to adapt instruction to different learners. ATI research is conducted in this study to investigate the interaction between aptitudes (spatial ability and learning style) and learning modes (VR mode and Non-VR mode) on the learning outcomes.

2.5.1 Spatial Ability and VR

Spatial ability refers to a group of cognitive functions and aptitudes that is crucial in solving problems that involve manipulating and processing visuo-spatial information (Bodner & Guay, 1997; Hannafin et al., 2008; Lajoie, 2008; Rafi et al., 2005), because it is the mental process used to perceive, store, recall, create, edit and communicate spatial images (Linn & Petersen, 1985). Gardner (1993) stated that spatial ability is one of the seven major components in multiple intelligences. He defined spatial intelligence as the ability to think in pictures and images, to perceive, transform, and recreate different aspects of the visuo-spatial world, whilst some of the overt spatial behaviors, identified by Durlach et al. (2000), include the behavior exhibited in exploring a space, searching for some items in a space, planning or following a route in a space, selecting and recognizing landmarks in a space, constructing or interpreting maps of a space, imagining how a space and objects in it would appear from different viewpoints.

Though a number of spatial abilities have been identified, a consensus concerning various factors of spatial ability has not been reached (Black, 2005; Rafi et al., 2005). According to Michael, Guildford, Fruchter, and Zimmerman (1957), there are two major spatial factors: spatial orientation and spatial visualization. Ekstrom,
French, Harman, and Dermen (1976) defined spatial orientation as a measure of the ability to remain unconfused by changes in the orientation of visual stimuli, and therefore it involves only a mental rotation of configuration. McGee (1979) defined spatial visualization as a measure of the ability to mentally restructure or manipulate the components of the visual stimulus and involves recognizing, retaining, and recalling configurations when the figure or parts are moved.

Research findings show that appropriate computer technologies can be used to improve spatial ability. Due to its interactive and animated features, VR serves as a promising technology to increase students’ spatial ability (Mohler, 1999). McLellan (1998) stated that “VR is a superb vehicle for enhancing and possibly improving spatial ability, because its interactive nature is aimed at extending and enhancing human cognitive abilities.” However, there is a concern as to whether learner characteristics might influence VR-based learning. Norman (1994) mentioned that the positive impact of computer-based technology in education depends on the individual ability of users. While some computer-based technologies may serve to benefit some learners, at the same time they may also serve to handicap others (Norman, 1994).

It is believed that spatial visualization ability is the primary cognitive factor that causes the differences in performance and has an impact on comprehension of 3-D computer visualization (Huk, 2006; Keelher, Montello, Hegarty, & Cohen, 2004; Norman, 1994). Students with different spatial visualization ability will benefit differently when learning with interactive 3-D animations or simulations (Hays,
1996; Huk, 2006; Mayer & Sims, 1994; Wu & Shah, 2004), which depends on their ability to extract relevant information and then reconstruct or incorporate the information into their existing mental models. Thus, it is inappropriate to think that the mere application of VR technology in education will benefit everyone equally in relation to spatial ability (Lee et al., 2009a). Owing to this, more research is needed to qualify and quantify the impact of the use of VR for learning.

2.5.2 Learning Style and VR

People learn in different ways according to their preferred learning style (Kolb, 1984). According to Cassidy (2004, p. 420), the manner in which individuals choose to or are inclined to approach a learning situation has an impact on performance and achievement of the learning outcomes. Kolb (1984) defined learning style as one’s preferred methods of perceiving and processing information based on the experiential learning theory. The theory of experiential learning propagates learning through experience and by experience (Müller & Ferreira, 2005). It is through the transformation of experience that knowledge is created. Kolb (1976) divided the learning process cycle into four learning modes: concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE) as shown in Figure 2.3. The four-stage model articulates that learning is an iterative process that generally begins with a concrete experience, which is followed by reflecting upon what has been observed in these experiences, then to assimilate and integrate conclusions into a theory by abstract conceptualization, and finally to test and apply new theories in new situations. Each individual is most likely to feel most comfortable in one of these four learning modes based on his or her preference along
two primary dimensions: the concrete-abstract dimension and the active-reflective
dimension (Kolb, 1984). That is, in perceiving or taking in new information, people
characteristically choose between a concrete (feeling) or an abstract (thinking)
approach; in processing what they take in, they tend to choose between an active
(doing) or a reflective (watching) approach (Kolb, 1984). By plotting the preference
along these two primary learning dimension continua, Kolb (1984) identified four
types of learning styles: accommodator, assimilator, diverger and converger.

Accommodators prefer CE and AE. They like doing and experiencing things. They
are risk-takers, tend to solve problems in an intuitive, trial-and-error manner, and
rely on others for information.

Divergers prefer CE and RO. They learn by feeling and watching. They are
imaginative, good at seeing things from different perspectives, creative, emotional,
sensitive to people, and have a broad cultural interest.

Assimilators prefer RO and AC. They learn by watching and thinking. They are
more concerned with abstract concepts and ideas, good at putting information into a
logical form, excel in inductive reasoning, and are less interested in people and
prefer to work alone.

Convergers prefer AE and AC. They learn by doing and thinking. They tend to be a
problem solver and decision maker, good at finding practical uses for ideas and
theories, are generally deductive in their thinking, and are relatively unemotional.
Bell and Fogler (1997) posited that experience—the main feature of VR—is of great benefit to all learning styles, which means it could provide support to all four of Kolb’s learning characteristics. Bricken (1990) has also theorized about VR as a tool for experiential learning because VR supports active construction of knowledge through experiment, users experience the consequences, and then choose from knowledge. Likewise, Fizpatrick (2008) asserted that VR learning systems embrace the concepts and models of learning from experience by immersing learners in an interactive 3-D computer generated world which very closely emulates operations and equipment found in the real world.

Chee’s (2001) C-Visions (Collaborative Virtual Interactive Simulations), Müller and Ferreira’s (2005) MARVEL (Virtual Laboratory in Mechatronics) and Chen, Toh &
Wan’s (2005) VR program for novice car driver have provided example applications of how VR can be designed to support Kolb’s model of experiential learning. According to Chee (2001), the first-person learning experience afforded by a virtual environment allows learners to directly experience things that they seek to learn and they have the autonomy and control over their own learning experience. The synthetic replica of objects and phenomena of interest by the virtual environment would help learners to concretize and reify ideas. Thus the virtual representations would help make what is otherwise unimaginable, imaginable and experienceable. Ultimately, learners need to generalize their learning experience to form appropriate rules and abstractions for the knowledge learned. VR is capable of supporting the experiential learning theory because it is able to provide “here-and-now” experience to test theories, as well as giving instant feedback to change these theories (Müller & Ferreira, 2005). Chen et al., (2005) have also found that their virtual environment that mimics the real world road scenarios provides a concrete experience for learners to explore actively and, at the same time, the text and image material presented require reflective observation and abstract conceptualization.

Various learning style models have been developed by scholars, such as the Honey and Mumford learning model (Honey & Mumford, 1992), the VARK learning model (Hawk & Shah, 2007), and the Felder-Silverman Learning model (Hawk & Shah, 2007). As VR and the Kolb learning style model are directly related, the Kolb Learning Style Inventory that categorize one’s learning style model based on the experiential learning theory was chosen in this study.
2.6 Theoretical Foundation for a Desktop VR-based Learning Environment

Research on how desktop VR supports and enhances learning is rare. A search of the literature shows that there is a lack of a broad framework and a theoretical model that is systematically and empirically tested to describe how desktop VR enhances the learning outcomes. This research aims to fill this gap. For parsimony and feasibility of practice, this study intends to identify the relevant constructs and measurement factors that play an important role in a desktop VR-based learning environment. The findings will present guidelines for desktop VR-based learning development. Hence, this section analyzes and synthesizes various relevant theoretical models and frameworks that could guide the development of the theoretical framework of how desktop VR could enhance the learning outcomes.

The literature search conducted in this study shows only one model has been developed to understand how VR influences the learning process and learning outcomes in the VR learning environment. The model is developed by Salzman et al. (1999) for immersive virtual learning and describes the importance of scrutinizing how VR features work together with other factors such as the concept that is to be learned, the learner characteristics, the interaction and learning experience that influence the learning process (the kinds of information to which one attends), which in turn affects the learning outcomes (the person’s level of understanding after the lessons have been completed)—see Figure 2.4. VR features influence not only learning, but the quality of the interaction and learning experience as well. The appropriate usage of VR features depends on the concepts to be learned and mastered.
Figure 2.4: Theoretical model describing how VR features, concept to be learned, learner characteristics, and the interaction and learning experiences work together to influence the learning outcomes in immersive VR learning environments (Saltzman et al., 1999)
According to the model of Salzman et al. (1999), learner characteristics are an important factor that may moderate the relationship between VR features and learning, and they may influence the interaction experience (e.g. how easily the user can interact with the system) and learning experience (e.g. motivation). Each individual has a unique experience when interacting with the VR learning environment which may help to motivate one to learn, and vice versa. The learner characteristics that are likely to be important are gender, domain experience, spatial ability, computer experience, motion sickness history and immersive tendencies.

Learning experiences such as motivation and presence, and interaction experiences such as usability and simulator sickness can be affected by VR features, which influence learning. The model demonstrates that the link between VR affordances and learning occurs within a web of other relationships (Salzman et al., 1999, p. 295).

The lack of literature on the theoretical model and framework of using non-immersive desktop VR in education has prompted a literature search in the field of information systems. It was found that there is a convergence among the theoretical perspectives between the model identified by Salzman et al. (1999) and the models used in other technology-mediated learning (e.g. web-based learning). The underlying reason could be that the use of VR in web-based learning is proliferating. Indeed, with the emergence of desktop VR technology, the simulation of a 3-D world on a 2-D computer screen is made possible and this form of VR has been on the Internet since the mid-1990s (Inoue, 2007; Kwan, Kim, & Kim, 2002), for
instance, in the studies of Li et al. (2002), Ong and Mannan (2004), Song and Lee (2002), Sharda et al. (2004), Kim et al. (2001), Creedy et al. (2007), and Monahan, McArdle and Bertolotto (2008). Technology-mediated learning models could help to shed some light on the learning effectiveness with VR technology because this technology has been used in web-based learning with the emergence of VRML and X3D to generate 3-D interactive graphical representations that can be delivered over the web. Learner-content interaction is crucial in web-based learning as well as in desktop VR-based learning.

Alavi and Leidner (2001), Piccoli, Ahmad and Ives (2001), Benbunan-Fich and Hiltz (2003), Sharda et al. (2004) and Wan et al. (2007) have offered a relatively complete view on the framework of technology-mediated learning. Alavi and Leidner (2001, p. 2) defined technology-mediated learning as an environment in which the learner’s interactions with learning material, peers and/or instructors are mediated through advanced information technologies. The focus of this study is on learning from instruction in the context of a desktop VR-based learning environment for secondary school education. Learning from instruction refers to situations where one individual intentionally creates and structures the environment of the learner in such a way that the learner will achieve the desired outcomes (Shuell & Lee, 1976). In this study, the environment strictly refers to the desktop VR-based learning environment in which the learners’ interaction with learning materials is mediated by the VR technology. The focus is on student-content interaction. Hence, the technology-mediated learning theory is adopted in this study.
Alavi and Leidner (2001) have proposed a framework for technology-mediated learning that addresses the question of how can technology enhance learning. This framework emphasizes the need to consider technology in relation to instructional methods, psychological and environmental factors to enhance learning outcomes (see Figure 2.5). Alavi and Leidner (2001) have called for greater depth of research on using technology in learning as there is a lack of studies that consider the internal psychological process through which learning occurs. Psychological processes refer to states within the learner that are involved in learning which include the learner’s cognitive and information processing activities, motivation, interest and cognitive structure.

Technology features are emphasized in the framework as they can influence learning through the psychological processes. Nevertheless, the framework of Alavi and Leidner (2001) ignores participant factors such as student characteristics which other researchers have found to be influential on the learning outcomes of technology-mediated learning (Benbunan-Fich & Hiltz, 2003; Piccoli et al., 2001; Sharda et al., 2004).

The learning experiences examined by Salzman et al. (1999) are in some ways parallel to the internal psychological process emphasized by Alavi and Leidner (2001). Both determine the impact of technology features on learning experiences and learning outcomes. However, the framework of Alavi and Leidner (2001) ignores construct such as learner characteristics as identified by Salzman et al. (1999) in the VR learning environment.
Drawing on the technology-mediator learning theory, Piccoli et al. (2001) have developed a conceptual framework that identifies the primary dimension for a web-based virtual learning environment. Two classes of determinants are identified by Piccoli et al. (2001): human dimension and design dimension. The student is one of the primary participants in the human dimension (see Figure 2.6).

Student characteristics such as maturity, motivation, technology comfort, technology attitudes, previous experience, computer anxiety and epistemic beliefs may influence students’ ability to learn effectively in a virtual learning environment. It is noted that the student characteristics identified by Piccoli et al. (2001) bear some similarity to those identified by Salzman et al. (1999). The design dimension emphasizes the learning model, the quality and reliability of the technology, the aspects of learner control, content and interaction. However, this framework ignores that role of learning processes that mediates the relationships between instructional design and technology dimension and learning outcomes as proposed by Alavi and Leidner (2001).
Benbunan-Fich and Hiltz’s (2003) research framework consists of moderator variables, mediator variables and independent variables (see Figure 2.7). The moderators consist of the factors of technology (e.g. functionality, usability and reliability which are akin to interaction experience), course (e.g. type of subject and...
organization context) and student characteristics (ability, skills and attributes). This framework highlights the mediating effect of the learning process on the relationships between technology, course, student characteristics and learning outcome which answers the call for greater depth in technology-mediated learning by Alavi and Leidner (2001).

![Figure 2.7: Research framework of Benbunan-Fich and Hiltz (Benbunan-Fich & Hiltz, 2003)](image)

To address the issue of an inconsistent measurement of learning outcomes, that is, some studies measured learning effectiveness whereas others measured in term of students’ perceptions, Sharda et al. (2004) have proposed a theoretical foundation of computer-supported collaborative learning requiring immersive presence (CSCLIP) which categorizes the learning outcomes into three components: cognitive learning
outcomes which include knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom, 1956); affective learning outcomes which include students’ perceptions of satisfaction, attitudes, respect and appreciation for the learning experiences (Sharda et al., 2004); and psychomotor learning outcomes which refer to efficiency, accuracy and response magnitude (Sharda et al., 2004).

The framework of CSCLIP is used to develop a simulated 3-D virtual lab for remote students to move around the lab in the virtual world, and manipulate components of live equipment. For instance, remote students can select the appropriate cable from a bin of virtual cables and plug it into the hub using the mouse and drag-and-drop action. This framework also emphasizes the dimension of technology in the form of process support (e.g. audio and video using Internet and VR technologies), process structure (e.g. embedded procedural order built into the remote-task software), task structure (e.g. instructional lab modules) and task support (e.g. virtual lab tours and virtual control) in technology-mediated learning, with the human dimension such as the student as the moderator variable that may influence the learning outcomes (see Figure 2.8).
Figure 2.8: Framework of outcomes and their causal relationships in CSCLIP (Sharda et al., 2004)

Legend
Instructional Design and Decision Influences
Causal Influences
Moderating Influences

Learning Objectives
Psychomotor
Cognitive
Affective

Task
Type
Difficulty
Time

CSCLIP Environment

Immersive Communication Technologies
(Process Support)
e.g. Reliability Richness Usefulness

Embedded Procedural Order
(Process Structure)
e.g. Subtask Order

Instructional Module
(Task Structure)
e.g. Redesigned Lab Modules to Accommodate CSCLIP

Instructional Infrastructure
(Task Support)
e.g. Virtual Tours Virtual Control

Human Dimension
Students
Learning Styles
Demographics
Groups
Size
Homogeneity
Instructors
Teaching Style
Technology Comfort

Psychomotor
Efficiency
Effectiveness
Response Magnitude

Cognitive
Comprehension
Knowledge
Problem Solving

Affective
Individual Satisfaction
Group Satisfaction
Task Satisfaction

(+/-)

Legend:
Instructional Design and Decision Influences
Causal Influences
Moderating Influences
Wan et al. (2007) have proposed an input-process-output framework for technology-mediated learning. It consists of three main dimensions as inputs: primary participant (e.g. students’ and instructors’ characteristics), instructional design (e.g. learning model) and technology (e.g. quality, reliability and accessibility) as shown in Figure 2.9. All these dimensions individually and collectively influence the students’ learning process, and eventually affect the learning outcomes (Wan et al., 2007, p. 184). This model also stresses the importance of the mediating process, that is, the internal psychological processes and the actual learning activities, while technology is being used for learning.

Figure 2.9: Theoretical framework for technology-mediated learning (Wan et al., 2007)
To summarize, the theoretical model of immersive VR-based learning by Salzman et al. (1999) and most of the theoretical frameworks for technology-mediated learning cover three main processes, that is, input, process and output. A summary of the comparison between the model by Salzman et al. (1999) and other technology-mediated frameworks is presented in Table 2.3. Almost all of them emphasize the relevant independent variables such as the technology factor and student characteristics, the mediating process such as the psychological learning experience, and finally the output such as the learning outcomes. It is noted that some technology-mediated frameworks illustrate the technology factor in terms of technology features while others illustrate in terms of quality and accessibility which is analogous to the interaction experience in the immersive VR model of Salzman et al. (1999). Likewise, the emphasis on the psychological learning process in technology-mediated learning is analogous to the learning experience in the model of Salzman et al. (1999). Student characteristics are also emphasized in most of the models as they could have some moderating effects on learning experience and learning outcomes. A summary of the literature relevant to the factors vital to the activities of desktop VR-based learning, and affecting the learning outcomes in desktop VR-based learning, is presented in Table 2.4.
Table 2.3: Comparison between the immersive VR theoretical model by Salzman et al. (1999) and technology mediated models

<table>
<thead>
<tr>
<th>Articles</th>
<th>Technology Features</th>
<th>Interaction Experience</th>
<th>Learning Experience</th>
<th>Participant Dimension</th>
<th>Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salzman et al. (1999)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Alavi and Leidner (2001)</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Piccoli et al. (2001)</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Benbunan-Fich and Hiltz (2003)</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Sharda et al. (2004)</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Wan et al. (2007)</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Table 2.4: Related references about the factors relevant to desktop VR-based learning

<table>
<thead>
<tr>
<th>Authors</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salzman et al. (1999)</td>
<td>VR features, ease of use, motivation, immersion, spatial ability, gender, computer experience</td>
</tr>
<tr>
<td>Piccoli et al. (2001)</td>
<td>Maturity, motivation, previous experience, constructivist, technology quality and reliability, learner control</td>
</tr>
<tr>
<td>Benbunan-Fich &amp; Hiltz (2003)</td>
<td>Usability, technology reliability, motivation, active participation</td>
</tr>
<tr>
<td>Sharda et al. (2004)</td>
<td>Usefulness, reliability, learning styles</td>
</tr>
<tr>
<td>Wan et al. (2007)</td>
<td>Technology quality and accessibility, learning model, motivation, interest, cognitive structures (e.g. memory), active participation</td>
</tr>
<tr>
<td>Sun, Tsai, Finger, Chen &amp; Yeh (2008)</td>
<td>Perceived usefulness, perceived ease of use</td>
</tr>
</tbody>
</table>

The literature review shows a lack of theoretical models or frameworks that emphasize the relevant constructs and their causal relationships for a desktop VR-based learning environment. In other words, there is a lack of greater depth of research that emphasizes the mediating process to understand how desktop VR
enhances learning. Hence, the theoretical model for the immersive VR-based learning environment by Salzman et al. (1999) is used as a starting point to develop a conceptual framework for a desktop VR-based learning environment, which is further supported by technology-mediated learning models. With such, a conceptual framework that is based on an input, process and output metaphor that emphasizes the psychology learning factors is developed in this study to guide the research design for evaluating how desktop VR enhances learning. The framework consists of the input factor, that is, technology factors and student characteristics. The attributes, quality and accessibility of the technology are studied. Student characteristics such as spatial abilities and learning styles are investigated as to how they influence the learning. As for the process, the internal psychological learning experience is investigated to provide evidence of what kind of learning experience is enhanced by VR and how important the learning experience is in shaping the learning outcomes. In addition, the interaction experience with desktop VR-based learning is also investigated to determine how it influences the learning outcomes. Finally, the learning outcomes are assessed in terms of cognitive and affective domains. This conceptual framework does not emphasize the direct influence of VR features on the learning outcomes, but emphasizes the mediating factors such as interaction experience and learning experience as supported by the technology-mediated models.

The results could show instructional designers and VR developers how to improve the learning effectiveness and further strengthen their desktop VR-based learning implementation. Furthermore, academia can use the findings of this study as a basis
to initiate other related studies in the desktop VR-based learning area. Apart from
telling educators and VR practitioners what has occurred, the findings also tell
educators and VR practitioners how learning occurs in a desktop VR-based learning
environment. A detailed description of the development of the conceptual framework
and model for evaluating a desktop VR-based learning environment is elaborated in
the next chapter.

2.7 Summary

This chapter provides a description of the various types of VR and their application
in instructional settings. In addition, the capability of VR technology to support the
constructivist learning model is discussed. Lastly, the theoretical foundation to
develop a framework that covers the relevant constructs and their interrelationships
to enhance learning with desktop VR was elaborated. A framework that emphasizes
the mediating process when using desktop VR technology would be developed
because this research would like to answer the call for a greater depth of research by
information system researchers to address the issue of “How can desktop VR
technology enhance learning outcomes?” apart from “Does desktop VR technology
influence learning outcomes?”

The findings of this study would contribute to the understanding of the learning
outcomes of a desktop VR-based learning environment and provide empirical
evidence of the merit (if any) of desktop VR-based learning to educators and policy
makers. Moreover, the ATI research would be beneficial to instructors to facilitate
individualized learning. It is hoped that the results of this study could create
awareness on the potential and/or weakness of the desktop VR technology for educational purposes. Most importantly, the model developed would assist instructional designers and VR software developers to leverage the desktop VR technology to enhance learning.
Chapter 3

RESEARCH FRAMEWORK AND HYPOTHESES DEVELOPMENT

3.0 Overview

This chapter discusses the research framework employed in this study in order to measure the effects of each different learning mode on learning and the moderating effects of student characteristics on learning. The hypotheses concerned are also discussed. Next, the development of the conceptual framework, model and hypotheses for evaluating how desktop VR enhances the learning outcomes are elaborated. A comprehensive framework that consists of relevant dimensions or constructs and their interrelationships is developed to explain how desktop VR improves and enhances the quality of student learning.

3.1 Framework for Determining the Effects of a Desktop VR-based Learning Environment and ATI Research

The research framework shown in Figure 1.1 presents the variables for determining the learning effectiveness of a desktop VR-based learning environment and the ATI research (see p. 12). The independent variable is the learning mode which consists of VR mode and Non-VR mode. A desktop VR-based learning environment is provided to the VR mode whereas the Non-VR mode follows a conventional classroom learning method. The VR mode supports the learning model of constructivism because learners are active, able to control the learning pace and be responsible for their learning, which follows a student-centric approach. Learners are actively
interpreting and constructing individual knowledge representations in the VR-based learning environment. One the other hand, the Non-VR mode follows the objectivist model which assumes the instructor is the source of knowledge to be transferred to the learners. The instructor is in control of the material and the pace, with students passively receiving facts and information. There are three dependent variables which serve as the learning outcomes for the treatments given. They are performance achievement, which is measured by the posttest score, perceived learning effectiveness and satisfaction towards the teaching and learning approach. To complete the ATI research, the effects of the moderator variables such as students’ spatial abilities and learning styles are investigated. In addition, the gain score (posttest score minus pretest score) is used to investigate the overall improvement in performance for students with different aptitudes in the VR mode.

### 3.2 Hypotheses for Determining the Effects of a Desktop VR-based Learning Environment and ATI Research

To address research questions 1 to 6, and to achieve the objectives of this research as described in Section 1.3, the following null hypotheses are developed.

- **H_{01}**: There is no significant difference in the performance achievement between students in the VR mode and Non-VR mode.

- **H_{02}**: There is no significant difference in the perceived learning effectiveness between students in the VR mode and Non-VR mode.

- **H_{03}**: There is no significant difference in the satisfaction between students in the VR mode and Non-VR mode.

- **H_{04}**: There is no interaction effect between the learners’ spatial abilities and the learning modes, related to the performance achievement.
$H_{05}$: There is no interaction effect between the learners’ spatial abilities and the learning modes, related to the perceived learning effectiveness.

$H_{06}$: There is no interaction effect between the learners’ spatial abilities and the learning modes, related to the satisfaction.

$H_{07}$: There is no interaction effect between the learners’ learning styles and the learning modes, related to the performance achievement.

$H_{08}$: There is no interaction effect between the learners’ learning styles and the learning modes, related to the perceived learning effectiveness.

$H_{09}$: There is no interaction effect between the learners’ learning styles and the learning modes, related to the satisfaction.

$H_{10}$: There is no significant difference in the performance achievement for high and low spatial ability learners in the VR mode.

$H_{11}$: There is no significant difference in the perceived learning effectiveness for high and low spatial ability learners in the VR mode.

$H_{12}$: There is no significant difference in the satisfaction for high and low spatial ability learners in the VR mode.

$H_{13}$: There is no significant difference in the overall improvement in performance for high and low spatial ability learners in the VR mode.

$H_{14}$: There is no significant difference in the performance achievement for accommodator learners and assimilator learners in the VR mode.

$H_{15}$: There is no significant difference in the perceived learning effectiveness for accommodator learners and assimilator learners in the VR mode.

$H_{16}$: There is no significant difference in the satisfaction for accommodator learners and assimilator learners in the VR mode.
There is no significant difference in the overall improvement in performance for accommodator learners and assimilator learners in the VR mode.

3.3 Framework and Model for Evaluating How Desktop VR Enhances Learning Outcomes

Based on the literature search, several research frameworks were used to guide the development of the conceptual framework for evaluating how desktop VR enhances learning outcomes. In view of the scarcity of literature on the VR-based learning model, models of technology-mediated learning were used to provide additional support.

The model of Salzman et al. (1999) provides a starting point for the framework of this study. The model of Salzman et al. (1999) is a comprehensive framework that has identified the relevant dimensions and their relationships in achieving successful learning outcomes in an immersive VR-based learning environment. Furthermore, there is a convergence among the theoretical perspectives between the model identified by Salzman et al. (1999) and the models of the technology-mediated learning theory as explained in the previous chapter. Greater depth of research was emphasized in some technology mediated models as there is a lack of studies that consider the internal psychological process through which learning occurs (Alavi & Leidner, 2001; Benbunan-Fich & Hiltz, 2003; Wan et al., 2007). Thus, the framework for a desktop VR-based learning environment is supported by the technology-mediated learning models and it focuses on the input, process and output factors as elaborated in the previous chapter. With such, a conceptual framework of the outcomes and their causal relationships in a desktop VR-based learning environment is developed.
environment as shown in Figure 1.2 is developed (see p. 12). The input factors that could affect the interaction and learning experience, which in turn would affect the learning outcomes in this study, are VR technology, that is, the VR features as measured by representational fidelity and immediacy of control as the independent variables. Student characteristics such as spatial abilities and learning styles are the moderator variables which would strengthen or weaken the relationships between variables.

The mediating processes comprise interaction and learning experiences. Both interaction experience and learning experience are the mediating variables that influence the learning outcomes. Some key process variables that act as the mediator variables would be investigated to explain how learning outcomes come about. These mediator variables are conceptualized as leading to the presence or absence of the desired learning outcomes (Benbunan-Fich & Hiltz, 2003). For interaction experience, usability as measured by perceived usefulness and perceived ease of use is studied in this research, whereas for learning experience, psychological factors consisting of presence, motivation, cognitive benefits, control and active learning, and reflective thinking are investigated. As mentioned by Yaman, Nerdel & Bayrhuber (2008), the impact of learners’ psychological perspective on their learning has hardly been studied in computer simulation-based learning. Finally, the effectiveness of the VR-based learning environment is measured in terms of cognitive domain through performance achievement as measured by the posttest, and affective domain through the students’ perceived learning effectiveness and
satisfaction with the learning environment. Hence, the dependent variables are performance achievement, perceived learning effectiveness and satisfaction.

Based on the conceptual framework of desktop VR-based learning, a model is developed for evaluating how VR enhances the learning outcomes as shown in Figure 3.1. The fit of the hypothesized model is assessed using SEM. This model addresses the constructs and their causal relationships. The hypothesized model consists of the constructs or latent variables of (1) VR features which are measured by representational fidelity and immediacy of control; (2) usability which is measured by perceived usefulness and perceived ease of use; (3) presence; (4) motivation; (5) cognitive benefits; (6) control and active learning; (7) reflective thinking; and (8) learning outcomes which are measured by performance achievement, perceived learning effectiveness and satisfaction. This study focuses on a greater depth of research by investigating the individual effect of the psychological factors on learning with VR technology; therefore, they are not collectively grouped under the construct of learning experience. As a result, this model can help make an opaque construct (i.e. all psychological factors were to be considered together as a single construct) more transparent (i.e. the effects of each psychological factor are more apparent), and thus produces important implications and insights. The relevance of the constructs and measurement variables are described below.
Notes: 
REP = Presentational fidelity; IMM = Immediacy of control; USE = Perceived usefulness; EASE = Ease of use; PERF = Performance achievement; PERC = Perceived learning effectiveness; SAT = Satisfaction

**Figure 3.1: Model for evaluating how desktop VR enhances learning outcomes**

### 3.3.1 VR Features

Technology quality is an important determinant of learning effectiveness (Arbaugh & Duray, 2002; Marks, Sibley, & Arbaugh, 2005; Webster & Hackley, 1997). Some technologies are best suited to support specific theoretical learning models (Leidner & Jarvenpaa, 1995). Technology itself does not produce desired learning outcomes, but it facilitates intentional changes in teaching and learning processes and so operates as an enabler (Leidner & Jarvenpaa, 1995). Technologies influence learning by providing support to the underlying psychological processes of learning such as the learner’s cognitive and information processing activities, motivation and interest (Alavi & Leidner, 2001). Similarly, Jonassen et al. (1999) mentioned that the role of technologies in learning is indirect. For instance, they can simulate and support
activities that engage learners in thinking, and thinking mediates learning. Hence, learners do not learn directly from the technology; they learn from thinking what they are doing. In other words, technologies can foster and support learning, if they are used as tools and intellectual partners that motivate learners to learn, engage and involve learners in the learning activities, help learners to construct, understand and apply new knowledge, and help learners to think.

In this study, it was hypothesized that the quality of the VR features have an indirect effect on the learning outcomes which are mediated by the interaction experience and learning experience as supported by Salzman et al. (1999). In other words, the qualities of the medium are regarded as determinants of the interaction experience (e.g. usability) and learning experience (e.g. the psychological state and experience of a learner as being physically located in a mediated space). Factors that influence the interaction experience and the learning experience are realism factors, the degree of realism of the objects or scenarios portrayed in the virtual environment; and control factors, the amount of control the user had on activities and events in the virtual environment (Witmer & Singer, 1998). The desktop VR features in this study are thus measured by representational fidelity (scene realism) and immediacy of control.

Representation fidelity is the degree of realism provided by the rendered 3-D images and scene content; the degree of realism provided by temporal changes to these images such as the motion of the objects that appears smooth enough to provide a very high degree of realism; and the degree to which objects behave in a realistic
way or in a way consistent with the ideas being modeled (Dalgarno et al., 2002). In short, representation fidelity refers to the connectedness and continuity of the stimuli being experienced (Witmer & Singer, 1998, p. 230).

Immediacy of control refers to the ability to change the view position or direction, giving the impression of smooth movement through the environment, and the ability to pick up, examine and manipulate objects within the virtual environment (Dalgarno et al., 2002). The consequences of the user’s action should be appropriately obvious and apparent to the user to afford expected continuities (McGreevy, 1992).

3.3.2 Usability

Based on the model of Salzman et al. (1999), VR features are the antecedents to interaction experience. Interaction experience in the framework refers to the user’s observation and interaction with the technology provided with regard to the aspect of quality and accessibility. The issue that learning outcomes are dependent on the technology quality and accessibility is highlighted in the model of Salzman et al. (1999) and the model of technology-mediated learning (Alavi & Leidner 2001; Piccoli et al., 2001; Benbunan-Fich & Hiltz, 2003; Sharda et al., 2004; Wan et al., 2007). Moreover, it is important to recognize that a virtual learning environment with a high degree of fidelity and user control, modeled on a real world system, will not necessarily facilitate the development of conceptual understanding (Dalgarno et al., 2002). Thus, an appropriate set of learning tasks needs to be designed, with appropriate task support that is deemed to be useful and easy to use by the learners (Dalgarno et al., 2002). This is to ensure that the learning activities that the learners
undertake while exploring and interacting with the learning environment do actually require them to develop such an understanding of the learning contents (Dalgarno et al., 2002).

Given the relative newness of VR-based learning in the school setting, theoretical perspectives of technology adoption seem appropriate for predicting student learning and satisfaction. Davis (1989) theorizes the widely accepted TAM in examining the acceptance of new information technology. TAM was adapted from the Theory of Reasoned Action (TRA) model, and posited that two beliefs, perceived ease of use and perceived usefulness, to determine one’s intention to use a technology. According to Davis (1989, p. 322), the information technology quality measured by Swanson (1987) which covered items such as “important”, “relevant”, “useful” and “valuable” is parallel to perceived usefulness, while accessibility items such as “convenient”, “controllable”, “easy”, and “unburdensome” correspond to perceived ease of use.

Therefore, in this study, the quality and accessibility of the desktop VR technology are measured by the perceived usefulness and perceived ease of use, and are collectively grouped as the construct of usability. TAM identifies perceived usefulness as the degree of work improvement after adoption of a system, whereas perceived ease of use is the users’ perception of ease of adopting a system. Applying this model to desktop VR-based learning, the presumption is the more learners perceive usefulness and ease of use in the instructional delivery media, the more positive their attitudes when interacting with the VR learning system, consequently
improving their learning experience and learning outcomes (Arbaugh & Duray, 2002; Sun et al., 2008). A sizable amount of literature has demonstrated the empirical validity of the TAM instrument on new software packages (Adams, Nelson, & Todd, 1992; Hendrickson, Massey, & Cronan, 1993; Szajna, 1994).

3.3.3 Presence

Presence refers to the user’s subjective psychological response to a system (Bowman & McMahan, 2007). It is the psychological sense of “being there” in the environment generated by the system. Users tend to behave as if they are in the real life situation though cognitively they know they are not. A key result of presence is that a person recalls the virtual environment experience as if recalling a visit to a place rather than a set of images and pictures (Schuemie et al., 2001; Usoh, Alberto, & Slater, 1996). According to Dalgarno et al., (2002), the sense of presence in a 3-D environment occurs as a consequence of the fidelity of representation and the high degree of interaction or user control, rather than just a unique attribute of the environment.

Slater (2003) mentioned that presence is a human reaction to immersion. It is the response to a given level of immersion. Different people may experience different levels of presence for the same system (Bowman & McMahan, 2007; Slater, 2003). This internal psychological process of the users in a virtual environment determines the extent to which they will be compelled by what they see, hear and feel and thus become immersed into the virtual world (Usoh et al., 1996). Furthermore, it may influence the learning outcomes of an individual (Salzman et al., 1999).
However, there were some inconsistent results reported on the relationship between presence and performance. Mania and Chalmers (2000) found that there was no correlation between presence and task performance in an empirical study with three conditions: lectures on a specific topic in the real world, in a virtual classroom, and an auditory-only environment. However, in a study using infomercials on television, Kim and Biocca (1997) found a weak but significant correlation between presence and performance in terms of factual memory and average recognition speed for recognizing stills from the infomercial. In a recent study, Ma and Kaber (2006) did not find any correlation between presence experiences and performance. In actual fact, empirical evidence to support the pervasive belief that presence is causally related to performance is still limited.

Generally, the more immersive a virtual environment is, the greater sense of presence users tend to experience in it (Schuemie et al., 2001). However, recently there was a debate that the low-immersion systems, such as desktop VR, are capable of providing high-presence experience to users (Nunez, 2004). High quality and high resolution information, interaction with the virtual environment, and anticipated effect of action in the virtual environment are some of the factors that contribute to presence (Slater & Usoh, 1994). This study is thus interested to gain a better understanding of this psychological factor underlying an experience in VR.

3.3.4 Motivation

Motivation refers to the magnitude and direction of behavior. It is the choices people make as to what experiences or goals they will approach or avoid, and the
degree of effort they will exert in that respect (Keller, 1983, p. 389). Research on this psychological response to a desktop system is to date rare. This learning experience could have an effect on learning effectiveness as posited by many researchers (Alavi & Leidner, 2001; Benbunan-Fich & Hiltz, 2003; Piccoli et al., 2001; Salzman et al., 1999; Wan et al., 2007).

It is believed that student motivation influences student performances in school which include attention, effort, quality, behavior, test scores, and grades (Hardré & Sullivan, 2008; Linnenbrink & Pintrich, 2002). Educational psychology studies have also shown a positive correlation between intrinsic motivation and academic achievement (Wilbourne, 2006). Intrinsic motivation occurs when the learning activities and learning environment elicit motivation in the students; intrinsic motivation behaviors are those that are freely engaged out of interest and do not depend on reinforcements, for example, rewards (Deci & Ryan, 2000). To maintain those behaviors, they require satisfaction of basic psychological needs such as autonomy and competence (Deci & Ryan, 2000).

Student motivation is a potentially important but understudied factor in the VR-based learning environment. According to Rezabek (1995), the study of motivation has long been neglected in instructional technology. This is supported by Yaman et al. (2008) who stated that the impact of the learner’s motivational perspective on its learning effects has hardly been studied though the effectiveness of a multimedia-based learning environment is greatly influenced by student motivation.
The reason is instructional designers assume that good quality instruction will be motivating (Keller, 1983). However, Rezabek (1995, p. 479) mentioned that “motivation is such a crucial issue in education that simple assumptions are not sufficient”. Using computer-based instruction, research by Rezabek (1995) confirmed that intrinsic motivation has an effect on learning effectiveness and achievement. Virvou, Katsionis, and Manos (2005) compared a virtual reality game named VR-ENGAGE with educational software without a gaming aspect, for learning primary school geography. Results show that the VR game is motivating and it influences students’ behavior in learning and also helps students to retain or improve their performance.

One of the assumptions of the currently accepted social cognitive motivational theories is that motivation is situated and contextualized (Linnenbrink & Pintrich, 2002). It is not an individual’s stable trait but is inherently changeable and sensitive to context. Thus, instructional efforts can make a difference in motivating students to learn because motivation can vary depending on the situation and context of learning (Linnenbrink & Pintrich, 2002). Therefore, based on the features of VR such as 3-D dimension, dynamic display, closed-loop interaction where users have control over the contents viewed or visited, motivational value is one of the justifications cited for using VR for learning (McLellan, 2004). Moreover, learning objectives are more transparent in the VR-based learning environment because it is able to help students to identify the learning objectives as well as the central issues of the learning topic. With such, the VR-based learning environment is able to increase student motivation for learning, which in turn influences the learning outcomes.
3.3.5 Cognitive Benefits

Antonietti, Rasi, Imperio, and Sacco (2000) have also identified cognitive benefits as one of the psychological correlates in the study of students’ representation of using VR in instruction. Cognitive benefits refer to better memorization, understanding, application and overall view of the lesson learned. In the six levels of Bloom’s taxonomy, memorization is synonymous with the knowledge level which emphasizes the ability to recall facts, terms or definitions, while understanding, application and overall view involve the remaining five levels of Bloom’s taxonomy.

Bell & Fogler (1997, p. 3) asserted that VR provides an environment in which students can exercise the higher levels of Bloom’s taxonomy in a manner totally unique from other educational methods. This is because in the VR-based learning environment, students have the freedom to explore, and view the environment from any vantage point desired. Thus, it allows them to analyze their problems and evaluate possible alternatives in ways that were impossible before (Bell & Fogler, 1997). Furthermore, through the interactive dynamic visualizations, students could adapt a presentation’s pace and sequence to their own cognitive needs and skills for better comprehension and assimilation of the knowledge learned (Schwan & Riemp, 2004).

VR is also capable of affording constructivist learning, which is a relatively new paradigm of instructional design. Constructivist learning focuses on helping learners to construct and build on their own new knowledge, based on their prior experiences and knowledge. This is mainly because in VR-based learning, learners are active
participants in a computer-generated world. They can navigate and manipulate the virtual object in the virtual world, and the interaction is observed by learners in real time. Therefore, VR is not only well-suited for providing exploratory learning environments in which learners learn through experimentation, it is also able to support situated learning where learners learn in the actual context where the learning is to be applied (Chen, 2005; Kim et al., 2001). These interactive learning activities may help to develop learners’ higher order thinking skills. Leidner and Jarvenpaa (1995) stated that technology that promotes interaction can be effectively used to develop higher-order thinking skills and build conceptual knowledge. Hence, the cognitive benefits gained through VR technology could lead to better learning outcomes.

3.3.6 Control and Active Learning

Control and active learning, which is akin to involvement, is a psychological state experienced as a consequence of focusing one’s attention on a coherent set of related activities and stimuli (Schuemie et al., 2001). Theorists and researchers have suggested that some degree of learner control is important in a learning process because students may better learn how to learn through making instructional choices and may feel more motivated to learn, which in turn results in better performance (Kinzie et al., 1988).

According to Williams (1996), learner control refers to “instructional designs where learners make their own decisions concerning the learning path, flow, or events of instruction”. Elements that can be controlled include learning pace, sequencing,
content of instruction, and amount of practice in a learning environment (Kinzie et al., 1988; Milheim & Martin, 1991). With total internal control by the learners, learners can better learn how to learn because they make their own instructional decisions, experience and are responsible for the consequences and results of those decisions, and in the process discover the best tactics for different situations (Merrill 1975). Consequently, learners are actively involved in the learning process and may feel more competent, self-determining, and intrinsically more interested in learning (Lepper, 1985).

Many studies have reported positive correlations between perceptions of control and achievement performance (Stipek & Weisz, 1981). Performance is measured in terms of lower error tests and higher learning satisfaction (Merrill, 1994). However, the superiority of learner control in learning remains inconclusive (Kinzie et al., 1988; Williams, 1996). Other researchers have shown that learners with instructional control decisions do not learn as effectively as those who do not have control over their learning. According to Kinzie et al. (1988), these different results may be a function of the degree and type of learner control given. Since individuals vary in their ability to make progress in learning, some may view less material and skip important instructional components, thus learner control should be accompanied by aids for self-monitoring of progress (Kinzie et al., 1988; Milheim & Martin, 1991: Williams, 1996). In this study, self-monitoring of progress is done through laboratory reports that come together with the desktop VR software.
Research has found that computer-simulated experiments permit more active student involvement in the learning process and thus leads to greater understanding of science concepts (Choi & Gennaro, 1987; Rivers & Vockell, 1987; Yang & Heh, 2007). This is in agreement with the principle of constructivism that the more opportunity for active learning, the more positive results the students would gain (Roblyer, 2003; Yang & Heh, 2007). The preliminary study of Jang, Jyung and Black (2007) revealed that active learner control in rotating the 3-D structures enhances a learner’s internal representation of a complex structure. However, research by Keehner and Khooshabeh (2002) showed that active learning does not contribute to improvement in performance in drawing tasks. In their studies, active learning is provided where students can rotate a 3-D visualization freely during the drawing task. Thus, more research is needed to acknowledge the inconsistency in empirical studies.

VR technology can provide multisensory and interactive experiences to enhance learning. Learners control their own learning pace and are actively involved in the learning activities. These interactions can be as good, or better, than traditional classroom lectures.

### 3.3.7 Reflective Thinking

To achieve meaningful learning and to support constructivist learning principles, learners must reflect on their learning activities and observations to learn the lessons. According to Jonassen et al. (1999, p. 9),

> New experiences often create a discrepancy between what learners observe and what they understand. They are curious about or puzzled by what they
see. That puzzlement is the catalyst for meaning making. By reflecting on the puzzling experience, learners integrate new experiences with their prior knowledge, or they establish goals for what they need to learn in order to make sense out of what they observe.

Research on reflective thinking in the context of a desktop VR-based environment is limited. Reflection is beneficial in the learning process as it enables students to think critically about their own learning (Phan, 2007), and to explore their experiences in a conscious manner that leads to a new understanding. Dewey (1933, p. 9) defined reflective thinking as “active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the conclusion to which it tends.” According to Dewey (1933, p. 12), “reflective thinking involves (1) a state of doubt, hesitation, perplexity, mental difficulty, in which thinking originates, and (2) an act of searching, hunting, inquiring, to find material that will resolve the doubt, settle and dispose of the perplexity.”

Mezirow (1991; 1998) theorized four stages of reflective thinking which include: habitual action, understanding, reflection, and critical reflection. Habitual action is activity that has been learned before and carried out frequently until it becomes a routine procedure which is performed automatically with little conscious thought. Understanding means comprehending without relating to other situations. Reflection is active, persistent, and careful consideration of any beliefs grounded in consciousness. The understood concepts are associated with related personal meaning and experience. Finally, critical reflection is considered as a higher level of reflective thinking that involves individuals becoming more aware of how they perceive things, think, feel, or act as they do, and it may result in a change of personal belief (Leung & Kember, 2003).
Research has shown that a surface approach to learning—that is, studying merely for the intention of reproducing information without any attempt to understand the contents acquired—is aligned with habitual action, whereas a deep approach to learning, which entails an intention to understand meaning and link it to previous knowledge and personal experience so as to construct new knowledge, is aligned to reflective thinking (Leung & Kember, 2003; Phan, 2007).

Empirical findings show that reflective thinking is predictive of performance outcomes if the learning objectives are aligned closely to assessment tasks (Phan, 2007). It is the interest of this study to investigate whether the VR-based learning environment engages learners in some form of reflective thinking, such as the understanding and reflection advocated by Mezirow (1991, 1998), that promotes deep learning, which is consistent with the constructivist approach of learning; in addition, to investigate if reflective thinking leads to greater perceived learning effectiveness and satisfaction.

3.3.8 Learning Outcomes
A central purpose of learning is to acquire knowledge and increase the capability to take effective action. However, knowledge is implicitly constructed in the mind of the learners and that knowledge and capability cannot be directly measured; only the action and performance resulting from learning can be observed and measured (Alavi & Leidner, 2001). Sharda et al. (2004) have classified learning outcomes into three groups: psychomotor outcomes, cognitive outcomes, and affective outcomes.
Psychomotor outcomes include efficiency, accuracy and response magnitude. Cognition outcomes include comprehension, knowledge, application and analysis based on Bloom’s taxonomy. Affective outcomes include students’ perceptions of satisfaction, attitude and appreciation for the learning experience (Sharda et al., 2004). Indeed, research suggests that technology-mediated learning environments may improve students’ achievements (Alavi, 1994; Hiltz, 1995; Maki, Maki, Patterson, & Whittaker, 2000; Schutte, 1997; Wetzel, Radtke, & Stern, 1994), their attitudes toward learning (Schutte, 1997), and their evaluation of the learning experience (Alavi, 1994; Hiltz, 1995). This study focuses on two domains, that is, the cognitive domain in terms of performance achievement, and the affective domain in terms of perceived learning effectiveness and satisfaction with the desktop VR-based learning environment.

3.3.9 Student Characteristics

Students are the primary participants in any learning environment (Piccoli et al., 2001). Students are generally comfortable with the traditional classroom learning environment. The VR-based learning environment departs noticeably from this dominant model as the students control, and are responsible for, their learning with the use of VR technology. Educators usually expect students to learn effectively with a new technology in a short time; however, because of individual differences, several factors could affect the final achievement (Wen & Hsu, 2000).

Student factors that could affect the learning outcomes include demographics (e.g. age and gender), language, communication skills, learning styles, spatial abilities,
problem solving styles or prior knowledge and attitudes toward technology, cognitive styles, cognitive needs, computer anxiety and technology experience (Arbaugh & Duray, 2002; Lee, Hong, & Ling, 2001; Piccoli et al., 2001; Wen & Hsu, 2000). It was reported in the ScienceSpace project of Salzman et al. (1999) that individual differences have affected the students’ abilities to interact with the virtual learning environment.

The influence of two individual learner characteristics, spatial abilities and learning styles, on learning outcomes was investigated in this study. These student characteristics may influence the perception towards VR technology and may serve to moderate the relationship between the learning experience and the learning outcomes, as advocated by Salzman et al. (1999).

3.4 Hypotheses for Evaluating How Desktop VR Enhances Learning Outcomes

Based on the hypothesized theoretical model, the following hypotheses were thus developed to answer research questions 7 and 8, that is, (7) What are the constructs that play an important role in a desktop VR-based learning environment? and (8) How do these constructs interrelate to enhance the VR-based learning effectiveness? Figure 3.2 represents the hypothesized relationships in the model.

Hypotheses for the Relationships between Constructs

H1: VR features are significantly related to usability.

H2: VR features are significantly related to presence.

H3: VR features are significantly related to motivation.
H4: VR features are significantly related to cognitive benefits.

H5: VR features are significantly related to control and active learning.

H6: VR features are significantly related to reflective thinking.

H7: Usability is significantly related to presence.

H8: Usability is significantly related to motivation.

H9: Usability is significantly related to cognitive benefits.

H10: Usability is significantly related to control & active learning.

H11: Usability is significantly related to reflective thinking.

H12: Presence is positively related to learning outcomes.

H13: Motivation is positively related to learning outcomes.

H14: Cognitive benefits are positively related to learning outcomes.
H15: Control and active learning is positively related to learning outcomes.
H16: Reflective thinking is positively related to learning outcomes.

**Hypotheses for the Moderating Effect of Student Characteristics**

H17: Spatial ability moderates the influence of presence on learning outcomes.
H18: Spatial ability moderates the influence of motivation on learning outcomes.
H19: Spatial ability moderates the influence of cognitive benefits on learning outcomes.
H20: Spatial ability moderates the influence of control and active learning on learning outcomes.
H21: Spatial ability moderates the influence of reflective thinking on learning outcomes.
H22: Learning style moderates the influence of presence on learning outcomes.
H23: Learning style moderates the influence of motivation on learning outcomes.
H24: Learning style moderates the influence of cognitive benefits on learning outcomes.
H25: Learning style moderates the influence of control and active learning on learning outcomes.
H26: Learning style moderates the influence of reflective thinking on learning outcomes.

**Hypotheses for Latent Mean Testing**

Based on the measurement models, further analysis was conducted to determine the latent mean differences in the perception of the technical features afforded by the
desktop VR technology by learners with different spatial abilities and learning styles. Thus, the following two hypotheses were developed for this purpose.

H27: Spatial ability influences the perception of VR features.
H28: Learning style influences the perception of VR features

3.5 Summary

There are two main purposes in this research: to investigate the learning effectiveness of a desktop VR-based learning environment as compared to the conventional classroom learning method; and to develop a framework and subsequently a model to evaluate how VR enhances the learning outcomes. The research frameworks that guide this study are presented as well as the hypotheses. In addition, the constructs of the hypothesized model to evaluate how desktop VR enhances the learning outcomes are also elaborated in detail before the hypotheses are discussed.
Chapter 4

METHODOLOGY

4.0 Overview

This chapter describes the research methodology adopted in this study. The chapter starts with the description of the research design. It continues on with the description of the population and sample. Next, it includes a detailed explanation of the instruments development, the software used, the data collection procedures and the data analysis techniques. In addition, a description of SEM which is used to test the model is provided. This chapter further explains the approach of using SEM which includes the measurement development models and structural model evaluation. It also elaborates the strategy used to investigate the moderating effects of student characteristics on the model. Finally, it concludes with the findings of the pilot study.

4.1 Research Design

A two-group pretest-posttest experimental design was employed in this study. The permission from the education department and school administrators, the willingness of teachers and students, and the computer system facilities in schools were all prerequisites required to execute this study. As the class organization could not be reorganized due to the fact that the students could only be allowed to participate in the experiment at certain times during the school hours, the pretest-posttest quasi-experimental design was employed to establish a cause-effect relationship between
the interventions and learning outcomes. This design involved an experimental group (VR mode) and a control group (Non-VR mode). The experimental group used desktop VR software for the lesson while the control group followed a conventional classroom learning method with PowerPoint slides (see Figure 4.1). Both the experiment and control groups constituted randomly selected intact classes from the randomly selected schools.

**Figure 4.1: Two-group pretest-posttest quasi-experimental design**

To minimize the learning content differences in the two learning modes, PowerPoint slides were used to deliver similar contents with texts and colored pictures as in the desktop VR software, but with no animations and interaction. PowerPoint slides also help to minimize the teaching capability differences of teachers from different classes and different schools in the Non-VR mode because the content and flow of the presentation could be kept as similar as possible. Furthermore, PowerPoint slides are a common teaching aid used by teachers in secondary classrooms, and real frog dissection is not compulsory for the Form Four biology syllabus where the study was conducted.
In addition, factorial design was used to investigate the interaction of the independent variables with one or more other variables, known as moderator variables (Fraenkel & Wallen, 1996). A 2 x 2 quasi-experimental factorial design was used in which learning modes were crossed with the spatial abilities of the learners (see Figure 4.2). The same method was used to determine the interaction effect of learning modes and learning styles (see Figure 4.3).

![Factorial Design Chart](chart1.png)

**Figure 4.2:** The factorial design to study the effects of learning mode and spatial ability on posttest score, perceived learning effectiveness and satisfaction

![Factorial Design Chart](chart2.png)

**Figure 4.3:** The factorial design to study the effects of learning mode and learning style on posttest score, perceived learning effectiveness and satisfaction

### 4.2 Population and Sample

The population for this study was senior high school science stream students, aged between 15 and 17 years old of any co-education secondary school in a city of East Malaysia. They were Form Four students in the Malaysian education system. These
students were chosen because they were within the target population as they have started to take a biology unit in Form Four.

A list of secondary schools in the city that fulfilled criteria such as (a) co-education, and (b) well-equipped with multimedia computer laboratories, was formed. Four secondary schools were first selected from the list using the simple random method. For each selected school, two to four intact classes were randomly chosen using the simple random method to take part in the experiment. These selected classes were then randomly assigned to either experimental (VR mode) or control groups (Non-VR mode).

4.3 Development of the Measurement Instruments

Altogether there were five sets of questions that the participants needed to answer. These included the pretest, posttest, spatial ability test, initial questionnaire (pre-experiment questionnaire) which comprised some demographic information of the participants and their learning styles, and a final questionnaire (post-experiment questionnaire). A summary of the measurement instruments used before and after the treatment is shown in Table 4.1. The instruments developed were attached in Appendix C to Appendix F.

The final questionnaire composed of a combination of five-point Likert-scaled items and open-ended questions (for the VR mode). The assessed domains of the final questionnaire included background information and affective learning outcomes (perceived learning effectiveness and satisfaction). For the VR learning mode, the
final questionnaire also included the assessed domains of interaction experience (perceived usefulness and perceived ease of use), learning experience (presence, motivation, cognitive benefits, control and active learning, and reflective thinking), VR features (representational fidelity and immediacy of control), and the potential use of the VR computer program. After the treatment, a few students were also randomly selected from the VR learning mode to provide some qualitative feedback during debriefing sessions.

Table 4.1: Measurement instruments for various stages of treatment

<table>
<thead>
<tr>
<th>Stage</th>
<th>Measurement Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Treatment</td>
<td>- Posttest</td>
</tr>
<tr>
<td></td>
<td>- Spatial Ability Test</td>
</tr>
<tr>
<td></td>
<td>- Initial Questionnaire</td>
</tr>
<tr>
<td></td>
<td>- Demographic information</td>
</tr>
<tr>
<td></td>
<td>- Learning style inventory</td>
</tr>
<tr>
<td>After Treatment</td>
<td>- Posttest</td>
</tr>
<tr>
<td></td>
<td>- Final Questionnaire</td>
</tr>
<tr>
<td></td>
<td>- Background information</td>
</tr>
<tr>
<td></td>
<td>- Perceived learning effectiveness</td>
</tr>
<tr>
<td></td>
<td>- Satisfaction</td>
</tr>
<tr>
<td></td>
<td>- Representation fidelity*</td>
</tr>
<tr>
<td></td>
<td>- Immediacy of control*</td>
</tr>
<tr>
<td></td>
<td>- Perceived usefulness*</td>
</tr>
<tr>
<td></td>
<td>- Perceived ease of use*</td>
</tr>
<tr>
<td></td>
<td>- Presence*</td>
</tr>
<tr>
<td></td>
<td>- Motivation*</td>
</tr>
<tr>
<td></td>
<td>- Cognitive benefits*</td>
</tr>
<tr>
<td></td>
<td>- Control and active learning*</td>
</tr>
<tr>
<td></td>
<td>- Reflective thinking*</td>
</tr>
<tr>
<td></td>
<td>- Potential use of VR* (Open-ended questions)</td>
</tr>
</tbody>
</table>

Note: * for VR learning mode

A five-point Likert scale ranging from (1) Strongly Disagree to (5) Strongly Agree was used for all scaled items in the final questionnaire, that is, perceived learning effectiveness, satisfaction, representational fidelity, immediacy of control, perceived
usefulness, perceived ease of use, presence, motivation, cognitive benefits, control and active learning, and reflective thinking. For all of these variables, an individual’s score on the scale was conducted by taking the mean of all items that comprised the scale. A high score on the scale meant a positive result was obtained. The higher the score, the better the result was. Before the mean scores of all items were calculated and formed into a single composite measure for these variables, the reliability and the unidimensionality of all items in the scale that measured these variables were determined. Cronbach’s alpha was used to determine the internal consistency reliability of the scale, that is, the consistency of the scale or the degree to which the items that make up the scale are all measuring the same underlying attribute (Kumar, 2005; Pallant, 2007). Factor analysis was used to determine the unidimensionality of the items, meaning that they are strongly associated with each other and represent a single concept (Hair et al., 2006; Hattie, 1985; McDonald, 1981).

The following describes the development of each measurement instrument for this study.

4.3.1 Pretest and Posttest

Both pretest and posttest were similar in content but the order of questions was different to avoid the set response effect. Some 38 questions regarding frog anatomy for the modules covered in this study were developed to test the students’ knowledge on this subject. Students were required to complete the sentences with the correct word(s), to label and draw the organs, and to answer multiple-choice questions.
4.3.1.1 Scoring

The total score for the test was 38 marks. One mark was given to each correct answer and zero to each incorrect answer. For questions that required the students to draw the organs, one full mark was given if the position and shape of the organs were correctly shown. The total score was then converted to a percentage score.

4.3.1.2 Test Validity

Content validity of these tests was determined by expert judgment. Three subject matter experts were requested to review the test questions and make a judgment about how well these items represent the intended content area. These three subject matter experts were biology teachers in the city where the study was conducted. Comments from the subject matter experts were taken into consideration before the test was used for the pilot study.

4.3.1.3 Test Reliability

A pilot study was carried out after the questions were validated. Item analysis was carried out to obtain two types of information to improve the tests. These included the item difficulty index and item discrimination index. The item difficulty index is the proportion of students who answered an item correctly, whereas the item discrimination index measures how adequately an item discriminates between high scorers and low scorers on an entire test (Cohen, Swerdlik, & Philips, 1996). The reliability of the test was estimated with Cronbach’s alpha coefficient.
4.3.2 Kolb Learning Style Inventory

The Kolb Learning Style Inventory Version 3.1 (KLSI 3.1) was used to categorize the learning style of each participant into either assimilator learner or accommodator learner (Kolb, 2007). Each participant needs to complete 12 sentences that describe learning. Each item has four endings and the participant is required to rank the endings for each sentence according to how well he or she thinks each ending describes the way he or she learned.

Based on the Learning Style Inventory scoring, the scores for each learning phase, AC, CE, AE and RO, were first obtained for each participant. Subsequently, the CE score was subtracted from the AC scores, and the RO score was subtracted from the AE scores to have two combination scores. These two combination scores were then put on the Learning Style Type Grid to determine the participant’s learning style, that is, accommodator, assimilator, diverger or converger (see Figure 2.3, p. 40). On the Grid, accommodator falls on the top left quadrant; diverger falls on the top right quadrant; converger falls on the bottom left quadrant; and assimilator falls on the bottom right quadrant.

However, for this study, based on the method of Chen et al. (2005), a dashed diagonal line was introduced to equally separate the grid into two halves as shown in Figure 4.4. Based on this diagonal line, any diverger learner or converger learner with the two combination scores that fell below the diagonal line was classified as an assimilator learner. Likewise, if the two combination scores fell above the diagonal line, the participant was classified as an accommodator learner. Thus, assimilator
included learners who fulfilled Kolb’s definition of assimilator, diverger learners with stronger Kolb’s characteristics of RO than CE, and converger learners with stronger Kolb’s characteristics of AC than AE (Chen et al., 2005). On the other hand, accommodator included learners who fulfilled Kolb’s definition of accommodator, diverger learners with stronger Kolb’s characteristic of CE than RO, and converger learners with stronger Kolb’s characteristic of AE than AC (Chen et al., 2005).

**Figure 4.4: Kolb’s learning styles (Adapted from Kolb, 1984)**

Several studies have shown that KLSI 3.1 has good internal consistency reliability across a number of different populations (Kolb & Kolb, 2005). Table 4.2 shows the Cronbach’s alpha coefficients for five different studies for the randomized KLSI 3.1: the norm subsample of online LSI users, Kayes’s (2005) study of liberal arts college students, Wierstra and DeJong’s (2002) study of psychology undergraduates, and two studies by Ruble and Stout (1990; 1991) of business students.
Table 4.2: Internal consistency alphas for the scale scores of the KLSI 3.1 (Kolb & Kolb, 2005)

<table>
<thead>
<tr>
<th>Source</th>
<th>N</th>
<th>CE</th>
<th>RO</th>
<th>AC</th>
<th>AE</th>
<th>AC-CE</th>
<th>AC-RO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Online Sample</td>
<td>5023</td>
<td>0.77</td>
<td>0.81</td>
<td>0.84</td>
<td>0.80</td>
<td>0.82</td>
<td>0.82</td>
</tr>
<tr>
<td>Kayes (2005)</td>
<td>221</td>
<td>0.81</td>
<td>0.78</td>
<td>0.83</td>
<td>0.84</td>
<td>0.77</td>
<td>0.84</td>
</tr>
<tr>
<td>Wierstra &amp; DeJong (2002)</td>
<td>101</td>
<td>0.81</td>
<td>0.78</td>
<td>0.83</td>
<td>0.84</td>
<td>0.83</td>
<td>0.82</td>
</tr>
<tr>
<td>Ruble &amp; Stout (1990; 1991)</td>
<td>323 (1990)</td>
<td>0.72</td>
<td>0.75</td>
<td>0.72</td>
<td>0.73</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>403 (1991)</td>
<td>0.67</td>
<td>0.78</td>
<td>0.78</td>
<td>0.78</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

4.3.3 Spatial Ability Test

The spatial ability test from Barrett and Williams (2003) was used to test the spatial visualization ability of the participants. It consists of 75 patterns that could be folded or formed into figures. This test explores how easily the participants can ‘see’ and manipulate shapes and figures in space (Barrett & Williams, 2003). In other words, this test evaluates the spatial visualization component of spatial ability, which is the spatial skill needed to see and manipulate the objects in the VR-based learning environment of this study.

First, students read instructions and saw sample problems similar to those tested, and then they had 10 minutes to complete the test. In this study, a median split was used to classify a participant as having high spatial visualization ability or low spatial visualization ability. This provides a rough way to categorize learners with different spatial abilities (Mayer, 2001). A pilot study was conducted to determine the test reliability of this test.
4.3.4  Perceived Learning Effectiveness

Perceived learning effectiveness was developed based on the instruments of Benbunan-Fich and Hiltz (2003), Marks et al. (2005) and Martens et al. (2007). An eight-item instrument was developed to measure perceived learning effectiveness on the issues of identification, integration and generalization of the lesson material. For all items, participants rated themselves on a five-point Likert scale ranging from (1) Strongly Disagree to (5) Strongly Agree. An individual’s score on the scale was conducted by taking the mean of the eight items. A high score on this scale indicated that the participant thought he or she learned effectively in this study. Perceived learning effectiveness has been used in numerous studies as a learning outcome measurement (Benbunan-Fich & Hiltz, 2003; Marks et al., 2005; Martens et al., 2007). The tests of unidimensionality and reliability were performed on the actual data.

4.3.5  Satisfaction

Students’ perceived satisfaction was measured by a scale consisting of seven items adapted from Chou and Liu (2005). The original instruments have eight items with an alpha coefficient of 0.8625. A five-point Likert scale ranging from (1) Strongly Disagree to (5) Strongly Agree was used to rate a participant’s perception on satisfaction. The mean of all the items was calculated to represent an individual’s score on this scale. A high score meant the participant was satisfied with the learning method provided. Internal consistency reliability was examined through a pilot study. Subsequently, unidimensionality and reliability tests were further conducted on the actual data.
4.3.6  Representational Fidelity

Three items were created based on the representational fidelity defined by Dalgarno et al. (2002). The opinions on representational fidelity were measured using a five-point Likert scale with (1) Strongly Disagree and (5) Strongly Agree. A pilot test was conducted to examine the internal consistency. Tests of unidimensionality and reliability were also conducted on the actual data.

4.3.7  Immediacy of Control

Four items were created based on the immediacy of control defined by Dalgarno et al. (2002). A five-point Likert scale with (1) Strongly Disagree and (5) Strongly Agree was used to measure immediacy of control. Internal consistency reliability was first determined through a pilot test. Unidimensionality and reliability test were further conducted on the actual data.

4.3.8  Perceived Usefulness

Perceived usefulness was measured with four items adapted from the instrument of Davis (1989). A five-point Likert scale with (1) Strongly Disagree and (5) Strongly Agree was used to measure perceived usefulness. Internal consistency reliability was first determined through a pilot test. Unidimensionality and reliability tests were further conducted on the actual data.

4.3.9  Perceived Ease of Use

Four items were adapted from the instrument of Davis (1989) to measure perceived ease of use. A five-point Likert scale with (1) Strongly Disagree and (5) Strongly Agree was used to measure perceived ease of use. Internal consistency reliability was first determined through a pilot test. Unidimensionality and reliability tests were further conducted on the actual data.
Agree was used to measure perceived ease of use. Internal consistency reliability was first determined through a pilot test. Unidimensionality and reliability tests were further conducted on the actual data.

4.3.10 Presence

Presence was measured using a single item with five-point Likert scale ranging from (1) Strongly Disagree to (5) Strongly Agree. Since it was a single item, internal consistency could not be determined.

4.3.11 Motivation

The motivation instrument consisted of fifteen items scored on a Likert scale ranging from (1) Strongly Disagree to (5) Strongly Agree. It was adapted from the Intrinsic Motivation Inventory (IMI) by McAuley, Duncan and Tammen (1989). The items were reworded to suit the current task studied. Negatively worded items were reverse coded prior to the analysis of the data. The original IMI by McAuley et al. (1989) has eighteen items which were categorized into four sub-categories. However, the overall scale was used in this study. The overall scale has an alpha coefficient of 0.85 (McAuley et al., 1989). A pilot test was conducted to determine the internal consistency of this fifteen-item instrument. Unidimensionality and reliability tests were also performed on the actual data.

4.3.12 Cognitive Benefits

Cognitive benefits were measured with five items, with four items adapted from the instrument of Antonietti et al. (2000). A five-point Likert scale was used with (1)
Strongly Disagree and (5) Strongly Agree. A pilot test was carried out to determine the internal consistency. Tests of unidimensionality and reliability were further conducted on the actual data.

4.3.13 Control and Active Learning
Four items were developed to measure learner control and active learning. A five-point Likert scale was used with (1) Strongly Disagree and (5) Strongly Agree. Internal consistency was first determined through a pilot testing of this instrument. Tests of unidimensionality and reliability were further conducted on the actual data.

4.3.14 Reflective Thinking
Maor and Fraser’s (2005) reflective thinking instrument was used as a starting point for the development of the items used to measure reflective thinking. Four items were developed, with three adapted from Maor and Fraser (2005). The instrument of Maor & Fraser (2005) has five items with an alpha coefficient of 0.87. A pilot test was carried out to determine the internal consistency. It was followed by the tests of unidimensionality and reliability on the actual data.

4.4 Software
A desktop virtual reality program, V-Frog™, was used to provide the virtual learning environment to students (Tactus Technologies, 2007). This software was developed and supplied by Tactus Technologies, Inc., New York. This virtual reality-based dissection simulator was developed using virtual surgery technology. Textual information to guide the virtual experiment and to explain the lesson content is on
the right panel on every screen page while the VR cognitive tool is on the left as shown in Figure 4.5. Students can have hands-on learning experience with V-Frog™. They can cut, pull, probe, and examine a virtual specimen, as they would with a real frog. Thus, each dissection is different, reflecting the individual work of each student. Actions are repeatable and the content presentation is nonlinear.

In each specimen window, there are viewpoint manipulation tools for students to rotate, slide and zoom the specimen. There is also a reset button to reset the position of the specimen. Additionally, in some specimen windows, dissection tools such as scalpels and tweezers for students to cut and peel the skin are provided. Moreover, there are also a query tool that allows students to get information about a part of the specimen; a magic wand tool that activates and brings parts of the specimen to life; and a probe tool that examines an orifice in the specimen. Besides, a virtual endoscopy can be conducted with the endoscoping tool to explore the entire alimentary canal. There is also a V-Frog™ lab report to guide students through all the modules, highlighting key points and relationships. The existence of a lab report icon on the screen indicates to students that information on the current screen can assist them to complete their lab report successfully. More screenshots from V-Frog™ are shown in Figures 4.6 to 4.10.
Figure 4.5: Screenshot of the desktop VR-based learning environment, the V-Frog™ (Courtesy of Tactus Technologies)

Figure 4.6: The virtual scalpel cuts the frog, just like a real dissection (Courtesy of Tactus Technologies)
Figure 4.7: The skin is being pulled back with the tweezers (Courtesy of Tactus Technologies)

Figure 4.8: The internal organs are exposed after the membrane is removed (Courtesy of Tactus Technologies)
Figure 4.9: Query tool is used to identify the organ (Courtesy of Tactus Technologies)

Figure 4.10: The comparison of human and frog’s heart. Magic wand can be used to animate the heartbeats (Courtesy of Tactus Technologies)
4.5 **Data Collection Procedures**

The following subsections describe the data collection procedures for both the actual and pilot study. Prior to the implementation of the study, human research ethics approval was first obtained from the Human Research Ethics Committee of Murdoch University, and permission was sought from the Ministry of Education in Malaysia, the Regional Education Department and school principals. Students and teachers’ consents were also prerequisites required to execute this study.

4.5.1 **Actual Study**

Standardized written research protocols were used for both the experimental and control groups respectively to minimize differences in data collection procedures (see Appendix A and Appendix B). A detailed research protocol was provided to each teacher who conducted the experiment. The researcher was also available to the teachers for consultation throughout the study.

Two weeks before the treatment, respondents were required to sit for a pretest regarding frog anatomy which took about 30 minutes and a spatial ability test which took 15 minutes to complete, respectively. Apart from the tests, students were also asked to answer a set of questionnaires (initial questionnaire) which took 15–20 minutes to complete.

During the treatment, both groups were given a lesson on frog anatomy for about 1.5 hours. The experimental groups learned with the VR software, V-Frog™, where each student was assigned to an individual computer. Just before the treatment, the
experimental groups were given training on how to use the V-Frog™ software program. On the other hand, the control groups underwent a conventional classroom learning method with PowerPoint slides conducted by their biology teacher.

Immediately after the treatment, respondents were required to answer a posttest regarding frog anatomy which took 30 minutes and a set of questionnaires (final questionnaire) which took 20 minutes to complete, respectively.

A gap of two weeks between the pretest and the posttest was meant to reduce the pretest sensitization threat. The respondents were assured that the results of the tests and questionnaires were solely for the research purposes and were not part of the subject assessment in school.

After completing the experiment, a few participants from the VR learning mode from each selected school were asked to provide additional qualitative feedback during debriefing sessions.

4.5.2 Pilot Study

A posttest only experimental design was conducted for the pilot study. A group of Form Four students, aged between 15 and 17 years old, from a co-education school from the same city in East Malaysia participated in the pilot study. These students were randomly selected from science stream classes. A day before the treatment, participants were given a spatial ability test to answer. Just before the treatment, the participants were given training on how to use the V-Frog™ software program.
Immediately after the treatment, which took about 1.5 hours, the participants were given a posttest and a set of questionnaires to answer.

4.6 Data Analysis Technique

This subsection describes the various statistical tests used to analyze the actual and pilot test data. Statistical Package for Social Sciences (SPSS) Version 16 was used to analyze the data for descriptive statistics such as frequency and proportion. SPSS Version 16 was also used to run the statistical tests which included independent-samples t-test, two-way analysis of variance (two-way ANOVA), factor analysis and internal consistency reliability. Analysis of Moment Structures (AMOS) Version 16 was used for SEM to determine the fit of the hypothesized model.

4.6.1 Actual Study

To answer the research questions and to achieve the research objectives, the quantitative data was analyzed using the software as mentioned above.

The initial plan to use analysis of covariance (ANCOVA) to explore differences between groups with pretest as a covariate to increase the likelihood to detect differences between groups was found to be not appropriate because the homogeneity of regression slopes that concerns the relationship between the covariate and the dependent variable for each group was violated. Unequal slopes would indicate the existence of interaction between the covariate and the treatment (Pallant, 2007, p. 293). A violation of this assumption would cause misleading results with ANCOVA, thus it should not be conducted (Stevens, 1996, p. 323;
Tabachnick & Fidell, 2007, pp. 203, 213). Hence, Independent-samples t-test was used to determine the differences in the dependent variables between groups.

4.6.1.1 Statistical Analysis for Determining the Learning Effectiveness of a Desktop VR-based Learning Environment

Independent-samples t-test was conducted to determine if there was statistical difference in the mean score of the dependent variables (pretest, posttest, perceived learning effectiveness and satisfaction) between the two learning modes (VR mode and Non-VR mode). Independent-sample t-test was also used to determine if there was difference in the mean score of the learning outcomes and overall improvement in performance for students with different characteristics in the VR mode. However, before this test was conducted, assumptions for this test were checked to ensure that there was no violation of the assumptions.

To determine the effects of the moderator variables (spatial ability and learning style), a two-way ANOVA was carried out to determine if any interaction existed between the learning modes and each of the moderators, related to the learning outcomes, that is, the performance achievement as measured by the posttest, and affective qualities as measured by the perceived learning effectiveness and satisfaction. Independent-samples t-test was also conducted for testing simple effects. A simple effect is the effect of one independent variable within one level of a second independent variable (Newsom, 2006), for instance, to determine if spatial ability has any effect in the VR mode.
4.6.1.2 Statistical Analysis for Evaluating How VR Enhances Learning Outcomes

The reliability and validity of the instruments mentioned in Sections 4.3.4 to 4.3.14 were further determined using the Cronbach’s alpha procedures and factor analysis. Items that are unidimensional, load highly on a factor and with good internal consistency reliability are combined into a single composite measure. In this study, the average (mean) score of the items was used. These single composite measures were for the indicators (observed variables) underlying the latent variables (constructs) in the model as shown in Figure 3.1 (see p. 64).

Evaluation of the model was undertaken using SEM with AMOS Version 16. SEM is a collection of statistical techniques that allows a hypothesized model to be tested statistically in a simultaneous analysis of the entire system of variables to determine the extent to which it is consistent with the data (Byrne, 2001, p. 3). If the goodness of fit is adequate, the model is considered plausible for the postulated relations among variables (Byrne, 2001). Two main characteristics of SEM are: (1) simultaneous estimation of multiple and interrelated dependence relationships, and (2) the ability to present unobserved concepts in these relationships and correct for measurement error in the estimation process (Hair et al., 2006). Thus, SEM is the only analysis that allows complete and simultaneous tests of all causal relationships and the relationships are free of measurement error because the error has been estimated and removed, leaving only common variance (Ullman, 2007, p. 679).

There are two major types of variables in SEM: observed variables (indicators) and latent variables (constructs). Latent variables are not directly observable or
measured, rather they are measured indirectly through observed variables that define the latent variable (Schumacker & Lomax, 2004). Thus, SEM involves consideration of two types of models: the measurement model and the structural model. The measurement model specifies the relationships among observed variables underlying the latent variables. The structural model specifies the theoretical relationships among the latent variables. Estimated path coefficients between the latent variables indicate the strength and sign of the theoretical relationship. Each latent variable or construct has a corresponding measurement model that provides an assessment of convergent and discriminant validity (Schumacker & Lomax, 2004). In other words, the measurement model can be used to assess the contribution of each indicator in the estimation of relationships between latent variables. The structural models provide an assessment of nomological validity, which means the correlation of the constructs in the models make sense (Hair et al., 2006; Schumacker & Lomax, 2004).

A two-step model-building approach which has been advocated by many authors (e.g. Anderson & Gerbing, 1988; Mulaik et al., 1989) was adopted to analyze the two conceptually distinct models: the measurement model followed by the structural model. This is because the testing of the structural model may be meaningless unless the reliability and validity of the indicators underlying the constructs can be established (Jöreskog & Sörbom, 1993). Once the measurement model development has been completed, the structural path of the SEM is estimated. This means to test the relationships among the independent and dependent latent variables in the structural models.
The evaluation of the measurement models and structural models was done using maximum likelihood estimation. Before the evaluation was conducted, the assumptions for maximum likelihood estimation were performed to make sure that it was appropriate for employment.

4.6.1.2.1 Measurement Model Development

Prior to the development of the measurement model, the unidimensionality and internal consistency of the items of each factor were determined. The unidimensionality of the items was determined by exploratory factor analysis while the internal consistency was determined by the Cronbach’s alpha coefficient.

After the unidimensionality of the items was determined, a composite measure using unit weights was created, that is, each item was assumed to contribute equally to the composite. The composite measures created were for the measured variables (indicators) underlying the respective latent constructs in the measurement models.

The aim of the measurement model development was to establish the reliability and validity of a set of indicators in each latent construct. The construct validity of the measurement model was assessed in terms of convergent validity and discriminant validity. Convergent validity means the indicators of a specific construct should converge or share a proportion of variance in common (Hair et al., 2006, p. 776). In this study, composite reliability and average variance extracted were used to determine convergent validity.
Composite reliability is a more general measure of reliability as it uses the item loadings estimated within the model. It is commonly used in SEM. It is calculated as:

$$\text{Composite reliability} = \frac{\left( \sum_{i=1}^{n} \lambda_i \right)^2}{\left( \sum_{i=1}^{n} \lambda_i \right)^2 + \left( \sum_{i=1}^{n} \delta_i \right)}$$

where $\lambda$ represents the standardized factor loading for the indicators on the latent variable, and $\delta$ is the measurement error for each indicator. A commonly used threshold value for composite reliability is 0.7 (Hair et al., 2006). However, values below 0.7 have been considered acceptable for exploratory research (Hair, Anderson, Tatham, & Black, 1988).

The average variance extracted reflects the overall amount of variance in the indicators accounted for by the latent construct. An average variance extracted of 0.5 or higher suggests adequate convergent (Hair et al., 2006). It is calculated as:

$$\text{Average variance extracted} = \frac{\left( \sum_{i=1}^{n} \lambda_i^2 \right)}{\left( \sum_{i=1}^{n} \lambda_i^2 \right) + \left( \sum_{i=1}^{n} \delta_i \right)}$$

where $\lambda$ represents the standardized factor loading for the indicators on the latent variable, and $\delta$ is the measurement error for each indicator.
Or a simpler formula which yields the same result (Hair, Black, Babin, & Anderson, 2010) is:

\[
\text{Average variance extracted} = \frac{\sum_{i=1}^{n} \lambda_i^2}{n}
\]

where \( \lambda \) represents the standardized factor loading for the indicators on the latent variable.

Discriminant validity is the extent to which a construct is truly distinct from other constructs (Hair et al., 2006, p. 778). The correlational method was used to determine discriminant validity. An indicator should correlate more highly with the construct that it is intended to measure than with other constructs to affirm the discriminant validity of the constructs (Garson, 2009).

For single-item constructs, reliability estimation was not possible. Their measurement paths and error variance terms should be set based on the best knowledge available. The loading estimate was set to the square root of the estimated reliability and the corresponding error term is set to one minus the reliability estimate (Hair et al., 2006). In this study, it was believed that the single-item constructs were mostly error free. Thus, for single indicators the loading of the indicator on its associated latent construct was specified at one and the error term was specified at zero.

In addition to construct validity, the significance of each estimated coefficient (loading) was examined to determine the probability that the indicator is valid for the
construct. The ratio of unstandardized coefficient to standard error which is the critical ratio (C.R.) or t value was used to test the significance of each coefficient. A C.R. of greater than 1.96 is considered significant. However, the higher the C.R. the more likely it is a valid indicator of the construct (Hayduck, 1987).

4.6.1.2.2 Structural Model Evaluation

The evaluation of the structural model was conducted with the entire sample. The estimation of parameters was based on maximum likelihood methods using AMOS Version 16.

The primary interest in SEM is to determine the extent to which a hypothesized model “fits” or adequately describes the sample data. The evaluation of the model fit was based on three criteria. The first criterion was the feasibility and significance of the estimated model parameters. The parameter estimates should exhibit the correct sign and size that are consistent with the underlying theory. Besides, they should fall within the admissible range (e.g. no correlations > 1.00 and negative variances). Furthermore, the proposed relationships should be significant. In AMOS, the critical ratio can be used to determine the significance of estimated parameters. Based on a level of 0.05, the C.R. needs to be > ± 1.96 to reject the hypothesis that the estimate equals to 0.0 (Byrne, 2001). For directional hypotheses, a one-tailed C.R. of 1.645 indicates significance at the p < 0.05 (Hair et al., 2006). For non-directional hypotheses, a two-tailed C.R. of 1.96 indicates significance at the p < 0.05 (Byrne, 2001).
The second criterion is the overall goodness of fit between the hypothesized model and the sample data. These goodness-of-fit measures include the chi-square statistics ($\chi^2$), normed $\chi^2$, the goodness-of-fit index (GFI), the comparative fit index (CFI), Tucker Lewis Index (TLI) and the root mean square error of approximation (RMSEA). The guidelines for interpreting these measures are shown in Table 4.3.

A non-significant $\chi^2 (p > 0.05)$ indicates a good fit. However, $\chi^2$ values depend on sample sizes. With large samples (generally above 200), trivial deviations from fit may be statistically significant, thus the $\chi^2$ test of model fit can lead to erroneous conclusions (Schumacker & Lomax, 2004). To eliminate or minimize this effect, other fit indices such as the normed $\chi^2$ ($\chi^2/df$) were used to look at model fit (Ullman, 2007, p. 695). Chin and Todd (1995) recommended a normed $\chi^2$ of smaller than three, while Jackson, Dezee, Douglas and Shimeall (2005) recommended a ratio of less than two as an excellent fit and three to five as a satisfactory fit.

The GFI was less sensitive to sample size (Hair et al., 2006). It is a measure of the relative amount of variance and covariance in the sample covariance matrix that is predicted by the estimated population covariance matrix (Byrne, 2001). One is a perfect fit; however, GFI > 0.9 indicates a good fit (Jackson et al., 2005). The adjusted goodness-of-fit index (AGFI) includes an adjustment for model complexity. It adjusts for the number of degrees of freedom in the specified model. An AGFI > 0.80 indicates a good fit (Segars & Grover, 1993).
The CFI measures how well a specified model fits relative to a null model, a model in which all observed variables have no relationship (Hair et al., 2006). A value close to 0.95 indicates a good model fit (Hu & Bentler, 1999).

The TLI is conceptually similar to the CFI. However, TLI is not normed, thus its value can fall below zero or above one (Hair et al., 2006). Values close to 0.95 indicate a good fit (Hu & Bentler, 1999).

The RMSEA measures the mean discrepancy (per degree of freedom) between observed and model implied covariances, thus this index is sensitive to the number of estimated parameters in the model (Byrne, 2001). A RMSEA < 0.05 indicates a good fit (Byrne, 2001). However, RMSEA values ranging from 0.05 to 0.08 represent a fair fit (Browne & Cudeck, 1993) and RMSEA values ranging from 0.08 to 0.10 indicate a mediocre fit (Hair et al., 2006; MacCallum, Browne, & Sugawara, 1996). Table 4.3 shows a summary of the goodness-of-fit indices and reliability measures adopted in this study.

The third criterion was the ability of the models to explain the variances in the dependent variables. The squared multiple correlations ($R^2$) of these variables were used as estimates of variance explained. Although no test of statistical significance can be performed, $R^2$ provides a relative measure of fit for each structural equation in the model.
Table 4.3: Summary of the guidelines for model fit

<table>
<thead>
<tr>
<th>Model fit measures</th>
<th>Guidelines for fit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goodness-of-fit measures</strong></td>
<td></td>
</tr>
<tr>
<td>▪ Chi-square ($\chi^2$)</td>
<td>Non significant $\chi^2$ (p &gt; 0.05)</td>
</tr>
<tr>
<td>▪ Normed $\chi^2$</td>
<td>&lt; 3 indicates a good fit</td>
</tr>
<tr>
<td>▪ Goodness-of-fit index (GFI)</td>
<td>&gt; 0.90</td>
</tr>
<tr>
<td>▪ Adjusted Goodness-of-fit index (AGFI)</td>
<td>&gt; 0.80</td>
</tr>
<tr>
<td>▪ Comparative fit index (CFI)</td>
<td>$\geq$ 0.95</td>
</tr>
<tr>
<td>▪ Tucker Lewis Index (TLI)</td>
<td>$\geq$ 0.95</td>
</tr>
<tr>
<td>▪ Root mean square error of approximation (RMSEA)</td>
<td>&lt; 0.05 indicates a good model fit</td>
</tr>
<tr>
<td></td>
<td>0.05 – 0.08 indicates a fair fit</td>
</tr>
<tr>
<td></td>
<td>&lt; 0.10 indicates an acceptable fit</td>
</tr>
</tbody>
</table>

| **Reliability measures** | |
| ▪ Cronbach’s alpha coefficient | $\geq$ 0.70 |
| ▪ Composite reliability | $\geq$ 0.70 |
| ▪ Average variance extracted | $\geq$ 0.50 |

4.6.1.2.3  Moderating Effects Analysis
The analytical strategy of Singh (1995) was used to examine the existence of the moderating effect on the structural model by using a subgroup analysis. First, an “unconstrained” simultaneous multi-group estimation of path coefficients was conducted where path coefficients were allowed to vary across the cross-group data set. This served as the baseline model. Next, a “partially constrained” model was estimated with the target path coefficient restricted to be equal for simultaneous multi-group estimation. By comparing the $\chi^2$ value for the “unconstrained” and “partially constrained” models, a $\chi^2$ difference test was then used to examine the
hypotheses. A statistically significant result indicates that the constrained model produced a poorer fit than the unrestricted model.

4.6.2 Pilot Study

Item analysis was performed on the posttest. Item discrimination and item difficulty indices were determined to improve the instrument. The reliability of the posttest, spatial ability test and instruments mentioned in Sections 4.3.5 to 4.3.14 was determined using the Cronbach’s alpha procedure. SPSS Version 16 was used to calculate Cronbach’s alpha. A Cronbach’s alpha value of 0.7 or higher indicates acceptable internal consistency (Nunnally, 1978).

Hopkins’s (1988) item discrimination index guidelines were used to interpret the item’s sensitivity to measure individual differences (see Table 4.4). These guidelines are relevant when there is a minimum of 30 examinees. An item discrimination index measures how adequately an item discriminates between high scorers and low scorers on an entire test (Cohen et al., 1996).

A difficulty index is the proportion of students who answered an item correctly. The value of an item difficulty index can range from zero (if no one got the item right) to one (if everyone got the index right). Hopkins (1988) articulates that items with a difficulty index between 0.25 and 0.75 are of moderate difficulty.
Table 4.4: Guidelines for interpreting item discrimination index (Hopkins, 1998)

<table>
<thead>
<tr>
<th>Discrimination Index, $d$</th>
<th>Item discrimination evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40 and above</td>
<td>Excellent discrimination</td>
</tr>
<tr>
<td>0.30 to 0.39</td>
<td>Good discrimination</td>
</tr>
<tr>
<td>0.10 to 0.29</td>
<td>Fair discrimination</td>
</tr>
<tr>
<td>0.01 to 0.10</td>
<td>Poor discrimination</td>
</tr>
<tr>
<td>Negative</td>
<td>Item may be mis-keyed or intrinsically ambiguous</td>
</tr>
</tbody>
</table>

4.7 Results of Pilot Study

The results of the pilot study are presented here while the results for the actual study are elaborated in the subsequent chapters.

4.7.1 Number of Samples

Fifty students were randomly chosen from the name lists of three science classes in the selected school. However, three students were absent on the day when the experiment was carried out. Thus, 47 students participated and sat for the posttest and spatial ability test. A total of 40 students had completed and returned the questionnaire.

4.7.2 Evaluation of Posttest

The posttest scores by 47 students ranged from the lowest of 24% to the highest of 92%. According to Kelley (1939), the optimal boundary lines to segregate the upper and lower areas of a score distribution are scores within the upper and lower 27% of the distribution of scores if the distribution is normal. The posttest data is normally distributed as showed by the Kolmogorov-Smirnov test where $p > 0.05$ (see Table 4.5). Hence, the students were ranked according to their posttest scores, and then the
The top 27% and the lowest 27% in terms of the posttest scores were selected to calculate the discrimination index. The top 27% was taken as Upper Group and the lowest 27% was taken as Lower Group with a total of 13 students in each group.

Table 4.5: Test of normality for Posttest

<table>
<thead>
<tr>
<th>Statistic</th>
<th>df</th>
<th>Sig.</th>
<th>Statistic</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>posttest score</td>
<td>.122</td>
<td>47</td>
<td>.977</td>
<td>47</td>
<td>.473</td>
</tr>
</tbody>
</table>

Table 4.5: Test of normality for Posttest

The proportion in the Upper Group ($P_U$) answering a particular item correctly was determined by dividing the number of correct responses from the Upper Group with the total number of people in the Upper Group, while the proportion in the Lower Group ($P_L$) answering a particular item correctly was determined in a similar way. The item discrimination index was obtained by subtracting $P_L$ from $P_U$, whereas the item difficulty index was calculated by taking the average of $P_U$ and $P_L$ as shown in Appendix H.

The results of item discrimination analysis showed that Item A6, A14, B1c, B1f and C1 were of poor discrimination (discrimination index, $d < 0.1$)—see Appendix G. Therefore, these items were removed. Internal consistency was measured using Cronbach’s alpha. Item deletion procedures suggested that Item B2d could be deleted to increase the alpha coefficient. This item had a low corrected item-total correlation, $r = 0.010$. Corrected item-total correlation is the Pearson correlation between the score on the individual item and the sum of the scores on the remaining items (Coakes & Steed, 2001). Thus, the deletion of this item did not affect the
overall reliability of the posttest. Originally, the Cronbach’s alpha for all 38 items was 0.833. However, when Items A6, A14, B1c, B1f, B2d and C1 were removed, the alpha coefficient was raised to 0.846 (see Table 4.6). Thus, the number of items for the posttest was reduced to 32 items.

Table 4.6: Cronbach’s alpha for posttest with 32 items

<table>
<thead>
<tr>
<th>N of Items</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>.846</td>
</tr>
</tbody>
</table>

The difficulty index showed that the majority of the questions were of moderate difficulty (see Appendix G). The reason why Items B1h and B1i had a lower item difficulty index was because many students missed out these questions. The students were requested to show these two answers on the same diagram where they were requested to label the given internal organs. Thus, to avoid this problem, a separate diagram was given for the students to show their answers for B1h and B1i for the actual survey.

In addition, it was found that Figure 1 and 2 of Part C in the posttest did not clearly show the internal organs due to the black and white printing. Therefore, these two diagrams were printed in color for the actual survey.

4.7.3 Reliability Test of Measurement Instruments

All instruments except the instrument to measure perceived ease of use have a Cronbach’s alpha coefficient that exceeded the recommended level of 0.70
(Nunnally, 1978), which was considered reliable and had good internal consistency (see Table 4.7). Though the motivation instrument has a Cronbach’s alpha coefficient that was greater than 0.70, item deletion procedures suggested that Items No. 5, No. 6, and No. 11 could be deleted to increase the alpha coefficient. Item No. 5 ($r = 0.078$) and Item No. 11 ($r = 0.070$) had the lowest corrected item-total correlations. Hence, deletion of these two items did not affect the overall reliability of this instrument. Item No. 6 was misinterpreted by many participants and it was very similar with Item No. 12, thus it was removed. When these three items were removed, the reliability coefficient, Cronbach’s alpha, was raised from 0.738 to 0.818 (see Table 4.7).

Table 4.7: Reliability test of instruments

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivation</td>
<td>0.738*</td>
</tr>
<tr>
<td>Cognitive Benefits</td>
<td>0.915</td>
</tr>
<tr>
<td>Control and Active Learning</td>
<td>0.888</td>
</tr>
<tr>
<td>Reflective Thinking</td>
<td>0.836</td>
</tr>
<tr>
<td>Representational Fidelity</td>
<td>0.838</td>
</tr>
<tr>
<td>Immediacy control</td>
<td>0.900</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>0.835</td>
</tr>
<tr>
<td>Perceived Usefulness</td>
<td>0.899</td>
</tr>
<tr>
<td>Perceived Ease of Use</td>
<td>0.636</td>
</tr>
<tr>
<td>Spatial ability test</td>
<td>0.757</td>
</tr>
</tbody>
</table>

*Cronbach’s alpha for motivation was raised to 0.818 after three items were deleted to improve the measurement. The final motivation measurement consists of 15 items.

The item deletion procedure suggested that Item No. 3 of the perceived ease of use instrument could be deleted to increase the reliability. However, it was not removed but rephrased so that the participants could apprehend the intended meaning of this item better. As mentioned by Kumar (2005, p. 157), a slight ambiguity in the wording of statements can affect the reliability of a research instrument as
respondents may interpret the statements differently at different times, resulting in different responses.

Tests of reliability and unidimensionality for measurements with Likert scale were further conducted on the actual data and the results are presented in Section 6.3.

4.8 Summary

This chapter provides an elaboration of the methodology that was used for determining the learning effectiveness in the VR-based learning environment and the evaluation of how VR enhances the learning outcomes. A two-group pretest-posttest quasi-experimental design was employed to evaluate the effects of each learning mode on learning, and factorial design was used to investigate the possible interaction effects between the two learning modes and the learner’s aptitudes in terms of spatial abilities and learning styles.

To evaluate how VR enhances learning outcomes, SEM with maximum likelihood estimation was employed to determine the model fit. A two-step model building approach was used, that is, the measurement model was first evaluated in terms of its convergent validity and discriminant validity and this was followed by the structural model evaluation to determine the causal relationships between independent and dependent latent variables. The analytical strategy of Singh (1995) was used to examine the existence of the moderating effect on the structural model by using a subgroup analysis, that is, accommodator learners and assimilator learners, and high and low spatial ability groups.
Finally, the pilot test results were presented. Item analysis was performed to improve the posttest. Reliability test results on pilot data indicated a good level of internal consistency for all the instruments except for the instrument to measure perceived ease of use in which the Cronbach’s alpha is slightly lower than the acceptable level of 0.7. For this instrument, the number of items was retained but the wordings of one of its items were rephrased in order to improve its reliability. The results of the actual study are reported in the following two chapters.
Chapter 5

RESULTS: LEARNING EFFECTIVENESS OF A DESKTOP VR-BASED LEARNING ENVIRONMENT AND ATI RESEARCH

5.0 Overview

One of the aims of this study was to obtain empirical data to investigate the effects of a VR-based learning environment on learning outcomes as compared to the conventional classroom learning method. The learning outcomes were measured by the performance achievement, perceived learning effectiveness and satisfaction of the learning modes. Besides, ATI research was also conducted in this study to investigate the effects of individual differences in terms of spatial abilities and learning styles on learning outcomes from different forms of treatments.

This chapter reports the results from the data analysis of the quasi-experimental study. The analyses were carried out through various statistical techniques such as the descriptive statistics analysis, the independent-samples t-test and two-way ANOVA. This chapter first describes the characteristics of the sample and the distribution of learners. It then presents the justification of the techniques used to analyze the data which is followed by the results of the hypotheses testing. Lastly, a summary of the findings to the research questions is presented.
5.1 Characteristics of Sample

A total of 431 students participated in this experiment. However, out of these students, 61 of them did not fully complete all the instruments, that is, they were either absent in the pretest or posttest during the day of testing or did not return the questionnaire. Hence, only 370 participants were taken into consideration in the analysis. The mean age of the participants was 15.68 years old.

5.2 Distribution of Learners

The 370 participants were randomly divided into two groups based on their intact classes. Each group was assigned to one of the two learning modes: VR mode and Non-VR mode. A total of 210 participants were in the VR mode whereas 160 participants were in the Non-VR mode. Some 23.8% (88) were male and 33% (122) were female in the VR mode while 18.4% (68) were male and 24.9% (92) were female in the Non-VR mode. Overall, the sample consisted of 42.2% (156) male students and 57.8% (214) female students (see Table 5.1).

Table 5.1: Cross tabulation of learning mode and gender

<table>
<thead>
<tr>
<th>Learning Mode</th>
<th>Gender</th>
<th>Count</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR</td>
<td>Male</td>
<td>88</td>
<td>23.8%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>122</td>
<td>33.0%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>210</td>
<td>56.8%</td>
</tr>
<tr>
<td>Non-VR</td>
<td>Male</td>
<td>68</td>
<td>18.4%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>92</td>
<td>24.9%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>160</td>
<td>43.2%</td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>156</td>
<td>42.2%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>214</td>
<td>57.8%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>370</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
As shown in Table 5.2, based on those who had answered this question, almost half of the participants, 46.2% have no knowledge about VR, 40.9% have some knowledge, only 3.8% have a lot of knowledge about VR, and 9.1% have some experience in using VR.

### Table 5.2: Virtual reality knowledge of students in the VR mode

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knew Nothing</td>
<td>96</td>
<td>45.7</td>
<td>46.2</td>
<td>46.2</td>
</tr>
<tr>
<td>Some Knowledge</td>
<td>85</td>
<td>40.5</td>
<td>40.9</td>
<td>87.0</td>
</tr>
<tr>
<td>Lots of Knowledge</td>
<td>8</td>
<td>3.8</td>
<td>3.8</td>
<td>90.9</td>
</tr>
<tr>
<td>Some Experiences</td>
<td>19</td>
<td>9.0</td>
<td>9.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>208</td>
<td>99.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Missing System</td>
<td>2</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>210</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3 Homogeneity of Pretest

Table 5.3 shows the Levene’s test of equality of variance of pretest across the two different learning modes. The \( p \)-value was greater than 0.05, thus the variance in pretest score was not significantly different for the two learning modes.

Independent-samples t-test was conducted to determine if the two learning modes were homogeneous in terms of existing knowledge of the subject matter, which was measured by the pretest. Statistical tests were conducted at the alpha = 0.05 significance level. The result shows that there was no statistically significant difference in the pretest score between VR mode (\( M = 43.14, SD = 19.98 \)) and Non-VR mode [\( M = 42.46, SD = 18.82, t(368) = 0.330, p = 0.741 \)] (see Table 5.4). It is
thus inferred that there was no significant difference in the prior knowledge on the
subject matter for both learning modes.

Table 5.3: Levene’s test of equality of variance of pretest across VR mode and
Non-VR mode

<table>
<thead>
<tr>
<th></th>
<th>Levene’s Test for Equality of Variances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
</tr>
<tr>
<td>Pretest</td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>1.048</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.4: Pretest mean score, standard deviation and t-test of pretest of VR
mode (N = 210) and Non-VR mode (N = 160)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>VR Mode</td>
<td>43.14</td>
<td>19.98</td>
<td>0.330</td>
<td>368</td>
</tr>
<tr>
<td>Non-VR Mode</td>
<td>42.46</td>
<td>18.82</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.4 Testing Assumptions for T-test and Two-way ANOVA

Independent-samples t-test was used to explore differences in the dependent
variables between groups, and two-way ANOVA was employed to investigate the
interaction effect of two independent variables on the dependent variable.

According to Pallant (2007), the following assumptions have to be met before t-test
and two-way ANOVA are conducted.
Assumption 1: Level of measurement

T-test and two-way ANOVA assume that the dependent variable is a continuous scale, measured at the interval or ratio level.

Assumption 2: Random sampling

T-test and two-way ANOVA assume that the scores are obtained using a random sample from the population. According to Pallant (2005, p. 203), though parametric techniques assumes the scores are obtained using a random sample from the population, this is often not the case in real-life research.

Assumption 3: Independence of observations

The observations that make up the data must be independent of one another. In other words, each observation or measurement must not be influenced by any other observation or measurement.

Assumption 4: Normal distribution

It is assumed that the population from which the samples are taken is normally distributed. However, with large sample sizes (e.g. 30+), reasonably accurate results will be obtained even though this assumption is violated (Pallant, 2007).

Assumption 5: Homogeneity of variance

T-test and two-way ANOVA assume that samples are obtained from populations of equal variances. In other words, the variability of scores for each of the groups is similar. For t-tests, two sets of results are provided, for situations where the
assumption is not violated and for when it is violated. Hence, the result is used that
is appropriate to the data. If this assumption is violated, then it is recommended that
a more stringent significance level (e.g. 0.01) is set in two-way ANOVA (Pallant,
2007).

The results of testing of each of the aforementioned assumptions were presented as
follows.

Assumption 1: Level of measurement
The dependent variables were measured at interval level. The posttest scores were
converted to percentage, and mean scores from the five-point Likert scale were used
as the composite measures for perceived learning effectiveness and satisfaction.

Assumption 2: Random sampling
The sample of this study was randomly selected from four co-education secondary
schools in East Malaysia. For each selected school, two to four intact classes were
randomly chosen and assigned to the VR and Non-VR mode. Thus, the groups
constituted intact classes, in which equivalency could not be presumed or assumed.
Though quasi-experimental design is not randomize, but it is useful in generating
results for general trends and it is most frequently used when it is not feasible to use
random assignment (Gribbons & Herman, 1997).
Assumption 3: Independence of observation

Each student was given the pretest, posttest, spatial ability test, initial questionnaire and final questionnaire to answer under the supervision of a teacher or researcher to avoid unnecessary interaction that might lead to the violation of this assumption.

Assumption 4: Normal distribution

The Kolmogorov-Smirnov test was used to assess the normality of the distribution for all dependent variables for the VR mode, Non-VR mode and whole sample (see Tables 5.5–5.7). A non-significant test (\( \text{Sig. values greater than 0.05} \)) indicates normality. As such, posttest has a normal distribution for the VR mode (\( p = 0.627 \)), Non-VR mode (\( p = 0.156 \)) and across the whole sample (\( p = 0.068 \)). Gain score was used to measure overall improvement in performance and it was normally distributed for the VR mode (\( p = 0.376 \)). However, perceived learning effectiveness was not normal for the Non-VR mode (\( p = 0.0210 \)) and satisfaction was not normal for the VR mode (\( p = 0.007 \)), Non-VR mode (\( p = 0.004 \)) and the whole sample (\( p = 0.023 \)). Nevertheless, according to Pallant (2007), a non-significant result is quite common in larger samples as mentioned earlier. With large sample sizes (e.g. 30+), reasonably accurate results will still be obtained even though this assumption is violated (Pallant, 2007).

Moreover, an inspection on the skewness and kurtosis values did not show that the data was highly skewed and highly kurtotic. The absolute value of critical ratio (skewness/standard error and kurtosis/standard error) of less than or equal to two indicates that skewness and kurtosis are not significantly different from zero, thereby
meeting the normality assumption (Brown, 1997)—see Table 5.8. Thus, perceived learning effectiveness was assumed normal for the VR mode. Satisfaction also met the normality assumption for the Non-VR mode and the whole sample. Although the critical ratio of kurtosis for satisfaction in the VR mode was slightly higher than two, the histogram of satisfaction for the VR mode appeared to be reasonably normally distributed (see Figure 5.1). This was also supported by an inspection of the normality plots as shown in Figure 5.2. The reasonably straight line suggested a normal distribution.

Table 5.5: Test of normality for posttest, perceived learning effectiveness, satisfaction and gain score for the VR mode

<table>
<thead>
<tr>
<th>Normal Parameters a</th>
<th>Posttest</th>
<th>Perceived Learning Effectiveness</th>
<th>Satisfaction</th>
<th>Gain Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>210</td>
<td>210</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>Mean</td>
<td>65.5095</td>
<td>3.9369</td>
<td>4.0245</td>
<td>22.3714</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>15.67561</td>
<td>.53022</td>
<td>.58609</td>
<td>19.25789</td>
</tr>
<tr>
<td>Most Extreme Differences</td>
<td></td>
<td>Absolute</td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.052</td>
<td>.086</td>
<td>-.051</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positive</td>
<td>-.080</td>
<td>-.048</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov Z</td>
<td>.750</td>
<td>1.246</td>
<td>1.691</td>
<td>.912</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.627</td>
<td>.090</td>
<td>.007</td>
<td>.376</td>
</tr>
</tbody>
</table>

a. Test distribution is Normal.
Table 5.6: Test of normality for posttest, perceived learning effectiveness and satisfaction for the Non-VR mode

<table>
<thead>
<tr>
<th></th>
<th>Posttest</th>
<th>Perceived Learning Effectiveness</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>160</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>Normal Parameters&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>60.5625</td>
<td>3.3008</td>
<td>3.2094</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>20.88474</td>
<td>.48651</td>
<td>.51453</td>
</tr>
<tr>
<td>Most Extreme Differences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute</td>
<td>.089</td>
<td>.119</td>
<td>.139</td>
</tr>
<tr>
<td>Positive</td>
<td>.049</td>
<td>.119</td>
<td>.139</td>
</tr>
<tr>
<td>Negative</td>
<td>-.089</td>
<td>-.093</td>
<td>-.122</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov Z</td>
<td>1.129</td>
<td>1.509</td>
<td>1.761</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.156</td>
<td>.021</td>
<td>.004</td>
</tr>
</tbody>
</table>

<sup>a</sup> Test distribution is Normal.

Table 5.7: Test of normality for posttest, perceived learning effectiveness and satisfaction for the whole sample

<table>
<thead>
<tr>
<th></th>
<th>Posttest</th>
<th>Perceived Learning Effectiveness</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>370</td>
<td>370</td>
<td>370</td>
</tr>
<tr>
<td>Normal Parameters&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>63.3703</td>
<td>3.6618</td>
<td>3.6720</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>18.25224</td>
<td>.60067</td>
<td>.68713</td>
</tr>
<tr>
<td>Most Extreme Differences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute</td>
<td>.068</td>
<td>.063</td>
<td>.078</td>
</tr>
<tr>
<td>Positive</td>
<td>.039</td>
<td>.063</td>
<td>.078</td>
</tr>
<tr>
<td>Negative</td>
<td>-.068</td>
<td>-.046</td>
<td>-.061</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov Z</td>
<td>1.300</td>
<td>1.210</td>
<td>1.498</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.068</td>
<td>.107</td>
<td>.023</td>
</tr>
</tbody>
</table>

<sup>a</sup> Test distribution is Normal.
Table 5.8: Assessment of normality with skewness and kurtosis for perceived learning effectiveness and satisfaction

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mode</th>
<th>Skew</th>
<th>Critical ratio</th>
<th>Kurtosis</th>
<th>Critical ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived Learning Effectiveness</td>
<td>Non-VR mode</td>
<td>0.174</td>
<td>0.906</td>
<td>0.058</td>
<td>0.152</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>VR mode</td>
<td>0.850</td>
<td>0.506</td>
<td>0.858</td>
<td>-2.569</td>
</tr>
<tr>
<td></td>
<td>Non-VR mode</td>
<td>0.178</td>
<td>0.927</td>
<td>0.516</td>
<td>1.354</td>
</tr>
<tr>
<td></td>
<td>Whole sample</td>
<td>0.158</td>
<td>1.244</td>
<td>-0.483</td>
<td>-0.253</td>
</tr>
</tbody>
</table>

Figure 5.1: Histogram of satisfaction for the VR mode
Assumption 5: Homogeneity of variance

The t-test gives two sets of results, that is, results for equal variances assumed and equal variances not assumed. Thus, this study interpreted the result that was appropriate to the data, whilst for two-way ANOVA, a more stringent significance level ($p = 0.01$) was used if this assumption was violated. In this study, significance level of 0.01 was used for posttest as a dependent variable due to the significant result (Sig. value less than 0.05) of Levene’s test of equality of error variances.

5.5 Testing of Hypotheses

Independent-samples t-test was used to compare the effects of the two learning modes on learning. The purpose was to determine if there was statistically significant difference in the dependent variables as measured by the posttest, perceived learning effectiveness and satisfaction between the two learning modes. The assumptions for
this test had been performed and this test was found to be appropriate for employment. Statistical tests were conducted at the alpha = 0.05 significance level.

5.5.1 Testing of $H_{01}$

$H_{01}$: There is no significant difference in the performance achievement between students in the VR mode and Non-VR mode.

The significance level for Levene’s test for the posttest was less than 0.05; the t-value under “Equal variances not assumed” was thus reported. The statistical results rejected the null hypothesis ($p < 0.05$). There was a significant difference in the posttest scores for the VR mode ($M = 65.51$, $SD = 15.68$) and the Non-VR mode [$M = 60.56$, $SD = 20.89$; $t(284.863) = 2.506$, $p = .013$] (see Tables 5.9–5.10). Students in the VR mode scored higher than students in the Non-VR mode on posttest.

Eta squared was used to determine the effect size which provides an indication of the magnitude of the differences between the two learning modes (Pallant, 2007). The formula for eta squared is as follows:

$$\text{Eta squared} = \frac{t^2}{t^2 + (N1 + N2 - 2)}$$

$t$ is the $t$ value, $N1$ and $N2$ are the sample sizes for the two respective modes.

The magnitude of the differences in the means of posttest for the two learning modes was small (eta squared = 0.02). This interpretation was based on the guidelines
proposed by Cohen (1988): 0.01 = small effect, 0.06 = moderate effect, and 0.14 = large effect.

5.5.2 Testing of $H_{02}$

$H_{02}$: There is no significant difference in the perceived learning effectiveness between students in the VR mode and Non-VR mode.

The significance level for Levene’s test was more than 0.05 which indicated that there was no violation in the homogeneity of variances of the perceived learning effectiveness for both learning modes; the $t$-value under “Equal variance assumed” was thus reported. The statistical results rejected the null hypothesis ($p < 0.05$).

There was a significant difference in perceived learning effectiveness for the VR mode ($M = 3.94, SD = 0.53$) and the Non-VR mode [$M = 3.30, SD = 0.49$; $t(368) = 11.844, p < 0.0005$] (see Tables 5.9–5.10). Students in the VR mode perceived a higher learning quality than students in the Non-VR mode. The magnitude of the differences in the means was large (eta squared = 0.28). So, 28% of the variance in perceived learning effectiveness was explained by the learning mode.

5.5.3 Testing of $H_{03}$

$H_{03}$: There is no significant difference in the satisfaction between students in the VR mode and Non-VR mode.

The significance level of Levene’s test was less than 0.05; the $t$-value under “Equal variance not assumed” was thus reported. The statistical results rejected the null
hypothesis \( (p < 0.05) \). There was a significant difference in the satisfaction for the VR mode \( (M = 4.02, \text{SD} = 0.59) \) and the Non-VR mode \( [M = 3.21, \text{SD} = 0.51; \text{t}(360.633) = 14.210, p < 0.0005] \) (see Tables 5.9–5.10). Students in the VR mode were more satisfied with their learning experience than students in the Non-VR mode. The magnitude of the differences in the means was large (eta squared = 0.35).

So, 35% of the variance in satisfaction was explained by the learning mode.

<table>
<thead>
<tr>
<th>Learning Mode</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest VR Mode</td>
<td>210</td>
<td>65.5095</td>
<td>15.67561</td>
<td>1.08172</td>
</tr>
<tr>
<td>Non-VR Mode</td>
<td>160</td>
<td>60.5625</td>
<td>20.88474</td>
<td>1.65108</td>
</tr>
<tr>
<td>Perceived Learning</td>
<td>Effectiveness</td>
<td>VR Mode</td>
<td>210</td>
<td>3.9369</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-VR Mode</td>
<td>160</td>
<td>3.3008</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>VR Mode</td>
<td>210</td>
<td>4.0245</td>
<td>.58609</td>
</tr>
<tr>
<td></td>
<td>Non-VR Mode</td>
<td>160</td>
<td>3.2094</td>
<td>.51453</td>
</tr>
</tbody>
</table>
Table 5.10: T-test of posttest, perceived learning effectiveness and satisfaction by learning mode

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>T-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Posttest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances</td>
<td>18.290</td>
<td><strong>.000</strong></td>
<td>2.603</td>
</tr>
<tr>
<td>assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances</td>
<td>2.506</td>
<td>.284.863</td>
<td>.013</td>
</tr>
<tr>
<td>not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perceived Learning</td>
<td>.617</td>
<td><strong>.433</strong></td>
<td>11.844</td>
</tr>
<tr>
<td>Effectiveness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances</td>
<td>11.983</td>
<td>355.503</td>
<td>.000</td>
</tr>
<tr>
<td>assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances</td>
<td>14.210</td>
<td>360.633</td>
<td>.000</td>
</tr>
<tr>
<td>not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td>4.726</td>
<td><strong>.030</strong></td>
<td>13.963</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.5.4 Testing of $H_{04}$

$H_{04}$: There is no interaction effect between the learners’ spatial abilities and the learning modes, related to the performance achievement.

Two-way ANOVA was conducted to explore the effects of the learning modes and spatial abilities on the performance achievement as measured by the posttest. The independent variables were the learning modes, that is, VR mode and Non-VR mode and spatial abilities, that is, low and high. The dependent variable was the posttest scores. Table 5.11 presents the two-way ANOVA results. The Levene’s test of equality of error variances showed a significant result (Sig. value less than 0.05), thus a more stringent significance level of 0.01 was used. The interaction effect was statistically significant $[F(1, 366) = 10.75, p = 0.001]$. An inspection of Figure 5.3 reveals that the effect of learning mode was much greater for the low spatial ability group than it was for the high spatial ability group. Indeed, an analysis of simple effects with independent-samples t-test showed that the learning mode effect was not significant for the high spatial ability group but it was significant for the low spatial ability group. Therefore, there was no evidence that performance achievement of the high spatial ability learners in the VR mode [$M = 70.35, SD = 16.05$] differ from the Non-VR mode [$M = 71.84, SD = 14.83, t(177) = 0.629, p = 0.530$] (see Table 5.12 & Table 5.13). However, there was evidence that performance achievement of the low spatial ability learners in the VR mode differs from the Non-VR mode. The low spatial ability learners in the VR mode [$M = 60.67, SD = 13.74$] scored higher in the posttest than the low spatial ability learners in the Non-VR mode [$M = 50.86, SD = 20.52, t(143.121) = 3.790, p < 0.0005$] (see Table 5.12 & Table 5.14).
Table 5.11: Two-way ANOVA of posttest by learning mode and spatial ability

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>24650.598*</td>
<td>3</td>
<td>8216.866</td>
<td>30.600</td>
<td>.000</td>
<td>.201</td>
</tr>
<tr>
<td>Intercept</td>
<td>1456752.504</td>
<td>1</td>
<td>1456752.504</td>
<td>5425.043</td>
<td>.000</td>
<td>.937</td>
</tr>
<tr>
<td>Learning Mode (LM)</td>
<td>1566.787</td>
<td>1</td>
<td>1566.787</td>
<td>5.835</td>
<td>.016</td>
<td>.016</td>
</tr>
<tr>
<td>Spatial Ability (SA)</td>
<td>21277.333</td>
<td>1</td>
<td>21277.333</td>
<td>79.238</td>
<td>.000</td>
<td>.178</td>
</tr>
<tr>
<td>LM * SA</td>
<td>2885.366</td>
<td>1</td>
<td>2885.366</td>
<td>10.745</td>
<td>.001</td>
<td>.029</td>
</tr>
<tr>
<td>Error</td>
<td>98279.675</td>
<td>366</td>
<td>268.524</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1608773.000</td>
<td>369</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>122930.273</td>
<td>369</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.12: Means, standard deviations of posttest by learning mode and spatial ability

<table>
<thead>
<tr>
<th>Learning Mode</th>
<th>Spatial Ability</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR Mode</td>
<td>Low</td>
<td>60.6667</td>
<td>13.74050</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>70.3524</td>
<td>16.05159</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>65.5095</td>
<td>15.67561</td>
<td>210</td>
</tr>
<tr>
<td>Non-VR Mode</td>
<td>Low</td>
<td>50.8605</td>
<td>20.51981</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>71.8378</td>
<td>14.83150</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>60.5625</td>
<td>20.88474</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>Low</td>
<td>56.2513</td>
<td>17.76631</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>70.9665</td>
<td>15.53354</td>
<td>179</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>63.3703</td>
<td>18.25224</td>
<td>370</td>
</tr>
</tbody>
</table>
Figure 5.3: Plot of interaction between learning mode and spatial ability, related to performance achievement
Table 5.13: T-test of posttest by learning mode for high spatial ability learners

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>T-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Posttest</td>
<td>.936</td>
<td>.335</td>
<td>.629</td>
</tr>
<tr>
<td></td>
<td>.638</td>
<td>164.556</td>
<td>.525</td>
</tr>
</tbody>
</table>

Table 5.14: T-test of posttest by learning mode for low spatial ability learners

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>T-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Posttest</td>
<td>19.839</td>
<td>.000</td>
<td>3.937</td>
</tr>
<tr>
<td></td>
<td>3.790</td>
<td>143.121</td>
<td>.000</td>
</tr>
</tbody>
</table>
5.5.5 Testing of \( H_{05} \)

\( H_{05} \): There is no interaction effect between the learners’ spatial abilities and the learning modes, related to the perceived learning effectiveness.

Two-way ANOVA was conducted to explore the effects of the learning modes and spatial abilities on perceived learning effectiveness. The independent variables were the learning modes, that is, VR mode and Non-VR mode and spatial abilities, that is, low and high. The dependent variable was the perceived learning effectiveness. The Levene’s test of equality of error variances showed a non-significant result (Sig. value more than 0.05), thus the significance level of 0.05 was used.

Figure 5.4 shows the interaction between learning mode and spatial ability, related to perceived learning effectiveness. Results in Table 5.15 shows the interaction effect between learning mode and spatial ability was not statistically significant, \( [F(1, 366) = 1.312, \ p = 0.253] \). This means the difference in perceived learning effectiveness between the learning modes did not vary as a function of learners’ spatial abilities. However, there was a main effect for learning modes \( [F(1,366) = 138.41, \ p < 0.0005] \) and for spatial ability \( [F(1, 366) = 5.94, \ p = 0.015] \). This means that there was a difference in perceived learning effectiveness for the two learning modes as well as for the high and low spatial ability learners. The mean score for the VR mode across the high and low spatial ability learner was higher than the Non-VR mode as reported in Section 5.5.2. The mean score of perceived learning effectiveness for the high spatial ability learners across the two learning modes was higher than the mean score of perceived learning effectiveness for the low spatial ability learners \( [M = \)
3.74, SD = 0.58 versus M = 3.59, SD = 0.61] (see Table 5.16). However, the
difference was small. The effect size was only 0.016 which was small according to
Cohen’s (1988) interpretation (see Table 5.15).

Table 5.15: Two-way ANOVA of perceived learning effectiveness by learning
mode and spatial ability

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>38.456^a</td>
<td>3</td>
<td>12.819</td>
<td>49.551</td>
<td>.000</td>
<td>.289</td>
</tr>
<tr>
<td>Intercept</td>
<td>4751.233</td>
<td>1</td>
<td>4751.233</td>
<td>18366.040</td>
<td>.000</td>
<td>.980</td>
</tr>
<tr>
<td>Learning Mode (LM)</td>
<td>35.807</td>
<td>1</td>
<td>35.807</td>
<td>138.413</td>
<td>.000</td>
<td>.274</td>
</tr>
<tr>
<td>Spatial Ability (SA)</td>
<td>1.536</td>
<td>1</td>
<td>1.536</td>
<td>5.939</td>
<td>.015</td>
<td>.016</td>
</tr>
<tr>
<td>LM * SA</td>
<td>.339</td>
<td>1</td>
<td>.339</td>
<td>1.312</td>
<td>.253</td>
<td>.004</td>
</tr>
<tr>
<td>Error</td>
<td>94.683</td>
<td>366</td>
<td>.259</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5094.453</td>
<td>370</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>133.139</td>
<td>369</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.16: Means, standard deviations of perceived learning effectiveness by
learning mode and spatial ability

<table>
<thead>
<tr>
<th>Learning Mode</th>
<th>Spatial Ability</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR Group</td>
<td>Low</td>
<td>3.9024</td>
<td>.53146</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3.9714</td>
<td>.52927</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.9369</td>
<td>.53022</td>
<td>210</td>
</tr>
<tr>
<td>Non-VR Group</td>
<td>Low</td>
<td>3.2122</td>
<td>.48396</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3.4037</td>
<td>.47206</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.3008</td>
<td>.48651</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>Low</td>
<td>3.5916</td>
<td>.61474</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3.7367</td>
<td>.57763</td>
<td>179</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.6618</td>
<td>.60067</td>
<td>370</td>
</tr>
</tbody>
</table>
Figure 5.4: Plot of interaction between learning mode and spatial ability, related to perceived learning effectiveness.

5.5.6 Testing of H₀₆

H₀₆: There is no interaction effect between the learners’ spatial abilities and the learning modes, related to the satisfaction.

Two-way ANOVA was conducted to explore the effects of the learning modes and spatial ability on satisfaction. The independent variables were the learning modes, that is, VR mode and Non-VR mode and spatial abilities, that is, low and high. The dependent variable was the satisfaction. The Levene’s test of equality of error variances showed a non-significant result (Sig. value more than 0.05), thus the significance level of 0.05 was used.
The results of two-way ANOVA were shown in Table 5.17. There was no significant interaction effect between learning mode and spatial ability on satisfaction, \([F(1, 366) = 0.225, p = 0.635]\). This indicates that the difference in the satisfaction between the learning modes did not vary as a function of learners’ spatial abilities. Figure 5.5 illustrates the interaction between the learning modes and the students’ spatial abilities on satisfaction. There was a main effect for learning modes \([F(1,366) = 194.28, p < 0.0005]\) and for spatial ability \([F(1, 366) = 4.592, p = 0.033]\). This means that there was a difference in satisfaction for the two learning modes. In fact, the early statistical analysis in Section 5.5.3 had revealed that this difference was significant. The mean score of satisfaction for the high spatial ability learners across the two learning modes \([M = 3.75, SD = 0.70]\) was higher than the mean score of satisfaction for the low spatial ability learners \([M = 3.60, SD = 0.67]\) (see Table 5.18). However, the difference was small because the effect size was small (0.012)—see Table 5.17.

**Table 5.17: Two-way ANOVA of satisfaction by learning mode and spatial ability**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>61.930a</td>
<td>3</td>
<td>20.643</td>
<td>67.285</td>
<td>.000</td>
<td>.355</td>
</tr>
<tr>
<td>Intercept</td>
<td>4741.584</td>
<td>1</td>
<td>4741.584</td>
<td>15454.638</td>
<td>.000</td>
<td>.977</td>
</tr>
<tr>
<td>Learning Mode (LM)</td>
<td>59.606</td>
<td>1</td>
<td>59.606</td>
<td>194.280</td>
<td>.000</td>
<td>.347</td>
</tr>
<tr>
<td>Spatial Ability (SA)</td>
<td>1.409</td>
<td>1</td>
<td>1.409</td>
<td>4.592</td>
<td>.033</td>
<td>.012</td>
</tr>
<tr>
<td>LM * SA</td>
<td>.069</td>
<td>1</td>
<td>.069</td>
<td>.225</td>
<td>.635</td>
<td>.001</td>
</tr>
<tr>
<td>Error</td>
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<td>366</td>
<td>.307</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>5163.168</td>
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<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>174.221</td>
<td>369</td>
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<td></td>
</tr>
</tbody>
</table>
Table 5.18: Means, standard deviations of satisfaction by learning mode and spatial ability

<table>
<thead>
<tr>
<th>Learning Mode</th>
<th>Spatial Ability</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR Mode</td>
<td>Low</td>
<td>3.9483</td>
<td>.58705</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>4.1007</td>
<td>.57789</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4.0245</td>
<td>.58609</td>
<td>210</td>
</tr>
<tr>
<td>Non-VR Mode</td>
<td>Low</td>
<td>3.1645</td>
<td>.48135</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3.2616</td>
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<td>74</td>
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<td></td>
<td>Total</td>
<td>3.2094</td>
<td>.51453</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>Low</td>
<td>3.5954</td>
<td>.66722</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3.7538</td>
<td>.70039</td>
<td>179</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.6720</td>
<td>.68713</td>
<td>370</td>
</tr>
</tbody>
</table>

Figure 5.5: Plot of interaction between learning mode and spatial ability, related to satisfaction
5.5.7 Testing of $H_{07}$

$H_{07}$: There is no interaction effect between the learners’ learning styles and the learning modes, related to the performance achievement.

Two-way ANOVA was conducted to explore the effects of the learning modes and learning styles on performance achievement. The independent variables were the learning modes, that is, VR mode and Non-VR mode and learning styles, that is, accommodator learners and assimilator learners. The dependent variable was the performance achievement as measured by the posttest. The Levene’s test of equality of error variances showed a significant result (Sig. value less than 0.05), thus a more stringent significance level of 0.01 was used.

The interaction effect between learning mode and learning style, and the main effect of learning mode and learning style are shown in Table 5.19. There was no significant interaction effect, $[F(1, 366) = 0.175, p = 0.676]$. This means that the difference in the performance achievement between the two learning modes did not vary as a function of students’ learning styles. Figure 5.6 illustrates the interaction between learning mode and learning style on performance achievement. The main effect for learning modes $[F(1,366) = 7.548, p = 0.006]$ was significant. In fact, the earlier statistical analysis in Section 5.5.1 had revealed that this difference was statistically significant. The main effect for learning style, $[F(1, 366) = 0.929, p = 0.336]$, did not reach statistical significance indicating that accommodator learners $[M = 62.97, SD = 18.34]$ and assimilator learners $[M = 63.75, SD = 18.21]$ did not
differ in their performance achievement across the two learning modes (see Table 5.20).

Table 5.19: Two-way ANOVA of posttest by learning mode and learning style

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>2552.244*</td>
<td>3</td>
<td>850.748</td>
<td>2.587</td>
<td>.053</td>
<td>.021</td>
</tr>
<tr>
<td>Learning Mode (LM)</td>
<td>1380061.037</td>
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<td>1380061.037</td>
<td>4195.968</td>
<td>.000</td>
<td>.920</td>
</tr>
<tr>
<td>Learning Style (LS)</td>
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<td>2482.388</td>
<td>7.548</td>
<td>.006</td>
<td>.020</td>
</tr>
<tr>
<td>LM * LS</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
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<td>1</td>
<td>305.430</td>
<td>.929</td>
<td>.336</td>
<td>.003</td>
</tr>
<tr>
<td>Total</td>
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<td>366</td>
<td>328.902</td>
<td>.175</td>
<td>.676</td>
<td>.000</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>122930.273</td>
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</tr>
</tbody>
</table>
Table 5.20: Means, standard deviations of posttest by learning mode and learning style

<table>
<thead>
<tr>
<th>Group</th>
<th>Learning Style</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR Mode</td>
<td>Accommodator</td>
<td>65.0504</td>
<td>15.72100</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>66.1099</td>
<td>15.68258</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>65.5095</td>
<td>15.67561</td>
<td>210</td>
</tr>
<tr>
<td>Non-VR Mode</td>
<td>Accommodator</td>
<td>58.9016</td>
<td>22.16883</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>61.5859</td>
<td>20.09976</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>60.5625</td>
<td>20.88474</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>Accommodator</td>
<td>62.9667</td>
<td>18.33515</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>63.7526</td>
<td>18.21352</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>63.3703</td>
<td>18.25224</td>
<td>370</td>
</tr>
</tbody>
</table>

Figure 5.6: Plot of interaction between learning mode and learning style, related to performance achievement
5.5.8 Testing of $H_{08}$

$H_{08}$: There is no interaction effect between the learners’ learning styles and the learning modes, related to the perceived learning effectiveness.

Two-way ANOVA was conducted to explore the effects of the learning modes and learning styles on perceived learning effectiveness. The independent variables were the learning modes, that is, the VR mode and Non-VR mode and learning styles, that is, accommodator learners and assimilator learners. The dependent variable was the perceived learning effectiveness. The Levene’s test of equality of error variances showed a non-significant result (Sig. value more than 0.05), thus a significance level of 0.05 was used.

The two-way ANOVA results are shown in Table 5.21. There was no significant interaction effect [$F(1, 366) = 0.204, p = 0.652$] which means learning styles did not moderate the effects of learning modes on perceived learning effectiveness. Figure 5.7 illustrates the interaction between learning mode and learning style on perceived learning effectiveness. The main effect for learning modes [$F(1,366) = 131.063, p < 0.0005$] was significant. The earlier statistical analysis in Section 5.5.2 had confirmed this difference was significant. The main effect for learning style, [$F(1,366) = 0.344, p = 0.558$] was not significant. This means that accommodator learners [$M = 3.74, SD = 0.59$] and assimilator learners [$M = 3.59, SD = 0.61$] did not differ in terms of their perceived learning effectiveness across the two learning modes (see Table 5.22).
Table 5.21: Two-way ANOVA of perceived learning effectiveness by learning mode and learning style

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
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<td>12.291</td>
<td>46.729</td>
<td>.000</td>
<td>.277</td>
</tr>
<tr>
<td>Intercept</td>
<td>4574.297</td>
<td>1</td>
<td>4574.297</td>
<td>17391.240</td>
<td>.000</td>
<td>.979</td>
</tr>
<tr>
<td>Learning Mode (LM)</td>
<td>34.473</td>
<td>1</td>
<td>34.473</td>
<td>131.063</td>
<td>.000</td>
<td>.264</td>
</tr>
<tr>
<td>Learning Style (LS)</td>
<td>.091</td>
<td>1</td>
<td>.091</td>
<td>.344</td>
<td>.558</td>
<td>.001</td>
</tr>
<tr>
<td>LM * LS</td>
<td>.054</td>
<td>1</td>
<td>.054</td>
<td>.204</td>
<td>.652</td>
<td>.001</td>
</tr>
<tr>
<td>Error</td>
<td>96.266</td>
<td>366</td>
<td>.263</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5094.453</td>
<td>370</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>133.139</td>
<td>369</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.22: Means, standard deviations of perceived learning effectiveness by learning mode and learning style

<table>
<thead>
<tr>
<th>Group</th>
<th>Learning Style</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR Mode</td>
<td>Accommodator</td>
<td>3.9401</td>
<td>.53502</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>3.9327</td>
<td>.52682</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.9369</td>
<td>.53022</td>
<td>210</td>
</tr>
<tr>
<td>Non-VR Mode</td>
<td>Accommodator</td>
<td>3.3361</td>
<td>.46466</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>3.2790</td>
<td>.50058</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.3008</td>
<td>.48651</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>Accommodator</td>
<td>3.7354</td>
<td>.58590</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>3.5921</td>
<td>.60769</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.6618</td>
<td>.60067</td>
<td>370</td>
</tr>
</tbody>
</table>
5.5.9 Testing of $H_{09}$

$H_{09}$: There is no interaction effect between the learners’ learning styles and the learning modes, related to the satisfaction.

Two-way ANOVA was conducted to explore the effects of the learning modes and learning styles on satisfaction. The independent variables were the learning modes, that is, the VR mode and Non-VR mode and learning styles, that is, accommodator learners and assimilator learners. The dependent variable was the satisfaction. The Levene’s test of equality of error variances showed non-significant result (Sig. value more than 0.05), thus a significance level of 0.05 was used.
The results in Table 5.23 show no significant interaction effect \( F(1, 366 = 1.923, p = 0.166 \). This means the difference in the satisfaction between the two learning modes did not vary as a function of learners’ learning styles. The main effect for learning modes \( F(1,366) = 188.444, p < 0.0005 \) was significant. In actual fact, the earlier statistical analysis in Section 5.5.3 had revealed this difference was significant. The main effect for learning style, \( F(1, 366) = 0.343, p = 0.558 \) did not reach statistical significance. This means that accommodator learners \([M = 3.72, SD = 0.66]\) and assimilator learners \([M = 3.62, SD = 0.71]\) did not differ in terms of their satisfaction (see Table 5.24). Figure 5.8 illustrates the interaction effect between the two learning modes and the learning styles on satisfaction.

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>61.133^a</td>
<td>3</td>
<td>20.378</td>
<td>65.951</td>
<td>.000</td>
<td>.351</td>
</tr>
<tr>
<td>Intercept</td>
<td>4578.586</td>
<td>1</td>
<td>4578.586</td>
<td>14818.187</td>
<td>.000</td>
<td>.976</td>
</tr>
<tr>
<td>Learning Mode (LM)</td>
<td>58.226</td>
<td>1</td>
<td>58.226</td>
<td>188.444</td>
<td>.000</td>
<td>.340</td>
</tr>
<tr>
<td>Learning Style (LS)</td>
<td>.106</td>
<td>1</td>
<td>.106</td>
<td>.343</td>
<td>.558</td>
<td>.001</td>
</tr>
<tr>
<td>LM * LS</td>
<td>.594</td>
<td>1</td>
<td>.594</td>
<td>1.923</td>
<td>.166</td>
<td>.005</td>
</tr>
<tr>
<td>Error</td>
<td>113.088</td>
<td>366</td>
<td>.309</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5163.168</td>
<td>370</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>174.221</td>
<td>369</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.24: Means, standard deviations of satisfaction by learning mode and learning style

<table>
<thead>
<tr>
<th>Group</th>
<th>Learning Style</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR Mode</td>
<td>Accommodator</td>
<td>3.9736</td>
<td>.59833</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>4.0911</td>
<td>.56605</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td><strong>4.0245</strong></td>
<td><strong>.58609</strong></td>
<td>210</td>
</tr>
<tr>
<td>Non-VR Mode</td>
<td>Accommodator</td>
<td>3.2389</td>
<td>.47718</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>3.1912</td>
<td>.53781</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td><strong>3.2094</strong></td>
<td><strong>.51453</strong></td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>Accommodator</td>
<td>3.7246</td>
<td>.65874</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Assimilator</td>
<td>3.6222</td>
<td>.71112</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td><strong>3.6720</strong></td>
<td><strong>.68713</strong></td>
<td>370</td>
</tr>
</tbody>
</table>

Figure 5.8: Plot of interaction between learning mode and learning style, related to satisfaction
5.5.10 Testing of H_{10}

H_{10}: There is no significant difference in the performance achievement for high and low spatial ability learners in the VR mode.

The basic assumption of homogeneity of variances was not violated. In other words, the variance of posttest scores for the two groups (high and low spatial ability learners) was the same. Thus, t-value under “Equal variance assumed” was reported. The statistical results rejected the null hypothesis \((p < 0.05)\). There was a significant difference in the posttest scores for high spatial ability learners \([M = 70.35, SD = 16.05]\) and low spatial ability learners \([M = 60.67, SD = 13.74; t(208) = -4.697, p < 0.0005]\) in the VR mode (see Table 5.25 & Table 5.26). High spatial ability learners have higher posttest scores than low spatial ability learners in the VR mode. The magnitude of the differences in the means was moderate \((\text{eta squared} = 0.10)\). So, 10% of the variance in posttest scores was explained by spatial ability.
Table 5.25: Means, standard deviations of posttest, perceived learning effectiveness, satisfaction and gain score for high and low spatial ability learners in the VR mode

<table>
<thead>
<tr>
<th>Spatial Ability</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>105</td>
<td>70.3524</td>
<td>16.05159</td>
<td>1.56647</td>
</tr>
<tr>
<td>Low</td>
<td>105</td>
<td>60.6667</td>
<td>13.74050</td>
<td>1.34094</td>
</tr>
<tr>
<td>Perceived Learning Effectiveness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>105</td>
<td>3.9714</td>
<td>.52927</td>
<td>.05165</td>
</tr>
<tr>
<td>Low</td>
<td>105</td>
<td>3.9024</td>
<td>.53146</td>
<td>.05186</td>
</tr>
<tr>
<td>Satisfaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>105</td>
<td>4.1007</td>
<td>.57789</td>
<td>.05640</td>
</tr>
<tr>
<td>Low</td>
<td>105</td>
<td>3.9483</td>
<td>.58705</td>
<td>.05729</td>
</tr>
<tr>
<td>Gain Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>105</td>
<td>22.7048</td>
<td>20.95413</td>
<td>2.04491</td>
</tr>
<tr>
<td>Low</td>
<td>105</td>
<td>22.0381</td>
<td>17.49281</td>
<td>1.70712</td>
</tr>
</tbody>
</table>
Table 5.26: T-test of posttest, perceived learning effectiveness, satisfaction and gain score for high and low spatial ability learners in the VR mode

<table>
<thead>
<tr>
<th></th>
<th>Levene’s Test for Equality of Variances</th>
<th>T-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Posttest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>2.196</td>
<td>.140</td>
<td>-4.697</td>
</tr>
<tr>
<td>Perceived Learning</td>
<td></td>
<td></td>
<td>-943</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>.648</td>
<td>.422</td>
<td>-943</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td>.648</td>
<td>.422</td>
<td>-943</td>
</tr>
<tr>
<td>Satisfaction</td>
<td></td>
<td></td>
<td>-1.895</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>.045</td>
<td>.833</td>
<td>-1.895</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td>.045</td>
<td>.833</td>
<td>-1.895</td>
</tr>
<tr>
<td>Gain Score</td>
<td></td>
<td></td>
<td>-.250</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>6.413</td>
<td>.012</td>
<td>-.250</td>
</tr>
</tbody>
</table>
5.5.11 Testing of H$_{11}$

H$_{11}$: There is no significant difference in the perceived learning effectiveness for high and low spatial ability learners in the VR mode.

The significance level of Levene’s test was more than 0.05, thus there was no significant difference in the variance of the perceived learning effectiveness for both groups. The statistical results did not reject the null hypothesis ($p > 0.05$). There was no significant difference in perceived learning effectiveness for high spatial ability learners [$M = 3.97$, $SD = 0.53$] and low spatial ability learners [$M = 3.90$, $SD = 0.53$; $t(208) = -0.943, p = 0.347$] in the VR mode (see Table 5.25 & Table 5.26).

5.5.12 Testing of H$_{12}$

H$_{12}$: There is no significant difference in the satisfaction for high and low spatial ability learners in the VR mode.

The variance of the satisfaction was the same as the significance level of Levene’s test was more than 0.05, thus t-value under “Equal variance assumed” was reported. The statistical results did not reject the null hypothesis ($p > 0.05$). There was no significant difference in the satisfaction for high spatial ability learners [$M = 4.10$, $SD = 0.58$] and low spatial ability learners [$M = 3.95$, $SD = 0.59$; $t(208) = -1.895, p = 0.059$] in the VR mode (see Table 5.25 & Table 5.26).
5.5.13 Testing of H_{13}

H_{13}: There is no significant difference in the overall improvement in performance for high and low spatial ability learners in the VR mode.

The significance level of Levene’s test was less than 0.05; the t-value under “Equal variance not assumed” was thus reported. The statistical results did not reject the null hypothesis ($p > 0.05$). There was no significant difference in overall improvement of performance (gain scores) for high spatial ability learners [$M = 22.70, SD = 20.95$] and low spatial ability learners [$M = 22.04, SD = 17.49; t(201.57) = -0.250, p = 0.803$] in the VR mode (see Table 5.25 & Table 5.26).

5.5.14 Testing of H_{14}

H_{14}: There is no significant difference in the performance achievement for accommodator learners and assimilator learners in the VR mode.

The significance level of Levene’s test was more than 0.05, thus the basic assumption of equal variances of the posttest scores for both groups (accommodator learners and assimilators learners) was not violated. The statistical results did not reject the null hypothesis ($p > 0.05$). There was no significant difference in the performance achievement for accommodator learners [$M = 65.05, SD = 15.72$] and assimilator learners [$M = 66.11, SD = 15.68; t(208) = -0.484, p = 0.629$] in the VR mode (see Table 5.27 & Table 5.28).
5.5.15 Testing of H_{15}

H_{15}: There is no significant difference in the perceived learning effectiveness for accommodator learners and assimilator learners in the VR mode.

There was no violation in the assumption of equal variances of the perceived learning effectiveness for both groups as the significance level of Levene’s test was more than 0.05. The statistical results did not reject the null hypothesis \((p > 0.05)\). There was no significant difference in perceived learning effectiveness for accommodator learners \([M = 3.94, SD = 0.54]\) and assimilator learners \([M = 3.93, SD = 0.53]; t(208) = 0.100, p = 0.920\] in the VR mode (see Table 5.27 & Table 5.28).

Table 5.27: Means, standard deviations of posttest, perceived learning effectiveness, satisfaction and gain score for accommodator learners and assimilator learners in the VR mode

<table>
<thead>
<tr>
<th>Learning Style</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accommodator</td>
<td>119</td>
<td>65.0504</td>
<td>15.72100</td>
<td>1.44114</td>
</tr>
<tr>
<td>Assimilator</td>
<td>91</td>
<td>66.1099</td>
<td>15.68258</td>
<td>1.64398</td>
</tr>
<tr>
<td>Perceived Learning Effectiveness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accommodator</td>
<td>119</td>
<td>3.9401</td>
<td>.53502</td>
<td>.04904</td>
</tr>
<tr>
<td>Assimilator</td>
<td>91</td>
<td>3.9327</td>
<td>.52682</td>
<td>.05523</td>
</tr>
<tr>
<td>Satisfaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accommodator</td>
<td>119</td>
<td>3.9736</td>
<td>.59833</td>
<td>.05485</td>
</tr>
<tr>
<td>Assimilator</td>
<td>91</td>
<td>4.0911</td>
<td>.56605</td>
<td>.05934</td>
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<tr>
<td>Gain Scores</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Accommodator</td>
<td>119</td>
<td>23.4790</td>
<td>19.26657</td>
<td>1.76616</td>
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<tr>
<td>Assimilator</td>
<td>91</td>
<td>20.9231</td>
<td>19.25630</td>
<td>2.01861</td>
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</table>
Table 5.28: T-test of posttest, perceived learning effectiveness, satisfaction and gain score for accommodator learners and assimilator learners in the VR mode

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>T-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Posttest</td>
<td>.029</td>
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<td>-.484</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-.485</td>
</tr>
<tr>
<td>Perceived Learning</td>
<td>.000</td>
<td>.991</td>
<td>.100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.101</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>.044</td>
<td>.834</td>
<td>-1.443</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-1.454</td>
</tr>
<tr>
<td>Gain Scores</td>
<td>.005</td>
<td>.946</td>
<td>.953</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.953</td>
</tr>
</tbody>
</table>
5.5.16 Testing of $H_{16}$

$H_{16}$: There is no significant difference in the satisfaction for accommodator learners and assimilator learners in the VR mode.

The Levene’s test revealed no significant difference in the variance of the satisfaction for both groups. The statistical results did not reject the null hypothesis ($p > 0.05$). There was no significant difference in satisfaction for accommodator learners [$M = 3.97$, $SD = 0.60$] and assimilator learners [$M = 4.09$, $SD = 0.57$; $t(208) = -1.443$, $p = 0.151$] in the VR mode (see Table 5.27 & Table 5.28).

5.5.17 Testing of $H_{17}$

$H_{17}$: There is no significant difference in the overall improvement in performance for accommodator learners and assimilator learners in the VR mode.

The significance level of Levene’s test was more than 0.05, thus the basic assumption of homogeneity of variances of the gain scores was not violated. The statistical results did not reject the null hypothesis ($p > 0.05$). There was no significant difference in overall improvement of performance (gain scores) for accommodator learners [$M = 23.48$, $SD = 19.27$] and assimilator learners [$M = 20.92$, $SD = 19.26$; $t(208) = 0.953$, $p = 0.342$] in the VR mode (see Table 5.27 & Table 5.28).
5.6 Summary of Hypotheses Testing

H₀₁: There was a significant difference in the performance achievement as measured by the posttest for learners of each learning mode. Therefore, H₀₁ was not supported.

H₀₂: There was a significant difference in the perceived learning effectiveness for learners of each learning mode. Therefore, H₀₂ was not supported.

H₀₃: There was a significant difference in the satisfaction for learners of each learning mode. Therefore, H₀₃ was not supported.

H₀₄: There was a significant interaction effect between the learners’ spatial ability and the learning modes, related to the performance achievement. Therefore, H₀₄ was not supported.

H₀₅: There was no significant interaction effect between the learners’ spatial ability and the learning modes, related to perceived learning effectiveness. Therefore H₀₅ was supported.

H₀₆: There was no significant interaction effect between the learners’ spatial abilities and the learning modes, related to the satisfaction. Therefore, H₀₆ was supported.

H₀₇: There was no significant interaction effect between the learners’ learning styles and the learning modes, related to the performance achievement. Therefore, H₀₇ was supported.
H₀₈: There was no significant interaction effect between the learners’ learning styles and the learning modes, related to the perceived learning effectiveness. Therefore, H₀₈ was supported.

H₀₉: There was no significant interaction effect between the learners’ learning styles and the learning modes, related to the satisfaction. Therefore, H₀₉ was supported.

H₁₀: There was significant difference in the performance achievement for high and low spatial abilities learners in the VR mode. Therefore, H₁₀ was not supported.

H₁₁: There was no significant difference in the perceived learning effectiveness for high and low spatial ability learners in the VR mode. Therefore, H₁₁ was supported.

H₁₂: There was no significant difference in the satisfaction for high and low spatial ability learners in the VR group. Therefore, H₁₂ was supported

H₁₃: There was no significant difference in the overall improvement in performance for high and low spatial ability learners in the VR mode. Therefore, H₁₃ was supported.

H₁₄: There was no significant difference in the performance achievement for accommodator learners and assimilator learners in the VR mode. Therefore, H₁₄ was supported.
H15: There was no significant difference in the perceived learning effectiveness for accommodator learners and assimilator learners in the VR mode. Therefore, H15 was supported.

H16: There was no significant difference in the satisfaction for accommodator learners and assimilator learners in the VR mode. Therefore, H16 was supported.

H17: There was no significant difference in the overall improvement in performance for accommodator learners and assimilator learners in the VR mode. Therefore, H17 was supported.

5.7 Summary

This chapter reports the results of the learning effectiveness of a desktop VR-based learning environment as compared to the conventional classroom learning practice and ATI research. The effects of individual difference were also investigated for students in the VR learning mode. The findings indicated that students’ performance achievement was better in the VR mode and the students’ perception on learning effectiveness and satisfaction was higher for the VR mode.

There was an interaction effect between the learners’ spatial abilities and the learning modes on performance achievement. The simple effect analysis revealed that the performance achievement was significantly different for low spatial ability learners between both learning modes, but was not statistically significant for high spatial ability learners. However, there was no interaction effect between the learners’
spatial ability and the learning modes on perceived learning effectiveness and satisfaction.

The findings also indicated there was no interaction effect between the learners’ learning styles and the learning modes on performance achievement, perceived learning effectiveness and satisfaction.

For students’ performance in the VR mode, there was a significant difference between high and low spatial ability learners in the performance achievement with high spatial ability learners having a better score in the posttest. However, there was no significant difference between high and low spatial ability learners in the overall improvement in performance, perceived learning effectiveness and satisfaction.

In terms of learning styles, no significant difference was found between accommodator learners and assimilator learners in the performance achievement, overall improvement in performance, perceived learning effectiveness and satisfaction. The findings to research questions 1–6 and hypotheses testing were summarized in Table 5.29. The results of this chapter are discussed in detail in Chapter 7.
Table 5.29: Summary of the findings to research questions 1–6 and hypotheses testing

<table>
<thead>
<tr>
<th>RQ</th>
<th>Test</th>
<th>Dependent Variables</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main effect LM</td>
<td>Performance Achievement</td>
<td>VR &gt; Non-VR S</td>
</tr>
<tr>
<td>1</td>
<td>Main Effect LM</td>
<td>Perceived Learning</td>
<td>VR &gt; Non-VR S</td>
</tr>
<tr>
<td>1</td>
<td>Main Effect LM</td>
<td>Satisfaction</td>
<td>VR &gt; Non-VR S</td>
</tr>
<tr>
<td>2</td>
<td>Interaction effect LM * SA</td>
<td>Performance Achievement</td>
<td>S</td>
</tr>
<tr>
<td>2</td>
<td>Interaction effect LM * SA</td>
<td>Perceived Learning Effectiveness</td>
<td>NS</td>
</tr>
<tr>
<td>2</td>
<td>Interaction effect LM * SA</td>
<td>Satisfaction</td>
<td>NS</td>
</tr>
<tr>
<td>2</td>
<td>Interaction effect LM * LS</td>
<td>Performance Achievement</td>
<td>NS</td>
</tr>
<tr>
<td>2</td>
<td>Interaction effect LM * LS</td>
<td>Perceived Learning Effectiveness</td>
<td>NS</td>
</tr>
<tr>
<td>2</td>
<td>Interaction effect LM * LS</td>
<td>Satisfaction</td>
<td>NS</td>
</tr>
<tr>
<td>3</td>
<td>VR Group Main effect SA</td>
<td>Performance Achievement</td>
<td>H &gt; L    S</td>
</tr>
<tr>
<td>3</td>
<td>VR Group Main effect SA</td>
<td>Perceived Learning Effectiveness</td>
<td>H &gt; L    NS</td>
</tr>
<tr>
<td>3</td>
<td>VR Group Main effect SA</td>
<td>Satisfaction</td>
<td>H &gt; L    NS</td>
</tr>
<tr>
<td>4</td>
<td>VR Group Main effect SA</td>
<td>Overall Improvement</td>
<td>H &gt; L    NS</td>
</tr>
<tr>
<td>5</td>
<td>VR Group Main effect LS</td>
<td>Performance Achievement</td>
<td>As &gt; Ac  NS</td>
</tr>
<tr>
<td>5</td>
<td>VR Group Main effect LS</td>
<td>Perceived Learning Effectiveness</td>
<td>Ac &gt; As  NS</td>
</tr>
<tr>
<td>5</td>
<td>VR Group Main effect LS</td>
<td>Satisfaction</td>
<td>As &gt; Ac  NS</td>
</tr>
<tr>
<td>6</td>
<td>VR Group Main effect LS</td>
<td>Overall Improvement</td>
<td>Ac &gt; As  NS</td>
</tr>
</tbody>
</table>

Notes: RQ = Research Question; LM = Learning Mode; SA = Spatial Ability; LS = Learning Style, H = High Spatial Ability Learners; L = Low Spatial Ability Learners; Ac = Accommodator learners; As = Assimilator learners; S = Significant; NS = Non Significant
Chapter 6

RESULTS: HOW DOES DESKTOP VR ENHANCE LEARNING OUTCOMES?

6.0 Overview

Apart from investigating the learning effectiveness of a desktop VR-based learning environment, the purpose of this study is to develop a theoretical model for evaluating how VR enhances the learning outcomes in order to provide more in-depth empirical findings to guide future VR-based learning developmental endeavors. Relevant constructs were identified and their relationships were examined. The model does not merely focus on the input (VR technology) and output (learning outcomes), but the process that the learners experience, such as the interaction and learning experience. Moreover, the moderating effects of learner characteristics on the structural paths were also investigated.

This chapter reports the results for the hypothesized model developed to investigate how desktop VR enhances the learning outcomes. SEM was employed to evaluate the model fit. This chapter first describes the characteristics of the sample, followed by the reliability and validity of the instruments that were used in SEM. Next, it presents the reliability and validity of the measurement models and the overall fit of the structural model. It is followed by the analysis of the total effects estimated for the hypothesized model and the analysis of the individual effect of mediating variables, that is, the psychological factors of learning experience on the learning outcomes. Subsequently, the effects of the moderator variables, the results on latent
mean testing and the findings of the hypotheses are presented. Finally, the chapter ends with the summary of the findings to the research questions.

6.1 Characteristics of Sample

For this analysis, only those who participated in the VR mode were taken into consideration. There were 232 students who participated in the VR mode. However, out of these students, 22 of them did not fully complete all instruments, that is, they were either absent in the pretest or posttest during the day of testing or did not return the questionnaires. Therefore, the results from a total of 210 students were analyzed. Out of 210 students in the VR mode, 41.9% (88) were male and 58.1% (122) were female students. The mean age of the participants was 16 years old.

6.2 Evaluation of Assumptions for Confirmatory Factor Analysis

This section describes the assumptions for undertaking the maximum likelihood estimation of SEM to test the goodness of fit of the hypothesized model. Maximum likelihood estimation techniques in SEM assume multivariate normality and a reasonable sample size.

6.2.1 Normality

Normality of the observed variables was assessed through examination of the critical ratio of skewness and kurtosis. The absolute value of critical ratio of less than or equal to two indicates that skewness and kurtosis are not significantly different from zero, thus meeting the normality assumption (Brown, 1997). To improve the normality of the measured variables, two cases of outliers were removed. Hence, the
data from 208 respondents was run with AMOS Version 16, which showed that the normality assumption was not violated. The critical ratio of skewness and kurtosis did not indicate high skewness and high kurtosis, as shown in Table 6.1.

Table 6.1: Assessment of normality

<table>
<thead>
<tr>
<th>Variable</th>
<th>Min</th>
<th>Max</th>
<th>Skew</th>
<th>Critical ratio</th>
<th>Kurtosis</th>
<th>Critical ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>EASE</td>
<td>2.500</td>
<td>5.000</td>
<td>-0.112</td>
<td>-0.657</td>
<td>-0.475</td>
<td>-1.398</td>
</tr>
<tr>
<td>USE</td>
<td>2.500</td>
<td>5.000</td>
<td>-0.343</td>
<td>-2.018</td>
<td>-0.256</td>
<td>-0.753</td>
</tr>
<tr>
<td>REF</td>
<td>2.000</td>
<td>5.000</td>
<td>0.025</td>
<td>0.148</td>
<td>-0.045</td>
<td>-0.132</td>
</tr>
<tr>
<td>CONT</td>
<td>2.000</td>
<td>5.000</td>
<td>-1.71</td>
<td>-1.009</td>
<td>0.353</td>
<td>1.040</td>
</tr>
<tr>
<td>COG</td>
<td>2.000</td>
<td>5.000</td>
<td>-0.230</td>
<td>-1.356</td>
<td>0.352</td>
<td>1.036</td>
</tr>
<tr>
<td>MOT</td>
<td>2.000</td>
<td>5.000</td>
<td>0.279</td>
<td>1.640</td>
<td>0.189</td>
<td>0.555</td>
</tr>
<tr>
<td>SAT</td>
<td>2.667</td>
<td>5.000</td>
<td>0.090</td>
<td>0.528</td>
<td>-0.867</td>
<td>-2.553</td>
</tr>
<tr>
<td>PERC</td>
<td>2.875</td>
<td>5.000</td>
<td>0.259</td>
<td>1.525</td>
<td>-0.461</td>
<td>-1.358</td>
</tr>
<tr>
<td>PERF</td>
<td>19.000</td>
<td>100.00</td>
<td>-0.046</td>
<td>-0.268</td>
<td>-0.520</td>
<td>-1.532</td>
</tr>
<tr>
<td>PRES</td>
<td>1.000</td>
<td>5.000</td>
<td>-0.320</td>
<td>-1.886</td>
<td>0.151</td>
<td>0.446</td>
</tr>
<tr>
<td>IMM</td>
<td>2.750</td>
<td>5.000</td>
<td>-0.224</td>
<td>-1.321</td>
<td>-0.759</td>
<td>-2.234</td>
</tr>
<tr>
<td>REP</td>
<td>2.333</td>
<td>5.000</td>
<td>-0.225</td>
<td>-1.326</td>
<td>-0.072</td>
<td>-0.212</td>
</tr>
</tbody>
</table>

6.2.2 Sample Size

The reasonable sample size for maximum likelihood estimation is about 200 (Hox & Bechger, 1998). The sample size for this study was 208 which met the reasonable sample size requirement. Furthermore, the ratio of cases to observed variables (indicators) is 17:1. As a rules of thumb, a ratio of 10:1 is considered sufficient (Schumacker & Lomax, 2004). The ratio of cases to estimated (free) parameters was 6:1 which also met the general minimum requirement of 5:1 under the normal distribution theory (Bentler & Chou, 1987). It is generally agreed that 100 to 150 subjects is the minimum satisfactory sample size when constructing structural equation models (Ding, Velicer, & Harlow, 1995)
6.3 Measurement Models

This section presents the measurement model for each latent variable in the model. The unidimensionality and internal consistency of the items that were measured with Likert scale of each indicator were first determined. The measurement models were then assessed based on the significance of each estimated coefficient or loadings, and the convergent and discriminant validity. A detailed elaboration of these was given in Section 4.6.1.2.1.

Exploratory factor analysis was first conducted to determine the unidimensionality of the items in each measurement instrument. Internal consistency was tested with Cronbach’s alpha coefficient. Criteria suggested by Nunnally (1978) were applied to determine the adequacy of the reliability coefficients obtained for each measurement. The number of items in each measurement and the source of the items were elaborated in Section 4.3.4 to Section 4.3.14. Convergent validity was then determined for latent variables (constructs) with multiple indicators. Discriminant validity was also performed for all latent variables.

Before factor analysis was performed, assessment of the suitability of the data for factor analysis was conducted. The assessment showed that factor analysis was appropriate for all the multi-item measurement instruments because the correlation coefficients among the items in all instruments were mostly greater than 0.3; the Barlett's test of sphericity was significant ($p < 0.05$); and the Kaiser-Meyer-Olkin (KMO) was greater than 0.6 (Pallant, 2007). Guidelines recommended by Hair, Anderson, Tatham and Black (1995) was used to determine the significance of the
factor loading of each item: loadings greater than 0.30 are considered significant; loadings greater than 0.40 are considered more important; and loadings 0.50 or greater are considered to be very significant.

Table 6.2 presents the test results on unidimensionality and reliability. The results revealed unidimensionality was achieved for all items in the respective measurements. The instruments also have good internal consistency as their Cronbach’s alpha coefficient was greater than 0.7. The detailed assessment results of the measurement models are as follows.

Table 6.2: Exploratory principal component and internal consistency analysis with actual data

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Eigenvalues</th>
<th>Factor Loadings</th>
<th>Significant level of correlation coefficient between pairs of items</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representational Fidelity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>2.199</td>
<td>0.820 – 0.883</td>
<td>0.01</td>
<td>0.816</td>
</tr>
<tr>
<td>Immediacy of Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>2.759</td>
<td>0.819 – 0.849</td>
<td>0.01</td>
<td>0.849</td>
</tr>
<tr>
<td>Perceived Usefulness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>2.552</td>
<td>0.711 – 0.839</td>
<td>0.01</td>
<td>0.807</td>
</tr>
<tr>
<td>Perceived Ease of Use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>2.234</td>
<td>0.693 – 0.802</td>
<td>0.01</td>
<td>0.728</td>
</tr>
<tr>
<td>Presence**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>NA*</td>
<td>NA*</td>
<td>Mostly significant at the 0.01 level</td>
<td></td>
</tr>
<tr>
<td>Motivation**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>5.171</td>
<td>0.500 – 0.853</td>
<td>Mostly significant at the 0.01 level</td>
<td>0.843</td>
</tr>
<tr>
<td>Component 2</td>
<td>1.407</td>
<td>0.376 – 0.850</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Component 3</td>
<td>1.223</td>
<td>0.527 – 0.743</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Component 4</td>
<td>1.119</td>
<td>0.572 – 0.825</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Cognitive Benefits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>3.486</td>
<td>0.764 – 0.883</td>
<td>0.01</td>
<td>0.890</td>
</tr>
<tr>
<td>Control and Active Learning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>2.486</td>
<td>0.758 – 0.826</td>
<td>0.01</td>
<td>0.796</td>
</tr>
<tr>
<td>Reflective Thinking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>2.645</td>
<td>0.806 – 0.821</td>
<td>0.01</td>
<td>0.828</td>
</tr>
<tr>
<td>Perceived Learning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>4.167</td>
<td>0.693 – 0.779</td>
<td>0.01</td>
<td>0.867</td>
</tr>
<tr>
<td>Satisfaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component 1</td>
<td>4.077</td>
<td>0.504 – 0.833</td>
<td>0.01</td>
<td>0.862</td>
</tr>
</tbody>
</table>

* Single item measurement; ** Exploratory principal component analysis with varimax rotation
6.3.1 VR Features

VR features construct consists of two indicators: representational fidelity and immediacy of control. Factor analysis was first conducted to determine the unidimensionality of these two indicators as well as their internal consistency. The degree to which these two indicators were related to each other was determined with correlation analysis.

Representational Fidelity

Representational Fidelity was measured by three items. An exploratory principal component analysis revealed a single factor solution which had an eigenvalue of 2.199. All three items loaded significantly on the factor ranging from 0.820 to 0.883 as shown in Table 6.2. The correlation coefficients between pairs of these items were all significant at the 0.01 level. The raw items have a Cronbach’s alpha coefficient of 0.816. Consequently, representational fidelity was represented by the mean of the responses across the three items, with higher scores indicating better representational fidelity.

Immediacy of Control

Four items were used to measure participants’ opinion on immediacy of control. An exploratory principal component analysis revealed a single factor solution which had an eigenvalue of 2.759 (see Table 6.2). All four items loaded significantly on the factor. The loadings ranged from 0.819 to 0.849. The correlation coefficients between pairs of these items were all significant at the 0.01 level. The raw items with a Cronbach’s alpha coefficient of 0.849 were then summed and averaged to
form the composite measure for immediacy of control. Higher scores indicated better
immediacy of control.

These two indicators of VR features were significantly correlated as shown in Table
6.3. As there were only two indicators to measure VR features, it was not possible to
determine measurement model fit in the initial modeling phase. However, the
measures of reliability of this scale were good. Composite reliability was 0.85 which
exceeded the threshold of 0.7, and average extracted variance was 0.79 which
exceeded the 0.5 threshold. Thus, the evidence supported the convergent validity of
the measurement model. Moreover, the C.R of indicators was greater than 1.96 and
thus can be considered valid indicators of the construct.

Table 6.3: Unstandardized parameter estimates (standardized parameter
estimates), correlation matrix and validity measures for VR features

<table>
<thead>
<tr>
<th>VR Features</th>
<th>Estimate (Standardized)</th>
<th>C.R.</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter estimates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| (1) Representation
  Fidelity                  | 0.98 (0.88)             | 16.336*** | 1.000 |
| (2) Immediacy of Control   | 1.00 (0.89)             |       | 0.784** | 1.000 |
| Validity measures          |                         |      |       |       |
| Composite reliability      | 0.9 (0.85)              |       |       |       |
| Average extracted variance | 0.8 (0.79)              |       |       |       |
| Notes: ** p < 0.01, ***p < 0.001

6.3.2 Presence

A single item was used to measure this variable as the main objective was to elicit
the opinion of the feeling of presence or “being there” while interacting with the VR
systems. Thus, measures of reliability and validity could not be calculated.
6.3.3 Motivation

Motivation was measured by fifteen items of the Intrinsic Motivation Inventory (IMI) by McAuley et al. (1989). The IMI was categorized into four sub-dimensions. An exploratory principal component analysis (with varimax rotation) revealed four factor solutions which was consistent with the study of McAuley et al. (1989). As presented in Table 6.2, the eigenvalues for all four factors were 5.171, 1.407, 1.223 and 1.119 respectively. The loading factors ranged from 0.376 to 0.853. The correlation coefficients between pairs of these items were mostly significant at the 0.01 level. The overall scale was used to measure motivation factor in this study. The raw items with a Cronbach’s alpha of 0.843 were then summed and average to form the composite measure for the motivation variable. Higher scores indicated higher motivation.

6.3.4 Cognitive Benefits

Cognitive benefits were measured with five items. An exploratory principal component analysis revealed a single factor solution with an eigenvalue of 3.486 (see Table 6.2). The factor loadings ranged from 0.764 to 0.883. The correlation coefficients between pairs of these items were significant at the level of 0.01. Cognitive benefits were represented by the mean of the responses across these five items which had a Cronbach’s alpha of 0.890. Higher scores indicated greater cognitive benefits.
6.3.5 **Control and Active Learning**

Learner control and active learning was measured by four items. An exploratory principal component analysis depicted a single factor solution with an eigenvalue of 2.486 (see Table 6.2). The factor loadings ranged from 0.758 to 0.826. The correlation coefficients between pairs of these items were significant at the level of 0.01. Its Cronbach’s alpha coefficient was 0.796. The mean score of all four items was the composite measure for control and active learning. Higher scores indicated greater control and active learning.

6.3.6 **Reflective Thinking**

Reflective thinking was measured by four items. An exploratory principal component analysis described a single factor solution with an eigenvalue of 2.645 (see Table 6.2). The factor loadings ranged from 0.806 to 0.821. The correlation coefficients between pairs of these items were significant at the 0.01 level. It had a Cronbach’s alpha of 0.828. The mean score of these four items was calculated as the composite measure that represented reflective thinking. Higher scores indicated better reflective thinking.

6.3.7 **Usability**

Usability was measured by two indicators: perceived usefulness and perceived ease of use. Factor analysis was first conducted to determine the unidimensionality of these two indicators as well as their internal consistency.
**Perceived Usefulness**

An instrument of four items was used to measure perceived usefulness. An exploratory principal component analysis revealed a single factor solution with an eigenvalue of 2.552 (see Table 6.2). The factor loadings ranged from 0.711 to 0.839. The correlation coefficients between pairs of these items were significant at the 0.01 level. The raw items with a Cronbach’s alpha of 0.807 were then summed and averaged to represent the composite measure of perceived usefulness. Higher scores indicated higher perceived usefulness.

**Perceived Ease of Use**

Perceived ease of use was measured by four items. An exploratory principal component analysis showed a single factor solution with an eigenvalue of 2.234 (see Table 6.2). The factor loadings ranged from 0.693 to 0.802. The correlation coefficients between pairs of these items were significant at the level of 0.01. Perceived ease of use was represented by the mean of the responses across these four items which had a Cronbach’s alpha of 0.728. Higher scores indicated greater perceived ease of use.

These two indicators of usability were significantly correlated as presented in Table 6.4. As there were only two indicators to measure VR features, it was not possible to determine measurement model fit in the initial modeling phase. However, the measures of validity of this scale have met the requirement. Average extracted variance was 0.51 which was above the 0.5 rule of thumb. Composite reliability was 0.67 which was close to the threshold of 0.7 for composite reliability. According to
Hair et al. (2010), reliability between 0.6 and 0.7 could be acceptable if other indicator of a model’s construct validity is good. Taken together, the scale was deemed reliable. Moreover, the C.R. of the indicators was greater than 1.96, and thus can be considered valid indicators of the construct.

<table>
<thead>
<tr>
<th>Usability</th>
<th>Estimate</th>
<th>C.R.</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter estimates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Usefulness</td>
<td>1.00 (0.73)</td>
<td>-</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>(2) Ease of Use</td>
<td>0.91 (0.69)</td>
<td>9.741***</td>
<td>0.557**</td>
<td>1.000</td>
</tr>
<tr>
<td><strong>Validity measures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite reliability</td>
<td>0.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average extracted variance</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: **p < 0.01, *** p < 0.001

6.3.8 Learning Outcomes

Learning outcomes were measured by performance achievement, perceived learning effectiveness and satisfaction. Factor analysis was first conducted to determine the unidimensionality of perceived learning effectiveness and satisfaction as well as their internal consistency. Content validity, a reliability test, and item analysis were performed on posttest which measured performance achievement as elaborated in Sections 4.3.1 and 4.7.2.

Perceived Learning Effectiveness

Eight items asked respondents about their opinions on perceived learning effectiveness. An exploratory principal component analysis revealed a single factor solution with an eigenvalue of 4.167 (see Table 6.2). The factor loadings ranged
from 0.693 to 0.779. The correlation coefficients between pairs of these items were significant at the level of 0.01. The raw scores were summed and averaged to form the composite measure of the perceived learning effectiveness variable. The Cronbach’s alpha coefficient was 0.867, with higher scores indicating greater perceived learning effectiveness.

Satisfaction

Satisfaction was measured by seven items. An exploratory principal component analysis revealed a single factor solution with an eigenvalue of 4.077 (see Table 6.2). The factor loadings ranged from 0.504 to 0.833. The correlation coefficients between pairs of these items were significant at the level of 0.01. Satisfaction was represented by the mean score of these seven items which had a Cronbach’s alpha of 0.862, with higher scores indicating greater sense of satisfaction.

The learning outcomes construct has three indicator variables: performance achievement, perceived learning effectiveness and satisfaction. These three indicators were significantly correlated as shown in Table 6.5. It is possible to determine the factor loadings but not the measurement model fit. Hence, no goodness-of-fit statistics were provided. However, the measures of validity for this scale have met the requirement of construct validity. Composite reliability was 0.70 and average extracted variance was 0.48 which was very close to the threshold of 0.5. The scale was therefore considered satisfactory for SEM. Moreover, the C.R. of all indicators was greater than 1.96 and they thus can be considered valid indicators of the construct.
Table 6.5: Unstandardized parameter estimates (standardized parameter estimates), correlation matrix and validity measures for learning outcomes

<table>
<thead>
<tr>
<th>Learning Outcomes</th>
<th>Estimate</th>
<th>C.R.</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter estimates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Performance</td>
<td>8.13 (0.27)</td>
<td>2.959**</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Perceived Learning</td>
<td>0.74 (0.74)</td>
<td>3.761***</td>
<td>0.200**</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>(3) Satisfaction</td>
<td>1.00 (0.90)</td>
<td>-</td>
<td>0.243**</td>
<td>0.664**</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Validity measures
- Composite reliability: 0.70
- Average extracted variance: 0.48

Notes: **p < 0.01; ***p < 0.001

6.4 Discriminant Validity

Table 6.6 shows the implied correlations between the variables in the model. Discriminant validity appeared to be satisfactory for all constructs as the estimated correlations were not excessively high except for usability and learning outcomes. The correlation between learning outcomes and usability was slightly higher than 0.9. However, it was evidenced that perceived usefulness and perceived ease of use correlated more highly with usability than with learning outcomes. Similarly, performance achievement, perceived learning effectiveness and satisfaction correlated more highly with learning outcomes than with usability (see Table 6.6). Discriminant validity is achieved if an indicator correlates more highly with the construct that it is intended to measure than with other constructs (Garson, 2009; Zen, 2007). Moreover, two constructs could be highly correlated and still be absolutely distinct (Zen, 2007). Thus, a decision was made to accept the identified constructs.
Table 6.6: Implied correlation between the variables in the model

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<tbody>
<tr>
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<td></td>
<td></td>
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<td>.600</td>
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<td>.534</td>
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<tr>
<td>14</td>
<td>.637</td>
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<td>.675</td>
<td>.683</td>
<td>.627</td>
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<td>.506</td>
<td>.781</td>
<td>.559</td>
<td>.569</td>
<td>.519</td>
<td>.491</td>
<td>.663</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>.208</td>
<td>.231</td>
<td>.221</td>
<td>.223</td>
<td>.205</td>
<td>.218</td>
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<td>.186</td>
<td>.170</td>
<td>.161</td>
<td>.217</td>
<td>.200</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Notes:
1 = VR features; 2 = Usability; 3 = Reflective thinking; 4 = Control and active learning; 5 = Cognitive benefits; 6 = Motivation; 7 = Presence; 8 = Learning outcomes; 9 = Representation fidelity; 10 = Immediacy of control; 11 = Perceived usefulness; 12 = Perceived ease of use; 13 = Perceived learning effectiveness; 14 = Satisfaction; 15 = Performance achievement
6.5 Analysis of the Structural Model

Following the assessment of the measurement models, the structural model was evaluated. The hypothesized model was evaluated based on three criteria: overall goodness of fit, the feasibility and significance of estimated model coefficients and the ability to explain the variance in the dependent variables. An acceptable model should meet the criteria for acceptable fit, would contain only valid paths and explain a moderate to high proportion of the variance in the dependent variables of interest. Table 6.7 displays the standardized loading, C.R. and goodness-of-fit measure for the hypothesized model. Figure 6.1 shows the standardized loading for each path, and the multiple squares correlation ($R^2$) for each dependent variable in the model.

All estimates were within the admissible range (i.e. correlation coefficient less than one and no negative covariance) and in the theoretically expected directions. In addition, based on a level of 0.05, all except three of the C.R.s were greater than 1.96 which indicated the significance of the estimated coefficients.

The goodness-of-fit measures indicated an acceptable fit of the model. The chi-square goodness-of-fit statistic is not a good model fit index because it is sensitive to sample sizes (Lin & Dembo, 2008). With large samples (generally more than 200), even small deviations from fit may be statistically significant which may lead to erroneous conclusions (Schumacker & Lomax, 2004). Hence, other fit indices were used to look at the model fit. A detailed elaboration of model fit indices was given in Section 4.6.1.2.2. Other fit indices have met the general guidelines of model fit. The normed chi-square was 1.825 which was less than 3, the GFI was 0.942 which
was greater than 0.9, AGFI was 0.895 which was greater than 0.8, CFI was 0.979 which was greater than 0.95, TLI was 0.968 which was higher than 0.95 and RMSEA was 0.063 which was below 0.08. All these goodness-of-fit measures indicated that the model has a good fit to the data.

The third criterion used to evaluate the model was the proportion of variance in dependent variables explained by the model. The squared multiple correlations, $R^2$, are measures of the ability of the model to explain the variance in the dependent variables. The model explained a moderate to high proportion of the variances in almost all of the dependent variables. The model explained 97% of the learning outcomes. Learning outcomes accounted for 61% of the variability in the satisfaction, 72% of the variability in perceived learning effectiveness, and 7% of the variability in performance achievement. The model accounted for 59% of the variance in usability, 42% in presence, 79% in motivation, 68% in cognitive benefits, 72% in control and active learning, and 63% in reflective thinking (see Figure 6.1).

The VR feature is a strong antecedent to usability (beta = 0.77, $p < 0.001$), presence (beta = 0.42, $p < 0.001$), control and active learning (beta = 0.35, $p < 0.001$), and motivation (beta = 0.22, $p < 0.05$). Usability is a strong antecedent to motivation (beta = 0.71, $p < 0.001$), cognitive benefits (beta = 0.75, $p < 0.001$), control and active learning (beta = 0.55, $p < 0.001$), and reflective thinking (beta = 0.70, $p < 0.001$). All the psychological learning factors are strong antecedents to learning outcomes: presence (beta = 0.20, $p < 0.001$), motivation (beta = 0.16, $p < 0.01$),
cognitive benefits (beta = 0.14,  p < 0.01), control and active learning (beta = 0.33,  
< 0.001) and reflective thinking (beta = 0.36,  p < 0.001).

Table 6.7: Standardized loading, C.R. and goodness-of-fit measure for the 
hypothesized model

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>From</th>
<th>To</th>
<th>Standardized Loading</th>
<th>C.R.</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>VR Features</td>
<td>Usability</td>
<td>0.770***</td>
<td>9.064</td>
</tr>
<tr>
<td>H2</td>
<td>VR Features</td>
<td>Presence</td>
<td>0.420***</td>
<td>3.548</td>
</tr>
<tr>
<td>H3</td>
<td>VR Features</td>
<td>Motivation</td>
<td>0.220*</td>
<td>2.262</td>
</tr>
<tr>
<td>H4</td>
<td>VR Features</td>
<td>Cognitive benefits</td>
<td>0.098</td>
<td>0.890</td>
</tr>
<tr>
<td>H5</td>
<td>VR Features</td>
<td>Control &amp; active learning</td>
<td>0.348***</td>
<td>3.686</td>
</tr>
<tr>
<td>H6</td>
<td>VR Features</td>
<td>Reflective thinking</td>
<td>0.123</td>
<td>1.114</td>
</tr>
<tr>
<td>H7</td>
<td>Usability</td>
<td>Presence</td>
<td>0.190</td>
<td>1.623</td>
</tr>
<tr>
<td>H8</td>
<td>Usability</td>
<td>Motivation</td>
<td>0.709***</td>
<td>6.805</td>
</tr>
<tr>
<td>H9</td>
<td>Usability</td>
<td>Cognitive benefits</td>
<td>0.749***</td>
<td>6.409</td>
</tr>
<tr>
<td>H10</td>
<td>Usability</td>
<td>Control &amp; active learning</td>
<td>0.551***</td>
<td>5.656</td>
</tr>
<tr>
<td>H11</td>
<td>Usability</td>
<td>Reflective thinking</td>
<td>0.697***</td>
<td>6.011</td>
</tr>
<tr>
<td>H12</td>
<td>Presence</td>
<td>Outcomes</td>
<td>0.200***</td>
<td>4.645</td>
</tr>
<tr>
<td>H13</td>
<td>Motivation</td>
<td>Outcomes</td>
<td>0.155**</td>
<td>2.383</td>
</tr>
<tr>
<td>H14</td>
<td>Cognitive benefits</td>
<td>Outcomes</td>
<td>0.139**</td>
<td>2.421</td>
</tr>
<tr>
<td>H15</td>
<td>Control &amp; active learning</td>
<td>Outcomes</td>
<td>0.327***</td>
<td>5.369</td>
</tr>
<tr>
<td>H16</td>
<td>Reflective thinking</td>
<td>Outcomes</td>
<td>0.360***</td>
<td>6.340</td>
</tr>
</tbody>
</table>

Goodness-of-fit measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square (χ²)</td>
<td>78.473</td>
</tr>
<tr>
<td>Degree of freedom (df)</td>
<td>43</td>
</tr>
<tr>
<td>Probability (p)</td>
<td>0.001</td>
</tr>
<tr>
<td>Normed chi-square (χ²/df)</td>
<td>1.825</td>
</tr>
<tr>
<td>Goodness-of-fit index (GFI)</td>
<td>0.942</td>
</tr>
<tr>
<td>Adjusted goodness-of-fit index</td>
<td>0.895</td>
</tr>
<tr>
<td>Comparative fit index (CFI)</td>
<td>0.979</td>
</tr>
<tr>
<td>Lewis Tucker index (LTI)</td>
<td>0.968</td>
</tr>
<tr>
<td>Root mean square error of</td>
<td>0.063</td>
</tr>
<tr>
<td>approximation (RMSEA)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: *p < 0.05; **p < 0.01; ***p < 0.001
The results for the hypotheses associated with the model are stated below.

H1: VR features were significantly related to usability. Therefore, this hypothesis was supported.
H2: VR features were significantly related to presence. Therefore, this hypothesis was supported.

H3: VR features were significantly related to motivation. Therefore, this hypothesis was supported.

H4: VR features were not significantly related to cognitive benefits. Therefore, this hypothesis was not supported.

H5: VR features were significantly related to control and active learning. Therefore, this hypothesis was supported.

H6: VR features were not significantly related to reflective thinking. Therefore, this hypothesis was not supported.

H7: Usability was not significantly related to presence. Therefore, this hypothesis was not supported.

H8: Usability was significantly related to motivation. Therefore, this hypothesis was supported.

H9: Usability was significantly related to cognitive benefits. Therefore, this hypothesis was supported.
H10: Usability was significantly related to control and active learning. Therefore, this hypothesis was supported.

H11: Usability was significantly related to reflective thinking. Therefore, this hypothesis was supported.

H12: Presence was significantly and positively related to learning outcomes. Therefore, this hypothesis was supported.

H13: Motivation was significantly and positively related to learning outcomes. Therefore, this hypothesis was supported.

H14: Cognitive benefits were significantly and positively related to learning outcomes. Therefore, this hypothesis was supported.

H15: Control and active learning was significantly and positively related to learning outcomes. Therefore, this hypothesis was supported.

H16: Reflective thinking was significantly and positively related to learning outcomes. Therefore, this hypothesis was supported.

### 6.5.1 Total Effects Analysis

Besides the direct relationships reported in Table 6.7, relationships may be direct or indirect, such that the relationship between two variables is mediated by one or more
intervening variables. Table 6.8 reports the standardized total effects (direct plus indirect effects) estimated for the hypothesized model.

Table 6.8: Standardized total effects on dependent variables

<table>
<thead>
<tr>
<th>VR Features</th>
<th>Usability</th>
<th>Presence</th>
<th>Motivation</th>
<th>Cognitive Benefits</th>
<th>Control &amp; Active Learning</th>
<th>Reflective Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>0.770</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence</td>
<td>0.566</td>
<td>0.190</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motivation</td>
<td>0.766</td>
<td>0.709</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive Benefits</td>
<td>0.675</td>
<td>0.749</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control &amp; Active</td>
<td>0.772</td>
<td>0.551</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning Thinking</td>
<td>0.660</td>
<td>0.697</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcomes</td>
<td>0.816</td>
<td>0.683</td>
<td>0.200</td>
<td>0.155</td>
<td>0.139</td>
<td>0.327</td>
</tr>
<tr>
<td>Performance</td>
<td>0.208</td>
<td>0.174</td>
<td>0.051</td>
<td>0.040</td>
<td>0.035</td>
<td>0.084</td>
</tr>
<tr>
<td>Perceived Learning</td>
<td>0.693</td>
<td>0.580</td>
<td>0.170</td>
<td>0.131</td>
<td>0.118</td>
<td>0.278</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>0.637</td>
<td>0.534</td>
<td>0.156</td>
<td>0.121</td>
<td>0.109</td>
<td>0.256</td>
</tr>
</tbody>
</table>

Note: Table shows total effects of each variable listed across the top of the table on each dependent variable listed in the left-hand column.

The results confirmed the significant indirect effect of VR features and usability on learning outcomes as supported by the model of Salzman et al. (1999). The relationships of VR features and usability on learning outcomes were mediated by learning experience. Likewise, some of relationships between VR features and learning experience were mediated by usability (interaction experience). For the relationships between VR features and learning outcomes, the total effect of VR features was the strongest for perceived learning effectiveness (0.693), followed by satisfaction (0.637) and performance achievement (0.208), whilst the total effect of VR features on the psychological factors of learning experience was the strongest for control and active learning (0.772). This was followed by motivation (0.766), cognitive benefits (0.675), reflective thinking (0.660) and presence (0.566). These
psychological factors of learning experience, in turn have a significant direct effect on learning outcomes (see Figure 6.1).

### 6.5.2 Individual Effect of Mediating Variables

Indirect effects through mediating variables could be further analyzed to examine their individual effect. Table 6.9 presents the individual effect the learning experience variables have upon the path of VR features to learning outcomes. The decomposition indicated that the mediated effect of VR features on learning outcomes which were measured by performance achievement, perceived learning effectiveness and satisfaction was the strongest through control and active learning (30.9%). This was followed by reflective thinking (29.2%), motivation (14.6%), presence (13.8%) and cognitive benefits (11.5%).

<table>
<thead>
<tr>
<th>Path</th>
<th>VR Features to Outcomes</th>
<th>VR Features to Performance</th>
<th>VR Features to Perceived Learning</th>
<th>VR Features to Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect effects through</td>
<td>Presence (13.8%)</td>
<td>Motivation (14.6%)</td>
<td>Cognitive Benefits (11.5%)</td>
<td>Control &amp; Active Learning (30.9%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.113</td>
<td>0.119</td>
<td>0.094</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.029</td>
<td>0.030</td>
<td>0.024</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.096</td>
<td>0.101</td>
<td>0.080</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.088</td>
<td>0.093</td>
<td>0.073</td>
</tr>
</tbody>
</table>
6.6 Moderating Effects of Student Characteristics

The subgroup analysis for the moderating effects of spatial ability and learning style is presented in Table 6.10 and Table 6.11. The chi-square difference test was used to examine the hypotheses. Spatial ability did not moderate all the paths from learning experience to learning outcomes except for the path from control and active learning to learning outcomes. The findings have also indicated that learning style did not moderate all the paths from learning experience to learning outcomes.

### Table 6.10: Spatial ability moderating effects

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>High Spatial Ability Group</th>
<th>Low Spatial Ability Group</th>
<th>Subgroup comparison</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standardized Coefficient</td>
<td>C.R.</td>
<td>Standardized Coefficient</td>
<td>C.R.</td>
</tr>
<tr>
<td>H17</td>
<td>0.19**</td>
<td>2.484</td>
<td>0.19*</td>
<td>1.066</td>
</tr>
<tr>
<td>H18</td>
<td>0.10</td>
<td>1.096</td>
<td>0.17</td>
<td>0.227</td>
</tr>
<tr>
<td>H19</td>
<td>0.21**</td>
<td>2.078</td>
<td>0.13</td>
<td>0.142</td>
</tr>
<tr>
<td>H20</td>
<td>0.39***</td>
<td>2.932</td>
<td>0.30*</td>
<td>1.678</td>
</tr>
<tr>
<td>H21</td>
<td>0.25***</td>
<td>2.390</td>
<td>0.43*</td>
<td>1.534</td>
</tr>
</tbody>
</table>

Notes: C.R. = Critical Ratio; H = High spatial ability group; L = Low spatial ability group
*p < 0.10; ** p < 0.05; *** p < 0.01

### Table 6.11: Learning style moderating effects

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Accommodator Learner</th>
<th>Assimilator Learner</th>
<th>Subgroup comparison</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standardized Coefficient</td>
<td>C.R.</td>
<td>Standardized Coefficient</td>
<td>C.R.</td>
</tr>
<tr>
<td>H22</td>
<td>0.13**</td>
<td>1.902</td>
<td>0.27*</td>
<td>1.588</td>
</tr>
<tr>
<td>H23</td>
<td>0.19**</td>
<td>1.748</td>
<td>0.10</td>
<td>1.010</td>
</tr>
<tr>
<td>H24</td>
<td>0.09</td>
<td>0.975</td>
<td>0.19*</td>
<td>1.416</td>
</tr>
<tr>
<td>H25</td>
<td>0.38***</td>
<td>2.595</td>
<td>0.30*</td>
<td>1.574</td>
</tr>
<tr>
<td>H26</td>
<td>0.33***</td>
<td>2.390</td>
<td>0.41*</td>
<td>1.621</td>
</tr>
</tbody>
</table>

Notes: C.R. = Critical Ratio; AC = Accommodator Learner; AS = Assimilator Learner
*p < 0.10; ** p < 0.05; *** p < 0.01
Based on the subgroup analysis in Table 6.10 and Table 6.11, the results for each of the hypotheses are stated below.

H17: Spatial ability did not moderate the influence of presence on learning outcomes. Therefore, this hypothesis was not supported.

H18: Spatial ability did not moderate the influence of motivation on learning outcomes. Therefore, this hypothesis was not supported.

H19: Spatial ability did not moderate the influence of cognitive benefits on learning outcomes. Thus, this hypothesis was not supported.

H20: Spatial ability moderated the influence of control and active learning on learning outcomes. Therefore, this hypothesis was supported.

H21: Spatial ability did not moderate the influence of reflective thinking on learning outcomes. Therefore, this hypothesis was not supported.

H22: Learning style did not moderate the influence of presence on learning outcomes. Therefore, this hypothesis was not supported.

H23: Learning style did not moderate the influence of motivation on learning outcomes. This hypothesis was not supported.
H24: Learning style did not moderate the influence of cognitive benefits on learning outcomes. This hypothesis was not supported.

H25: Learning style did not moderate the influence of control and active learning on learning outcomes. This hypothesis was not supported.

H26: Learning style did not moderate the influence of reflective thinking on learning outcomes. This hypothesis was not supported.

6.7 Latent Mean Testing

Latent Mean Testing was conducted to determine the main effects of spatial ability and learning style on the VR features. In order to have the hypotheses meaningfully tested, latent mean testing was conducted as in the following steps (Byrne, 2001): (1) Variance of the exogenous construct (VR features) was freely estimated in each group. (2) Means of the error terms are not estimated and remain constrained to zero. Variances of the error terms are freely estimated in each group. (3) Except for those fixed to 1.00, all factor loadings were constrained to be equal across groups. (4) All intercepts for the observed measures were constrained to be equal across groups. (5) The mean for exogenous construct (VR features) was freely estimated for one of the group, but was constrained to zero for the other group. The latter group was therefore regarded as the “reference” group.

Table 6.12 reports the results of latent mean testing across groups. To examine the main effects of spatial ability, the high spatial ability group was set as the reference
group. The low spatial ability group has a latent mean estimate of -0.106 which means the VR features mean was estimated to be 0.106 units below the high spatial ability group. However, the low spatial ability group’s latent mean estimate has a critical ratio of -1.429 which was not significantly different from zero ($p = 0.153$). In other words, it was not significantly different from the latent mean of the high spatial ability group. Hence, the perception of VR features was not significantly different across groups.

Though the equality of constraints was imposed on both the factor loadings and the observed variable intercepts across the two groups, the goodness-of-fit measures show that the model fitted the data well (e.g. normed $\chi^2 = 1.771$; CFI = 0.949; RMSEA = 0.061)—see Appendix H. Therefore, the results obtained could be interpreted confidently.

<table>
<thead>
<tr>
<th>Group</th>
<th>Estimate</th>
<th>S.E.</th>
<th>C.R.</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR Features</td>
<td>Spatial Ability</td>
<td>-.106</td>
<td>.074</td>
<td>-1.429</td>
</tr>
<tr>
<td>Learning Style</td>
<td>Learning Style</td>
<td>.070</td>
<td>.072</td>
<td>.971</td>
</tr>
</tbody>
</table>

To examine the main effects of learning style, the accommodator group was set as the reference group. Assimilator learners have a latent mean estimate of 0.070 which means the VR features mean was estimated to be 0.070 units above the accommodator learners. However, the assimilator learners’ latent mean estimate has a critical ratio of 0.971 which was not significantly different from zero ($p = 0.332$).
In other words, it was not significantly different from the latent mean of the accommodator learners. Hence, the perception of VR features was not significantly different across the accommodator learners and assimilator learners.

Though the equality of constraints was imposed on both the factor loadings and the observed variable intercepts across the two groups, the goodness-of-fit measures show that the model fitted the data well (e.g. normed $\chi^2 = 1.812$; CFI = 0.947; RMSEA = 0.063)—see Appendix H. Thus the results obtained could be interpreted confidently.

Based on the latent mean testing, the following results were obtained.

H27: Spatial ability did not influence the perception on VR features. Thus, H27 was not supported.

H28: Learning style did not influence the perception on VR features. Thus, H28 was not supported.

6.8 Summary

This chapter reports the analysis of how desktop VR enhances the learning outcomes. The fit of the hypothesized model was determined using SEM. First, the unidimensionality and reliability of the measurements were determined. The results of the factor analysis revealed unidimensionality was achieved for all items in the respective measurements. Based on the criteria suggested by Nunnally (1978), the
measurements have good internal consistency. The reliability and validity of the measurement models were investigated before the structural model was evaluated. The results on convergent validity and discriminant validity of the measurement models were considered satisfactory. Subsequently, the assessment of the structural model indicated an acceptable fit of the model that supported the hypothesis that VR features indirectly affect the learning outcomes. The model evaluation has provided the answers to the seventh and eighth research questions of this study as summarized below.

The seventh research question was:

*What are the constructs that play an important role in a desktop VR-based learning environment?*

The SEM analysis indicated that the major significant constructs that affect the learning outcomes in a VR-based learning environment are the VR features, usability (interaction experience), psychological factors of learning experience, that is, presence, motivation, cognitive benefits, control and active learning, and reflective thinking. The findings revealed that all these constructs are interrelated in an input, intermediary and output process to enhance learning. Student characteristics could also influence the learning outcomes. Student characteristics, such as spatial ability, have a minimal influence on certain structural path in the model.
The eighth research question was:

*How do these constructs interrelate to enhance the VR-based learning effectiveness?*

VR features enhance the learning outcomes through usability and learning experience. VR features have a strong and positive direct effect on usability. Results have also shown that VR features were directly and significantly related to the psychological factors of learning experience, that is, presence, control and active learning, and motivation; however, they were indirectly and significantly related to cognitive benefits and reflective thinking through usability. Among the indirect effects of VR features to the learning outcomes through learning experience, the mediating effect was the strongest through the psychological factor of control and active learning. This was followed by reflective thinking, motivation, presence and cognitive benefits.

Student characteristics did not moderate the path from the learning experience to the learning outcomes in the VR-based learning environment except for the path from control and active learning to learning outcomes. This path was moderated by students’ spatial abilities. Overall, individual differences such as spatial abilities and learning styles did not widen the gap of learning effectiveness among students in the desktop VR-based learning environment.

The results of latent mean testing for examining the main effects of spatial ability and learning style have indicated that there was no significant difference in the
The results reported in this chapter are discussed in detail in Chapter 7.
Chapter 7

DISCUSSION

7.0 Overview

The aims of this study were to determine “Does, and how does, desktop VR influence the learning outcomes of the learners?” It investigated the learning effectiveness of a desktop VR-based learning environment and developed a theoretical model for evaluating how desktop VR enhances the learning outcomes.

The effects of two learning modes, the desktop VR-based learning environment (VR mode) and conventional classroom learning method (Non-VR mode) on the learning outcomes, the possible interaction effects between the learning modes and the learners’ aptitudes, that is, spatial ability and learning style on learning, and the effects of learners’ aptitudes on learning outcomes in the VR group were studied. A theoretical model was developed to gain insights into the relevant constructs that influence the learning outcomes in a desktop VR learning environment.

This chapter presents discussion and implications of the obtained empirical results. It first discusses the results on “Does desktop VR influence the learning outcomes?” and its effects on learners with different characteristics. The discussion and implications on the learning outcomes is categorized into cognitive learning outcome (i.e. performance achievement) and affective learning outcome (i.e. perceived learning effectiveness and satisfaction). This is followed by the discussion and
implications of the results for the evaluation of the theoretical model on how desktop VR enhances the learning outcomes.

7.1 Effects of the Learning Modes on Learning

The sample consisted of 370 Form Four science students, aged between 15 and 17 years old from four co-education secondary schools in a city of East Malaysia. These students were exposed to different learning modes of the learning environment. The independent variable was the learning mode (VR and Non-VR); the moderator variables were the spatial ability (high and low) and the learning style (accommodator learners and assimilator learners); and the dependent variables were the performance achievement (cognitive outcome), and the perceived learning effectiveness and satisfaction (affective outcome).

7.1.1 Cognitive Learning Outcome

The experimental results have shown that significantly higher scores were obtained for the cognitive learning outcome in the desktop VR-based learning environment as presented in Section 5.5.1. The result of better performance achievement was consistent with the studies by Chen et al. (2005) and Yang and Heh (2007). However, some studies have shown no obvious benefits of using desktop VR-based learning over traditional instruction on students’ science achievement, as in the study of Crosier et al. (2000). Nevertheless, it was argued that only those science experiments that cover hands-on and minds-on activities and in which students could be actively involved in the learning process can enhance the effect of computer assisted learning (Berger, Lu, Belzer, & Voss, 1994; Chang & Barufaldi, 1999).
These activities were integrated in the software used in this study where the students did the virtual dissection and enhanced their understanding by completing the lab report that scaffolded their understanding. It is possible that these have helped the students to grasp scientific facts and concepts more easily.

Furthermore, students controlled their own learning pace and were actively involved in the learning activities because they made their own instructional decisions, experienced and were responsible for the consequences of those decisions. Thus, active and self-paced learning could be the partial cause as to why students’ learning achievement was better in the desktop VR-based learning environment. This is congruent with the principles of constructivism that advocate better learning results with active learning (Jonassen, 1993; Roblyer, 2003).

The ability of VR technology to allow the user to see a person, place or thing as it would appear in real life has opened up the possibilities of using this technology in classrooms where students can learn about science anatomy, geography or astronomy by interacting with the content rather than reading it in a textbook (Nichols, 2009). Indeed, in the open-ended sections of the survey, one student wrote, “Through it, self learning is not difficult and boring anymore. I learn more and easily compared to reading from the text book.” Another wrote, “It helps me to memorize the parts of the frog better than reading it from a book.”

The fact that students in the VR learning mode performed better than students in the Non-VR learning mode could also be explained by the cognitive load theory.
Cognitive load refers to the total amount of mental activity imposed on working memory when processing information (Cooper, 1998; Sweller, 1999). The process of learning requires working memory to be actively engaged in comprehension of instructional material to encode to-be-learned information for appropriate schema construction that will be stored in long-term memory (Cooper, 1998). The capacity of working memory is limited, thus the cognitive load theory asserts that learning is inhibited when the working memory capacity is exceeded by the total cognitive load in a learning task (Cooper, 1998; De Jong, 2009).

There are three types of cognitive load: intrinsic, extraneous and germane. Intrinsic cognitive load refers to the difficulty of the content and cannot be changed by instructional design and treatments. This is because it is determined by the interaction between the nature of the materials being learned and the expertise of the learner (Cooper, 1998; Sweller & Chandler, 1994; van Merriënboer & Sweller, 2005). Extraneous cognitive load is the load that does not directly contribute to learning (i.e. schema construction), is evoked by the instructional material and can be altered by instructional interventions (van Merriënboer & Sweller, 2005). Germane cognitive load is the load that is necessary for learning and it results from the way information is presented and the circumstances in which it is presented (Khalil, Paas, Johnson, & Payer, 2005). These three cognitive loads are additive and the sum should not exceed the memory resources available (see Figure 7.1).
For learning to be effective, activities and representations that maximize germane load should be provided while extraneous load should be minimized to ensure that the total cognitive load is within the memory resources available. If the learning content is difficult (a high intrinsic cognitive load) and if the strategy to present the information has created a high extraneous cognitive load, then the total cognitive load may exceed the available memory resources (see Figure 7.2). As a result, learning will be impeded and may fail to occur.

Based on the cognitive load theory, it is believed that students in the VR mode performed better because the available memory resources were not exceeded by the total cognitive load imposed. VR instructional intervention has helped to reduce extraneous cognitive load and at the same time increase germane cognitive load. The
ability to control the learning activities while interacting with the dynamic visualizations allows learners to adapt the instructional material to their cognitive system to decrease extraneous load; and engages learners in active processing of instructional material to increase germane cognitive load (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; Khalil et al., 2005; Schwan & Riempp, 2004).

Moreover, the spatial contiguity principle was adopted in the VR-based learning environment because the text and graphics are placed close to each other on each screen. This appears to help decrease extraneous cognitive load as well (Mayer, 2001; Moreno & Mayer, 1999). In addition, the virtual environment in the VR learning mode provides a more automated spatial encoding and therefore does not require specific spatial processing schema to mentally transform 2-D objects into 3-D objects. Such support could help to reduce the extraneous cognitive load (Chen, 2006).

On the other hand, in the PowerPoint slides for the Non-VR learning mode, due to a limited space on each page, different sources of information are separated in time, that is, texts are on one page that is presented after or before the graphic illustrations which are on another page. This separation design has caused the learners to be less likely to be able to hold both words and pictures in working memory at the same time (Mayer, 2001). The process of information integration may burden the working memory (Kalyuga, Ayres, Chandler, & Sweller, 2003). This probably explains the significant positive effects of the VR learning mode as compared with the Non-VR learning mode.
It is noted that small effect size was found for group differences in students’ performance achievement. This indicates that the result should be interpreted more cautiously in a practical sense and further replication studies should be conducted. Nevertheless, the research findings have shown that desktop VR could improve academic performance of the learners and could serve as an alternative way of providing instruction within secondary-school classrooms.

7.1.2 Affective Learning Outcome

There were significantly higher scores in both the perceived learning effectiveness and satisfaction for students in the VR mode (see Section 5.5.2 and Section 5.5.3). The results imply that desktop VR technology was effective in boosting the students’ affective behavior and the perception of their learning experience. The same results were obtained in the study of Wekesa, Kiboss & Ndigangu (2006). The higher perception in learning effectiveness in the VR learning mode indicates that VR was seen as an educational tool that could enhance learning and make learning more interesting and stimulating. The VR technology has helped them to have a good understanding of the basic concepts of the learning material; to identify the central issue of learning; and to make conclusions and generalizations. The learning activities in the desktop VR-based learning environment were perceived as meaningful, and the learning experience with VR technology has made the students interested to learn more. These positive learning attitudes are imperative for successful learning achievement.
Likewise, students in the VR learning mode exhibited much higher satisfaction in learning. This could be due to the positive emotions generated during learning. It was shown that positive emotions experienced during learning improve learners’ performance, satisfaction and perception towards learning (Um, 2008). Learning is more likely to occur with a positive state of emotion because learners make more constructive judgments as they interpret situations more positively (Um, Song, & Plass, 2007). The esthetic elements such as colors, layout and graphics illustration of the VR learning material could be the partial cause of the positive effects on perceived learning effectiveness and satisfaction (Lee, Wong, & Fung, 2009b).

7.2 Interaction Effects

The following subsections discuss the interaction effects between the learners’ spatial abilities and the two learning modes, and the interaction effects between the learners’ learning styles and the two learning modes on the learning outcomes based on the ATI model.

7.2.1 Interaction Effect of Spatial Ability and Learning Mode on Cognitive Learning Outcome

There was a significant interaction between the spatial abilities and learning modes on performance achievement (see Section 5.5.4). Thus, performance achievement varies as a function of spatial abilities and learning modes. Low spatial ability learners’ performance, compared with high spatial ability learners, appeared to be more positively affected by the learning mode. There was evidence that low spatial ability learners performed better in the VR learning mode, but there was no significant difference in performance for high spatial ability learners between the
two learning modes. However, the performance of high spatial ability learners in the VR learning mode was slightly lower than high spatial ability learners in the Non-VR learning mode.

The findings could be explained by the cognitive load theory. The major factor that contributes to cognitive load is the number of elements that a learner needs to attend to. The capability of working memory is limited to deal with about seven items or elements of information simultaneously (Baddeley, 1992; Miller, 1956). However, since working memory is also used to compare, contrast, organize or work on that information, thus probably only two or three items of information can be processed at any one time (Kirschner, 2002). The number of elements of information presented in the instructional material for the Non-VR learning mode could have imposed extraneous load for the low spatial ability learners. They need to mentally transform the 2-D objects into 3-D objects while at the same time to organize, compare and contrast different organs in the digestive tract and different parts of the veins and arteries in the circulatory system. Thus, their learning was hindered because the total cognitive load was not within the confines of working memory.

Low spatial ability learners are generally novices. They usually have relatively fewer and less sophisticated schemas on spatial intelligence (Cooper, 1998; Kalyuga et al., 2003). For instance, they have trouble recognizing visuo-spatial representations that require them to mentally transform 2-D graphics into 3-D representations; less ability to mentally restructure or manipulate the components of visual stimulus; and less ability to recognize, retain, and recall configurations when figure or parts are
moved. The level of automation, that is, the ability to perform tasks without concentrating is relatively lower for novices. They need to concentrate intently to avoid making errors (Cooper, 1998).

The superior test performance of the low spatial ability learners in the VR learning mode compared to the Non-VR learning mode indicated that the interactive learning environment, animated pictures and on screen text did not provide redundant information imposing extraneous working memory load. All sources of information provided were necessary for more understanding to occur. The VR-based learning has in fact managed to reduce the extraneous load for the low spatial ability learners, thus enabling more working memory to be used for processing and encoding to-be-learned information into the long-term memory. In other words, germane cognitive load occurred because free working memory resources were actively devoted to learning activities.

The following reasons could further explain why low spatial ability learners performed much better in the VR learning mode. Learner control allows low spatial ability learners to control their interactivity with the instructional material; actively participate to search for some items in space; and closely monitor the information given to follow the lesson. These learning activities may increase the germane cognitive load to assist in schema acquisition when learning in the VR-based learning environment. According to Hasler, Kersten & Sweller (2007, p. 725), the deeper cognitive processing of the instructional information in terms of a higher germane cognitive load is likely to result in better learning performance. This could
help to explain why low spatial ability learners performed better in the VR learning mode than those in the Non-VR learning mode.

In addition, the split attention effect is reduced for low spatial ability learners in the VR learning mode. Split attention occurs when students need to attend to more than one source of information such as both the graphic and the text if the associated text is placed above, below or the side of the graphic. The instructional material can only be understood after the multiple sources of information are mentally integrated by the learners (Cooper, 1998).

A lot of information needs to be labeled in anatomical visuals. The instructional material in the VR learning mode has physically integrated the multiple sources of information and has also used visual cues such as color cueing to direct the learners’ attention to the relevant parts of the diagram. For instance, in V-Frog™ the anatomical image is highlighted with a different color when it is activated with the query tool and at the same time the labeling of the image is given which is embedded onto the image as shown Figure 7.3. Thus, instructional guidance could act as a substitute to the missing schemas and help to construct schemas and automation for low spatial ability learners.
Based on the cognitive load theory (Sweller, 1999), the fact that there was no difference in performance for the high spatial ability learners in both learning modes suggested that the cognitive load imposed by both learning modes fell to a level that was within the bounds of mental resources, thus learning was not impeded.

High spatial ability learners usually have a more expansive set of schemas on spatial intelligence, and bring their activated schemas to the process of constructing mental representations of a task or situation (Cooper, 1998; Kalyuga et al., 2003). As mentioned by Cooper (1988), when learners hold high levels of expertise in the content area then their working memory may attend to elements with large complex knowledge networks. Thus, their working memory needs to attend only a few elements in order to hold all of the to-be-learned information in long-term memory. Moreover, those with high levels of expertise in the content area can categorize
multiple elements or related information as a single higher level element which requires considerably less working memory capacity for processing (Kalyuga et al., 2003). Consequently, ample cognitive resources are available for the process of learning. High spatial ability has compensated for a non interactive 3-D virtual learning environment in the Non-VR mode. Hence, instructional design manipulations for this group of learners is ineffective because their working memory capacity is not being exceeded (Cooper, 1998).

Such findings could be explained by the ability-as-compensator hypothesis (Mayer, 2001). High spatial ability learners could use their ability to compensate in an environment without explicit presentation of 3-D representation and dynamic visualization, but low spatial ability learners could not. Thus, the ability-as-compensator hypothesized that low spatial ability learners should gain particular benefit from the interactive 3-D virtual learning environment as they have difficulty in mentally constructing their own visualization. The explicit presentation of 3-D representations and dynamic visualizations may keep the need for using spatial processing schema to the very minimum, thus reducing the extraneous cognitive load. In fact, one of the strategies used to solve the information overload problem is to present the information spatially and to use virtual environment interfaces to help users to perceive, understand, and manipulate visuo-spatial information (Durlach et al., 2000).

The slightly lower posttest score of high spatial ability learners in the VR learning mode as compared to the Non-VR learning mode could be due to the expertise
reversal effect (Kalyuga et al., 2003). Essential information for the novices, in this case, the lower spatial ability learners, may be redundant for advanced learners, that is, the high spatial ability learners. Advanced learners cannot ignore the redundant information, but try to integrate and cross-reference the redundant information with its overlapped schemas that are already stored in long-term memory. This unnecessary process would exert irrelevant cognitive load that causes adverse effects in learning (Khalil et al., 2005, p. 18).

In such a case, the split-attention effect for novices is replaced by the redundancy effect for the advanced learners. Information that is relevant to the process of schema construction for a novice may hinder this process for a more advanced learner. In short, both scheme-based and instructional-based guidance for dealing with the same units of information may consume more mental resources and cause cognitive overload, thus learning is hindered for advanced learners.

7.2.2 Interaction Effect of Spatial Ability and Learning Mode on Affective Learning Outcome

There was no significant interaction between spatial abilities and learning modes on perceived learning effectiveness and satisfaction (see Section 5.5.5 and Section 5.5.6). This means the effects of the learning modes on perceived learning effectiveness and satisfaction did not depend on the learners’ differences in terms of spatial abilities. However, among the two learning modes, both high and low spatial ability learners perceived a higher level of learning effectiveness and were more satisfied with their learning experience in the VR learning modes. The possible cause
of positive effects on perceived learning effectiveness and satisfaction in the VR learning mode was explained in Section 7.1.2.

7.2.3 Interaction Effect of Learning Style and Learning Mode on Cognitive Learning Outcome

The interaction effect between the learners’ learning styles and the two learning modes on performance achievement was not significant (see Section 5.5.7). This indicates that the effects of the learning modes on performance achievement did not depend on the learning styles of the learners. However, among the two learning modes, both accommodator learners and assimilator learners have higher performance achievement scores in the VR learning mode. The underlying reasons for better cognitive learning outcomes for learners in the VR learning mode were explained in Section 7.1.1.

7.2.4 Interaction Effect of Learning Style and Learning Mode on Affective Learning Outcome

There was no significant interaction effect between the learners’ learning styles and the two learning modes on perceived learning effectiveness and satisfaction (see Section 5.5.8 & Section 5.5.9). In other words, the effects of the learning modes on perceived learning effectiveness and satisfaction did not depend on the learners’ learning styles. Nevertheless, among the two learning modes, the VR mode provided a more positive effect to both accommodator learners and assimilator learners. Both accommodators and assimilators perceived a higher level of learning effectiveness and satisfaction in the VR learning mode. The positive effects on affective domain for learners in the VR learning mode were elaborated in Section 7.1.2.
7.3 VR and Individual Differences

The following subsections discuss the effects of the VR learning mode on both the cognitive and affective learning outcomes for learners with different characteristics, that is, spatial abilities and learning styles.

7.3.1 Effects of VR-based Learning on Cognitive Learning Outcome for Learners with Different Spatial Abilities

There was a significant difference in the posttest score for high and low spatial ability learners (see Section 5.5.10). The scores for high spatial ability learners are higher than the low spatial ability learners. This is in agreement with the research by Huk (2006) where students with high spatial ability benefited from learning with interactive 3-D Quick-Time-VR animations on understanding cell biology. High spatial ability learners scored better because they have a more hierarchically organized schema on spatial intelligence and this may assist them in the process of constructing mental representations of a task or situation. On the other hand, low spatial ability learners have insufficient cognitive resources to build connections between the graphic and text representations of the information they select and hold in working memory, thus hindering their learning (Plass & Homer, 2002).

In general, it is expected there is a multiplicative effect when user proficiency and system power are combined, that is, the performance for individuals with high proficiency is amplified with the effect of an increase in the power of technology while there is no significant improvement for individuals with low proficiency (Norman 1994). However, when the overall improvement in performance as measured by the gain scores was determined in this study, there was no significant
difference in the overall improvement in performance between high and low spatial abilities learners (see Section 5.5.13). This shows that desktop VR-based learning did not magnify the gap of achievement between high and low spatial ability learners. This findings are consistent with the study of Chen (2006) where both spatial ability groups benefited from the desktop VR-based learning environment when additional navigational aids were provided in the virtual environment.

Messick (1976) proposes the compensatory match strategy to match individual differences to learning tasks. The compensatory match aims to offset learners’ deficiencies by providing mediators or cognitive tools that learners cannot provide for themselves. The use of virtual environment in the VR learning mode compensates for the need to mentally construct and maintain the 3-D representations and dynamic visualizations. The non-significant difference in the overall improvement in performance between high and low spatial ability learners proves the success of the compensatory match. Hence, the performance gap between high and low spatial ability groups was not widened with the use of the virtual learning environment. This is consistent with the study of Chen (2006). Consequently, the VR learning mode is beneficial to both groups in terms of overall improvement in performance.

7.3.2 Effects of VR-based Learning on Affective Learning Outcome for Learners with Different Spatial Abilities

There was no significant difference in perceived learning effectiveness and satisfaction between high and low spatial ability learners (see Section 5.5.11 and Section 5.5.12). In other words, all learners regardless of their spatial abilities had a
similar perception of the learning quality in the VR-based learning environment and experienced the same level of satisfaction with the VR learning mode. Both groups scored approximately four out of the five-point Likert scale on perceived learning effectiveness and satisfaction. In terms of perceived learning effectiveness, this shows that both groups agreed that the VR-based learning environment allowed them to achieve the desired learning effectiveness in identifying the issue learned, making generalizations and conclusions. In terms of satisfaction, both groups agreed that there was a high level of satisfaction in learning with the VR technology. Learner satisfaction and perceived learning effectiveness are important factors in how readily this VR-based learning will be adopted by learners. In short, VR has appealed positively to the affective and emotional state of the learners regardless of their spatial abilities, this implies that learners will accept and adopt VR-based learning.

7.3.3 Effects of VR-based Learning on Cognitive Learning Outcome for Learners with Different Learning Styles

There was no significant difference in the performance achievement and the overall improvement in performance between accommodator learners and assimilator learners in the VR learning mode (see Section 5.5.14 and Section 5.5.17). This implies that the effects of this learning on both accommodator learners and assimilator learners were almost equivalent. Indeed, Bell and Fogler (1997) have mentioned that, experience—the main feature of VR—is of great benefit to all learning styles. In other words, VR could provide support to all elements of Kolb’s model. A possible explanation for the findings is that in the VR learning mode, the virtual environments that mimic the real world provide concrete experience to the learners (Lee, Wong, & Fung, 2010a). Learners could actively construct knowledge
through experiment (Fitzpatrick, 2008); experience the consequences as they could actively explore the virtual environment; and have the autonomy and control over their own leaning (Chee, 2001; Fitzpatrick, 2008).

Moreover, the synthetic replica of objects by the virtual environment would help to concretize and reify ideas. Besides, the instructional material in text and images could provide reflective observation and abstract conceptualization to learners (Lee et al., 2010a). Thus, the VR learning mode covers all four extreme ends of the information perception continuum and the information processing continuum of Kolb’s model. In other words, this learning model supports Kolb’s model of experiential learning by providing concrete experience, abstract conceptualization, active experimentation and reflective observation. The findings are consistent with the study of Chen et al. (2005) in which their VR (guided exploration) mode has equally benefited both accommodator learners and assimilator learners.

### 7.3.4 Effect of VR-based Learning on Affective Learning Outcome for Learners with Different Learning Styles

There was no significant difference in perceived learning effectiveness and satisfaction between accommodator learners and assimilator learners (see Section 5.5.15 and Section 5.5.16). In other words, all learners regardless of their learning styles had a similar perception of the learning quality in the VR-based learning environment and experienced the same level of satisfaction with the VR learning mode. Based on a five-point Likert scale with higher scores indicating better perceptions of learning quality and satisfaction, both groups scored approximately four on perceived learning effectiveness and satisfaction. Thus, this indicates that
both groups agreed that the VR-based learning environment allowed them to achieve the desirable learning effectiveness in identifying the issues learned, making generalizations and conclusions. Likewise, both groups experienced a high level of satisfaction in the VR-based learning environment. To conclude, VR has appealed positively to the affective and emotional state of the learners irrespective of their learning styles. The high level of perceived learning effectiveness and satisfaction implies that learners irrespective of their learning styles are willing to adopt this technology and this will have an impact on the success of this technology (Lee at al., 2010a).

7.4 Theoretical Model for Evaluating How Desktop VR Enhances Learning Outcomes

This study examined how desktop VR enhances the learning outcomes by identifying the relevant constructs and their causal relationships that play an important role in shaping the learning process and learning outcomes in the desktop VR-based learning environment. The mediating effects of interaction experience and the psychological factors of learning experience between the desktop VR technology and the learning outcomes were empirically tested. With survey data from 208 respondents, a research model with eight latent variables was proposed and analyzed. Overall the model explained 97% of variance in learning outcomes. In addition, the moderating effects of learner characteristics (spatial ability and learning style) on the model paths were analyzed using analytical analysis, and the mean latent testing for the exogenous construct (i.e. VR features) across subgroups was also determined. Table 7.1 summaries the results of these hypotheses, indicating which were supported and which were not. The detailed results were presented in Section 6.5.
This section will first discuss the causal paths (relationship between constructs) of the model. Next, the hypotheses testing for the influence of moderators on the model paths will be discussed, and this will be followed by the hypotheses for mean latent testing for the exogenous construct across subgroups.

Table 7.1: Summary of the hypotheses investigated in the hypothesized model

<table>
<thead>
<tr>
<th>Hypotheses supported</th>
<th>Relationships between constructs</th>
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<tbody>
<tr>
<td></td>
<td>• VR features → usability</td>
</tr>
<tr>
<td></td>
<td>• VR features → presence</td>
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<tr>
<td></td>
<td>• VR features → motivation</td>
</tr>
<tr>
<td></td>
<td>• VR features → control and active learning</td>
</tr>
<tr>
<td></td>
<td>• Usability → motivation</td>
</tr>
<tr>
<td></td>
<td>• Usability → cognitive benefits</td>
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<td>• Usability → control and active learning</td>
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<tr>
<td></td>
<td>• Usability → reflective thinking</td>
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<tr>
<td></td>
<td>• Presence → learning outcomes</td>
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<tr>
<td></td>
<td>• Motivation → learning outcomes</td>
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<tr>
<td></td>
<td>• Cognitive benefits → learning outcomes</td>
</tr>
<tr>
<td></td>
<td>• Control and active learning → learning outcomes</td>
</tr>
<tr>
<td></td>
<td>• Reflective thinking → learning outcomes</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>Hypotheses supported</th>
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7.4.1 Causal Path

Using AMOS Version 16, the results supported the causal paths from VR features to presence, motivation, control and active learning, and usability; from usability to motivation, cognitive benefits, control and active learning, and reflective thinking; and from presence, motivation, cognitive benefits, control and active learning, and reflective thinking to learning outcomes. Learning experience which was individually measured by the psychological factors—that is, presence, motivation, cognitive benefits, control and active learning, and reflective thinking—took central stage in affecting the learning outcomes in the VR-based learning environment.

7.4.1.1 Presence

Presence was found to be significantly and positively related to learning outcomes in the VR-based learning environment. This is in agreement with the findings of Salzman et al. (1999) and Mania and Chalmers (2000) that presence could influence learning outcomes. The antecedent to presence was VR features and not usability. This could be explained by the argument of Dalgarno et al. (2002) that presence is not a unique attribute of the environment, but it is induced by the fidelity of representation and the high degree of interaction or user control. Presence is a user’s reaction to the given level of immersion in the VR-based learning environment, thus it is a subjective psychological response to a system. The positive relationships between VR features and presence indicated that the better the VR features in terms of realism and control factors, the higher level of presence the users experienced. And the higher the level of presence, the better the learning outcomes. The finding implies that low-immersion systems, such as desktop VR, are capable of providing
presence experience to users. Furthermore, it provides empirical evidence on the causality relationship between presence and learning outcomes which until today is still relatively limited (Lee, Wong, & Fung, 2010b). Most of the research findings were analyzed with correlation analysis which does not imply causality relationship.

7.4.1.2 Motivation

In the desktop VR-based learning environment, the results show that motivation was significantly and positively related to learning outcomes. This is in line with the model proposed by Salzman et al. (1999) and Benbunan-Fich and Hiltz (2003). Similar with the findings by Rezabek (1995) and Virvou et al. (2005), motivation was found to have an effect on learning effectiveness and achievement. The finding has contributed to the limited studies on the impact of the learners’ motivational perspective on its learning effects in a multimedia-based learning environment (Yaman et al., 2008).

VR features were a significant antecedent to motivation. The result is consistent with the finding of Virvou et al. (2005) where their VR educational software game named VR-ENGAGE was found to be very motivating. Indeed, instructional efforts can make a difference in motivating students to learn and this is in line with the social cognitive motivational theories that motivation is not an individual’s stable trait but varies depending on the situation and context of learning. Indeed, the realism of the scene, dynamic displays and closed-loop interaction where users have control over the contents viewed of the VR software used have been shown to be motivating in
this research, and this has supported the view on why motivational value was one of the justifications cited for using VR for learning (McLellan, 2004).

In fact, when the students were asked in the open-ended sections of the survey why the desktop VR program was effective as an educational tool, students reported the desktop VR program was interesting and had motivated them to put more efforts in the related subjects. One student wrote in the survey, “The realism of the image makes it easier for students to learn as they won’t get bored. The ability to manipulate the objects makes the learning session more interesting and effective.” Another mentioned, “I think the software program motivates students to learn and makes the learning environment more fun. Its 3-D images are very interesting.”

Usability was also a significant antecedent to motivation in the desktop VR-based learning environment. This shows that learning activities that are perceived as useful and easy to use in the desktop VR-based learning environment help to motivate the students. A learning system that is useful and easy to use makes it possible for individuals to devote their attention to learning materials (Sun et al., 2008), and thus they are more motivated to learn with the system provided (Lee et al., 2010b). It may eventually influence the intention of the students to adopt this system for learning.

7.4.1.3 Cognitive Benefits
Cognitive benefits were positively related to learning outcomes of the desktop VR-based learning environment. The better the cognitive benefits, the better the learning outcomes in terms of performance achievement, perceived learning effectiveness and
satisfaction of learning in a desktop VR-based learning environment. This finding has supported the study of Antonietti et al. (2000) in that students perceived cognitive benefits such as better memorization, understanding, application and overall view of the lesson learned were the advantages of using VR for learning.

Though VR is able to provide an environment in which students can develop higher levels of Bloom’s taxonomy, the findings of this research show that VR features did not directly relate to cognitive benefits, but were mediated by usability. A possible explanation for this is that VR technology itself does not have any influence on cognitive benefits; cognitive benefits are caused by the instructional method embedded in the media presentation, for instance, learning content and instructional strategy (Lee et al. 2010b). As mentioned by Dalgarno et al. (2002), the high degree of fidelity and user control will not necessarily facilitate the development of conceptual understanding. It is an appropriate set of learning tasks that is deemed useful and easy to use by the learners that is crucial. This is to ensure that the learning activities that the students undertake have a positive impact on cognitive benefits (Dalgarno et al., 2002).

7.4.1.4 Control and Active Learning

Control and active learning was proven to be positively related to learning outcomes in the desktop VR-based learning environment. This implies that the higher the level of control and active learning afforded by the VR-based learning environment, the better the learning outcomes as measured by performance achievement, perceived learning effectiveness and satisfaction. The result corroborates those of Stipek and
Weisz (1981), Choi and Gennaro (1987), Rivers and Vockell (1987), Yang and Heh (2007), and Jang et al. (2007). In essence, it is important to integrate both the hands-on and minds-on activities in which students could actively be involved in the learning process to enhance the effect of computer assisted learning (Berger et al., 1994; Chang & Barufaldi, 1999).

In addition, students’ positive reactions to learner control and active learning could also be one of the factors. From the open-ended sections of the survey, students reacted positively to learner control and active learning. One student wrote in the survey, “We can study on our own, can always review back. We learn to be responsible for our own learning.” Others mentioned, “This type of computer program allows the students to be more active in learning and the students would be more interested to learn.” “Students can study at their own pace without being pressured. Apart from that, immediate information is gained, making it easier for students to learn.” “Students can learn the subject by doing. This helps students to learn and understand better and makes the lesson more interesting.” Indeed, the results of this study indicate that learner control and active learning could positively affect the learning outcomes in a desktop VR-based learning environment.

Both VR features and usability were the antecedents to control and active learning. It was an expected finding because the feature of immediacy of control provided interactive experiences to learners, and learning tasks and activities that were useful and easy to use provided pleasant experiences when interacting with the VR system. Students could focus their attention on a coherent set of related activities and stimuli.
As one student mentioned, “It gives a clear picture to me. I understand more through exploration. Furthermore, it is not difficult to operate.”

7.4.1.5 Reflective Thinking

Reflective thinking was another significant psychological learning factor that influenced the learning outcomes in the desktop VR-based learning environment. The result implies that the desktop VR-based learning environment could engage learners in a deep approach of learning where they could actively search for information from the learning material to resolve their doubts, to understand the lesson and link it to previous knowledge and experiences to construct new knowledge. Through reflective thinking, the learners’ mental models to explain their worlds will become more complex, and enable them to reason more consistently and productively about the phenomena they are observing (Jonassen et al., 1999). Consequently, better learning outcomes were achieved, that is, better performance achievement, perceived learning effectiveness and satisfaction were attained.

The finding has shown that VR features were indirectly related to reflective thinking which was mediated by usability. Similar to cognitive benefits, a possible explanation is that reflective thinking is caused by the instructional method embedded in the media presentation (Lee et al., 2010b). In fact, the consensus among scholars is that technology does not cause learning, but the learning and teaching behaviors do (Chickering & Ehrmann, 1996). Nevertheless, technology can enhance certain behaviors or methods (Ahmad, Piccoli, & Ives, 1998). As mentioned by Collis (1995, p. 146), it is the instructional implementation of technology, and not
technology itself, that determines learning outcomes. This is also supported by Dalgarno et al. (2002) who stated that a virtual learning environment that is modeled on a real world system with high degree of fidelity and immediacy of control will not necessarily facilitate better learning and understanding. There must be an appropriate set of learning tasks and activities that are considered to be useful and easy to use by learners in order to facilitate reflective thinking, which in turn affect the learning outcomes (Dalgarno et al., 2002).

Learners must be able to reflect on their activities and observations to learn the lesson that the activities have to teach. It is believed the requirement to complete the lab report had helped the learners to reflect on their activities and observations, to integrate new experiences with their prior knowledge to construct new knowledge, and to make sense out of what they observe. As one student mentioned during the debriefing session, “I think, reflect, and answer the lab report.” Others mentioned, “I do my own learning. I read, understand, reflect and answer the lab report.” “It is an interactive program which allows me to do discovery learning. Thus, the whole learning process was interesting. I did reflect on what had been learned.” Hence, the interactive virtual learning, coupled with the appropriate instructional strategy that is perceived as useful and easy to use by learners, helps to facilitate reflective thinking.

7.4.1.6 Usability

Usability was found to be a significant antecedent to a number of the psychological learning factors as elaborated above. This implies that usability, the interaction experience with the desktop VR-based learning environment, plays a significant role
in influencing the learning experience, which in turn affects the learning outcomes. Moreover, usability plays the role of mediating the VR features to some psychological factors such as cognitive benefits and reflective thinking which indicates that the unique desktop VR features alone are not sufficient to facilitate learning, thinking and understanding. The learning activities and tasks provided must be useful and easy to use for the desktop VR to fully captivate its capabilities and potentials to improve the learner’s learning experience. In short, the design dimension of the VR-based learning environment that takes into account the perceived usefulness and ease of use has a significant impact on learning experience and learning outcomes. This research echoes that of Sun et al. (2008) and Arbaugh and Duray (2002) in technology-mediated learning.

VR features were significant antecedents to usability, as predicted by the model. This was consistent with the findings of Salzman et al. (1999). The VR features that were measured by the representational fidelity and the ability to control, manipulate and interact with the virtual objects in the VR-based learning environment collectively influenced the interaction experience of the users. The relationship between VR features and usability were positively related, indicating that the better the realism and control factors, the better the interaction experience.

In the open-ended question, many students reported that the VR features have enhanced their interaction experience. In terms of perceived usefulness, students stated that “The most important part is students are able to learn at their own pace. Besides, this software enables students to view the objects in 3-D which further
enhances their understanding.” “We are able to rotate the specimen or zoom it. We won’t be able to do this with the real specimen. This is the good part where you can turn and play with the specimen and this helps to understand more.” “It is an effective educational tool as there are pictures and images throughout the learning. I will never feel bored with this type of computer-based learning. The information is always clear and detailed.” “I think it is very useful and should be used continuously for students to understand more on the topics.” From the perspective of perceived ease of use, students mentioned, “It is easy and fun to use. It helps me to understand more about the subject.” “It is easy to use and I can get a lot of information from this type of computer program.”

7.4.1.7 VR Features

VR features were found to be directly and indirectly related to all psychological factors, the learning experience and also a significant antecedent to usability, the interaction experience as explained in detail above. These findings support what other researchers have argued in terms of leveraging the uniqueness of the VR technology to enhance the learners’ interaction and learning experience, which in turn affects the learning outcomes (Barnett et al., 2005; Salzman et al., 1999). VR technology may have significant potential to improve student learning; however, it is the aspects of this technology that are best leveraged for enhancing the learning effectiveness that need to be examined (Barnett et al., 2005). This study has shown that representational fidelity and immediacy of control are the two unique features of desktop VR that play a significant role in influencing the interaction and learning experience of learners, which eventually enhances the learning outcomes.
VR features had a stronger direct effect on perceived learning effectiveness and satisfaction than on performance achievement. A possible explanation is that the cognitive tool (3-D interactive features) in the VR-based learning environment has helped the students to understand, to build new knowledge, to make generalizations and conclusions to the lesson learned, and has provided the students a satisfying learning experience. However, good and impressive VR features might not lead to better performance achievement because getting a good score might not be necessary the goal of all students (McGill & Klobas, 2009). Furthermore, other factors could influence the performance outcomes of the students such as cognitive style and attitude towards computer. It was found that the total effect of VR features was the strongest for the psychological factors of control and active learning (see Section 6.5.1). This implies the capability of desktop VR to provide more active student involvement in the learning process.

Another significant finding of this research was that the indirect effects analysis from the path of VR features to learning outcomes indicated that the mediated effect through control and active learning was the strongest among the psychological factors (see Section 6.5.2). This implies that the students are more sensitive to this psychological factor when learning in a desktop VR-based learning environment. This is consistent with the nature of human beings. When learning about things, humans want to be active, to control and interact with the environment, to manipulate objects in that environment, and to observe the effect of their interventions and construct their own interpretation for the phenomena and the results of the manipulation (Jonassen et al., 1999). Thus, instructional designers and
desktop VR developers should be aware that real learning requires active learners who are engaged by meaningful tasks and not just merely pressing the space bar or clicking the button to continue.

7.4.2 Moderating Effects of Learner Characteristics

The influence of presence, motivation, cognitive benefits and reflective thinking on learning outcomes being similar for high and low spatial ability groups indicates that these psychological factors to learning outcomes are not spatial ability specific (see Section 6.6). The phenomenon implies that these psychological factors are the common success factors, regardless of the learners’ spatial abilities. Thus, a VR-based learning environment that is able to provide such learning experience (e.g. presence, motivation, cognitive benefits and reflective thinking) is crucial to achieve good learning outcomes.

The influence of control and active learning on learning outcomes is stronger for the high spatial ability than the low spatial ability group, implying that the high spatial ability group displays more sensitivity to control and active learning rather than to the rest of the psychological factors. This difference between both groups may result from the phenomenon that the high spatial ability learners generate a higher level of performance achievement, perceived learning effectiveness and satisfaction if control and active learning is provided. This shows that control and active learning is more of a concern factor for the high spatial ability group. A possible explanation could be control and active learning enable learners to adapt the pace of presentation to their individual cognitive needs, thereby ameliorating their performance and
helping them perceive the learning process as effective and satisfying (Lee et al., 2010b).

Likewise, the influence of presence, motivation, cognitive benefits, control and active learning and reflective thinking on learning outcomes being similar for accommodator learners and assimilator learners indicates that these psychological factors to learning outcomes are not learning style specific (see Section 6.6). The phenomenon implies that these psychological factors are the common success factors, regardless of the learners’ learning styles (Lee et al., 2010b). Thus, a VR-based learning environment that is able to provide such learning experiences is crucial to achieve good learning outcomes (Lee et al., 2010b).

The implication of these findings is that a VR-based learning environment is found to be suitable for learners with different learning styles because learning style does not influence learning experience on learning outcomes. Likewise, a VR-based learning environment is also suitable for learners with different spatial abilities because spatial ability does not influence the learning experience paths to learning outcomes except from the path of control and active learning to learning outcomes. Thus, the efforts to improve the learning outcomes are only subjected to very minimal influence of spatial ability. Consequently, VR is an educational tool that could accommodate individual differences in terms of learning styles and spatial abilities.
7.4.3 Latent Mean Testing

The non-significant difference for the means of the exogenous construct (VR features) across the subgroups of spatial ability and learning style shows that all subgroups have given similar evaluation to the VR features (see Section 6.7). This indicates that all learners regardless of which subgroups they were assigned to have the same perception on the VR features of the software program. This shows that there was a consistent perspective on the technical features that were afforded by the desktop VR technology between all types of learners in terms of spatial ability and learning style.

7.5 Summary

This chapter presents the discussion and implications of the research results: the learning effectiveness of a VR-based learning environment, the ATI research, VR and individual differences, and the model evaluation of how VR enhances the learning outcomes.

The possibilities of why the VR-based learning environment outperformed the conventional classroom learning practice were discussed in great detail. It was argued that interactive, active and self-paced learning in the VR learning mode could be the partial causes. The argument was further supported by the cognitive load theory. It was believed that the VR instructional intervention has helped to reduce extraneous cognitive load and at the same time increased the germane cognitive load. Thus, the available memory resources were not exceeded by the total cognitive load imposed, which fostered better learning in the VR-based learning environment.
As for the ATI research, the interaction effect was found significant only for spatial abilities and learning modes on cognitive learning outcome. Low spatial ability learners performed better in the VR mode as compared to the Non-VR mode. Again, the findings could be explained by the cognitive load theory, that is, the learning of low spatial ability learners in the VR mode was not hindered because the total load was within the confines of working memory. Other arguments include learner control and the split attention effect.

In terms of individual differences in the VR learning mode, only spatial ability has an influence on the performance achievement. High spatial ability learners did better than the low spatial ability learners. This was an expected result because high spatial ability learners have a more hierarchically organized schema on spatial intelligence than low spatial ability learners, which may assist them in the process of constructing mental representations of a task or situation.

To evaluate how VR enhances learning outcomes, the results have supported the relationships in the hypothesized model that VR features did not directly influence the learning outcomes, but did so indirectly through interaction experience and learning experience. VR features, that is, representational fidelity and immediacy of control were found to collectively influence the psychological factors of learning experience, that is, presence, motivation, and control and active learning directly. The positive relationship between them indicates that the better the realism and control factor, the better the level of presence, motivation, and control and active learning. VR features were also found to directly influence the interaction
experience of the users. The relationship between VR features and usability were positively related, indicating the better the realism and control factors, the better the interaction experience. These findings have shown that representational fidelity and immediacy of control are two unique features of desktop VR that could play a significant role in influencing the learners’ interaction and learning experience, which in turn enhances the learning outcomes.

Some of the psychological factors of the learning experience are not directly related to the VR features, but are related indirectly to the VR features through usability, the interaction experience. The implication of this result is that interaction experience (usability) plays an important role in a desktop VR-based learning environment. Learning tasks and activities that are deemed useful and easy to use by learners are crucial to provide better learning experiences and learning outcomes to the users.

Students were found to be more sensitive to the mediating effect of control and active learning from the indirect effects analysis from the path of VR features to learning outcomes. This is consistent with the nature of human beings. When learning, humans want to be active, to be able to control and interact with the environment, to observe the effect of their inventions and to construct their own interpretation of the phenomena (Jonassen et al., 1999).

Desktop VR was found to be able to accommodate individual differences. Learning style did not moderate any paths from learning experience to learning outcomes and the influence of spatial ability is minimal. High spatial ability learners are more
sensitive to control and active learning. A possible explanation could be that control and active learning enables learners to adapt the pace of presentation to their individual cognitive needs, thereby improving their learning outcomes.

Lastly, the latent mean testing shows all subgroups which were based on spatial abilities and learning styles had given similar evaluation to the VR features. This implies that there was a similar perspective on the technical features that were afforded by the desktop VR technology between all types of learners in terms of spatial ability and learning style.
Chapter 8

CONCLUSIONS

8.0 Summary of the Research and Its Contributions

The main aims of this research are two-fold. First, it investigates the learning effectiveness of a desktop VR-based learning environment as compared to a conventional classroom learning method. The results have contributed to our understanding of the learning outcomes of a student-centered approach in a desktop VR-based learning environment that supports the constructivist learning model. Consequently, the findings provide empirical evidence on the merit of desktop VR-based learning to educators, VR software developers and policy makers. Besides, through the ATI research, the understanding of how individual differences interact with different learning environments could help the instructors to identify instructional treatments that facilitate individualized learning, and also to provide evidence that VR could accommodate individual differences. The influence of individual differences was further analyzed in the VR learning mode.

Next, the research centered around the development of a theoretical model of determinants for effective desktop VR-based learning to understand how a desktop VR system is capable of enhancing and improving the quality of student learning, and also the types of students that would benefit from this technology. The model provides some insights into the relationships among the relevant constructs that work together to shape learning in a desktop VR-based learning environment. With such
understanding and knowledge, desktop VR technology could be best leveraged for enhancing the learning effectiveness to maximize the benefits of using this technology for educational purposes. For instance: Which VR feature is prominent? How does the VR feature influence the learning outcomes? Which psychological factors that are induced by the VR technology play a significant role in the learning environment? And which characteristics of the learners require careful attention in a desktop VR-based learning environment?

Through this research, an initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment was developed and evaluated. The proposed model appeared to provide a useful model of the relationships under consideration. Thirteen of the sixteen hypotheses on causal paths were supported when the model was tested with the sample data. The results of the structural model evaluation have pointed out the relevant constructs and their causal relationships that could enhance and improve the learning outcomes of a desktop VR-based learning environment. Furthermore, the investigation of the moderating effect of learner characteristics on the structural paths suggests that the desktop VR-based learning environment is suitable for learners with different learning styles and spatial abilities. The influence of spatial abilities is minimal in a desktop VR-based learning environment.

8.1 Limitations of the Study

There are some limitations that may restrict the probability of generalizing the findings of this study.
First, it is noted that the learning outcomes accounted for 61% of the variability in satisfaction, 72% of the variability in perceived learning effectiveness, but only 7% of the variability in performance. Though performance achievement is a significant indicator for learning outcomes, only a small proportion of variability in performance achievement was explained. Student performance achievement is influenced by a myriad of other factors including personal goals (Yi & Im, 2004), cognitive styles (Witkin, 1976), and computer attitudes (Teo, 2008). Getting better scores is not necessarily the goal of all students (McGill & Klobas, 2009). A short exposure with desktop VR might not be sufficient to gauge students’ performance achievement.

Second, the findings were limited to the context of a biology topic on frog anatomy. The results obtained here are primarily dependent on the context of biology learning. Different learning content may arouse different attitudes, perceptions and results.

Third, the subjects were confined to the context of Malaysia. Research has shown that cultural backgrounds of students from different cultures could influence how they use and think about learning with computer based technologies (Colis, 1999; Lal, 2002; Palma-Rivas, 2002).

Fourth, the novelty effect cannot be ruled out. Almost half of the samples have never heard of VR and used VR before. Thus, this new technology may create a sense of new excitement that could influence the students’ perception on the factors measured in this study.
Fifth, presence is a highly complex construct which should be measured by a more comprehensive measurement and not with a single questionnaire item.

Sixth, instead of straight gain scores, modified percent gain scores generally provide a better alternative as not to penalize the scores of high pretest scorers in the calculation of gains to measure the overall improvement in the performance of students with different characteristics.

8.2 Recommendations for Future Investigations

This study raises several issues that worth further research.

First, to study students in a desktop VR-based learning environment over a longer period will be useful as the impact of the VR-based learning on student achievement may be cumulative over time. It is also recommended to delay the posttest to measure the retention rate as compared to conventional classroom learning methods. Furthermore, studying students in the desktop VR-based learning environment over a number of terms or semesters might diminish the novelty effect.

Second, is it suggested that future research looks into the influence of desktop VR-based learning on individual indicators instead of collectively grouping the indicators under one construct of learning outcomes.

Third, replication of the study in a different learning context is recommended for future research to determine whether the identified constructs and the pattern of
relationships in the tested structural model is restricted to the present sample and design or if it can be observed in samples for other learning programs with different content and over a period of time.

Fourth, it is recommended that similar study to be carried out for students with different cultural backgrounds from different geographical areas to generalize the result findings.

8.3 Implications of the Study

The findings have important implications to instructional designers, desktop VR software developers and educators.

8.3.1 Conceptual Framework and Theoretical Model of How Desktop VR Enhances Learning Outcomes

It is hoped that the framework and model that evaluates how desktop VR enhances the learning outcomes will serve as a feasible and useful template to guide the development efforts of desktop VR-based learning. By understanding how the relevant factors or constructs work together to shape learning, instructional designers and desktop VR software developers will be able to maximize the benefits of desktop VR technology. The model has highlighted the influence of the psychological learning factors by both the VR features and interaction experience that eventually enhance the learning outcomes. For instructional designers and desktop VR software developers, this study would help them to leverage the VR features to enhance the desired interaction and learning experience that play a
significant role in improving the learning outcomes. Among the psychological factors of learning experience, it was also found that control and active learning was the most influential in affecting the learning outcomes in the desktop VR-based learning environment. An important finding is that great VR features alone might not achieve the desired learning experience. An appropriate set of learning tasks and activities that are afforded by the VR technology—and that are considered to be useful and easy to use by learners—is crucial in enhancing the learning outcomes.

The findings on the influence of student characteristics on the structural paths have suggested to educators that desktop VR-based learning could accommodate students with different learning styles and spatial abilities. The influence of spatial abilities on learning outcomes is minimal in a desktop VR-based learning environment. Furthermore, all learners irrespective of their spatial abilities and learning styles have a similar perspective on the technical features afforded by the desktop VR technology.

8.3.2 A VR-based Learning Environment—An Effective Alternative

The significant positive effects of the VR-based learning environments on both the cognitive and affective domains when compared with the Non-VR mode have provided empirical evidence of the potential of desktop VR as an alternative to the traditional way of teaching and learning. These findings imply that a student-centered approach in a desktop VR-based learning environment that supports constructivist learning principles is superior to the teacher-centered approach in a learning environment that supports objectivist learning principles.
The findings have further supported the use of VR for learners with different aptitudes. There was no significant difference in the overall improvement in performance, perceived learning effectiveness and satisfaction between high and low spatial ability learners and between accommodator learners and assimilator learners in the desktop VR-based learning environments, which imply that a VR-based learning mode provides equivalent benefits to learners of different spatial abilities and learning styles. Besides cognitive gains, VR has appealed positively to the affective and emotional state of the learners regardless of their spatial abilities and learning styles. These findings have provided evidence on the potential of VR to empower students’ learning and as a curriculum enhancement in secondary classrooms. Furthermore, the new generation in schools is in a digital generation where the computer has become part of everyday life. Desktop VR therefore should be considered as an alternative way of providing instruction in schools.

8.3.3 Aptitude-by-Treatment Interaction Study

There is little research that looks into how learner characteristics could aid or inhibit learning in a virtual environment as most research for instructional use is technology-driven, rather than taking into account human factors (Chen, 2005). Thus, the ATI study undertaken would provide more understanding of this aspect. The findings show that the learners irrespective of their learning styles benefit more from the VR-based learning environment in terms of performance achievement, perceived learning effectiveness and satisfaction. This proves the VR-based learning environment could be used to accommodate learners with different learning styles. The ATI findings show that a VR-based learning environment benefits more the low
spatial ability learners in terms of performance achievement. Thus, this could help educators to facilitate individualized learning. In terms of perceived learning effectiveness and satisfaction, the learners irrespective of their spatial abilities benefit more from the VR-based learning environment. This implies that in terms of affective domain, VR-based learning offers a promising medium to accommodate individual differences pertaining to this aptitude.

In conclusion, this research makes a significant contribution by bringing VR practitioners one step closer to understanding the potential of desktop VR technology to support and enhance learning. The findings contribute to the understanding of the learning outcomes of a desktop VR-based learning environment and the merit of using desktop VR for learning. A broad framework that identifies the theoretical constructs and their relationships in a desktop VR-based learning environment has been developed and the fit of the theoretical model has been systematically and empirically tested. The framework and model are intended to guide the future development efforts of a desktop VR-based learning environment. Moreover, the framework and model have enlightened educators and practitioners to the capability of desktop VR to enhance learning and to support educators and practitioners using desktop VR-based learning. Taken together, the findings from this study not only tell VR practitioners what has occurred but also how the learning has occurred in a desktop VR-based learning environment.
Appendix A

Data Collection Procedures for VR Mode
(Actual Study)
Data Collection Procedures (VR Mode)

Two weeks before the treatment

The students answer the spatial ability test, pretest and initial questionnaire.

First Part (Spatial Ability Test)

Directions:

1. Introduction – The teacher will put the participants at ease by briefly explaining the purpose of the test.
2. Spatial Ability Test and Answer Sheet – The participants will be given the spatial ability test and answer sheet.
3. Identification Information – The teacher must ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the answer sheet and question paper.
4. Administration of the Spatial Ability Test – The teacher will say: “Please refer the spatial ability test. This test consists of 75 questions. You are given 3 minutes to go through the examples of the type of questions being asked in this test. Please read the instructions on what you should do in order to answer each question. Show your choice of answer by marking your answer on the answer sheet provided. You will have 10 minutes for this test. Work as rapidly and as accurately as you can.”
5. Collection of Question Paper and Answer Sheet – The teacher needs to ensure the number of answer sheets and question papers tally with the number of participants present.

Second Part (Pretest)

Directions:

1. Introduction – The teacher will put the participants at ease by briefly explaining the purpose of the test.
2. Pretest and Answer Sheet – The participants will be given the pretest question paper and answer sheet.
3. Identification Information – The teacher must ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the answer sheet and question paper.
4. Administration of Pretest – The teacher will say: “Please refer to the pretest. This test consists of three parts. You are given 30 minutes to complete the test. For each Part, please read the instructions carefully before answering the questions.”
5. Collection of Question Paper and Answer Sheet – The teacher needs to
ensure the number of answer sheets and question papers tally with the number of participants present.

Third Part (Initial Questionnaire)

Directions:

1. Introduction – The teacher will put the participants at ease by briefly explaining the purpose of the test.
2. Initial Questionnaire – The participants will be given the initial questionnaire.
3. Identification Information – The teacher must ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the questionnaire.
4. Administration of the Questionnaire – The participants complete the questionnaire and submit to their teacher. Participants are advised to read the instructions carefully before answering.

During the Treatment

All the computers are ensured to be properly set-up for learning with the virtual reality computer software program with a computer for each participant.

Directions:

1. Introduction – The teacher/researcher will put the participants at ease and explain the purpose of this lesson, the topics involved, and the time given to complete the lesson.
2. Stationery – Each participant will be given a pencil and an eraser and a set of lab report, which is to be answered while learning the lesson with the virtual reality computer software program.
3. Identification Information – The teacher/researcher will ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the lab report.
4. Tutorial Session – Participants will be directed to start the tutorial session of V-Frog to learn how to use V-Frog.
5. Learning Session – Participants will then be directed to start the lesson by clicking on Internal Anatomy from the main menu of V-Frog. Participants will be asked to go through the lesson according to their own pace and to complete the lab report while doing so. However, participants will be informed that the teacher/researcher will provide technical support if needed. After completing Internal Anatomy, participants will be asked to proceed to Digestive System and lastly to Circulatory System.
6. Collection of lab report – Lab report will be collected from the participants who have finished the lesson. The computer software program will be closed.

7. Posttest and Answer Sheet – The participants will be given the posttest question paper and the answer sheet immediately after the learning session.

8. Identification Information – The teacher/researcher will ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the answer sheet and question paper.

9. Administration of Posttest – Participants will be given 30 minutes to complete the posttest.

10. Collection of Question Paper and Answer Sheet – The teacher/researcher needs to ensure the number of answer sheets and question papers tally with the number of participants present.

11. Final Questionnaire – Participants will be given the final questionnaire to answer and submit to the teacher.
Appendix B

Data Collection Procedures for Non-VR Mode
(Actual Study)
Data Collection Procedures (Non-VR Mode)

Two weeks before the treatment

The students answer the pretest, spatial ability test and initial questionnaire.

First Part
Directions:

1. Introduction – The teacher will put the participants at ease by briefly explaining the purpose of the test.
2. Spatial Ability Test and Answer Sheet – The participants will be given the spatial ability test question paper and answer sheet.
3. Identification Information – The teacher must ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the answer sheet and question paper.
4. Administration of the Spatial Ability Test – The teacher will say:
   “Please refer to the spatial ability test. This test consists of 75 questions. You are given 3 minutes to go through the examples of the type of questions being asked in this test. Please read the instructions on what you should do in order to answer each question. Show your choice of answer by marking your answer on the answer sheet provided. You are given 10 minutes for this test. Work as rapidly and as accurately as you can.”
5. Collection of Question Paper and Answer Sheets – The teacher needs to ensure the number of answer sheets and question papers tally with the number of participants present.

Second Part
Directions

1. Introduction – The teacher will put the participants at ease by briefly explaining the purpose of the test.
2. Pretest and Answer Sheets – The participants will be given the pretest question paper and answer sheet.
3. Identification Information – The teacher must ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the answer sheet and question paper.
4. Administration of Pretest – The teacher will say:
   “Please refer to the pretest. This test consists of three parts. You are given 30 minutes to complete the test. For each Part, please read the instructions carefully before answering the questions.”
5. Collection of Question Paper and Answer Sheet – The teacher needs to ensure the number of answer sheets and question papers tally with the number of participants present.
Third Part
Directions

1. Introduction – The teacher will put the participants at ease by briefly explaining the purpose of the initial questionnaire.
2. Initial Questionnaire – The participants will be given the initial questionnaire.
3. Identification Information – The teacher must ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the questionnaire.
4. Administration of the Questionnaire – The participants complete the questionnaire and submit to their teacher. Participants are advised to read the instructions carefully before answering.

During the Treatment

The computer, projector and screen are ensured to be properly set-up for learning with PowerPoint presentation.

Directions:

1. Introduction – The teacher will put the participants at ease and explain the purpose of this lesson, the topics involved, and the time (about 1.5 hours) taken to complete the lesson.
2. Learning Session – The teacher will conduct the lesson by using PowerPoint slides for the topics of Internal Anatomy, Digestive System and Circulatory System.
3. Posttest and Answer Sheet - The participants will be given the posttest question paper and answer sheet immediately after the learning session.
4. Identification Information – The teacher will ensure each participant fills in his or her identification information, that is, the participant’s last four digits of their Identity Card Number and their home address number on the answer sheet and question paper.
5. Administration of Posttest – Participants will be given 30 minutes to complete the posttest.
6. Collection of Question Papers and Answer Sheets – The teacher needs to ensure the number of answer sheets and question papers tally with the number of participants present.
7. Final Questionnaire – Participants will be given the final questionnaire to answer and submit to their teacher.
Appendix C

Pretest/Posttest
(Actual Study)
Please write down:

i. The last four digits of your Identification Card Number: ___________

ii. Your home address number: ___________

Instruction: The test is about the anatomy of the frog. Answer all questions in Part A, Part B and Part C. Please write down all answers on the Answer Sheet provided.

Part A: Fill in the blank with the correct word or words.

(liver, gall bladder, right, coelum, truncus arteriosis, stomach, oxygenated, left, pulmonary veins, duodenum, small intestine, spleen, veins)

1. The organ that is the first major site of chemical digestion is the ________ .

2. The body cavity where the internal organs are located is called the __________.

3. Deoxygenated blood from all parts of the body enters the heart through the ______________ atrium.

4. The __________________ connects the ventricle to the pulmonary arteries to carry deoxygenated blood away from the heart.

5. __________________ are blood vessels that always carry blood to the heart.

6. ___________________ blood leaves the heart and travels through the rest of the frog’s body.

7. The first part of the small intestine is the __________________________ .

8. The organ found under the liver which stores bile is the ________________ .

9. The largest organ in the body cavity is the _______________________.

10. The organ that functions as an emergency storage area for red blood cells is the ___________________________.

11. The ___________________ carry oxygenated blood from the lungs to the heart.

12. The esophagus leads to the ____________________________ .
13. Oxygenated blood from the lungs enter the heart through the __________ atrium.

**Part B:**

1. On the diagram below, label the following organs of the frog internal anatomy:

   esophagus  cloaca  duodenum  ileum  jejunum

![](image)

Figure 1  The internal organs
2. **Draw and label** (i) pancreas and (ii) gall bladder at the correct position on the diagram below.

![Figure 2](image)

3. Identify the following items on the drawing below:

   truncus arteriosus  ventricle  left atrium  sinus venosus

![Figure 3](image)  The heart, dorsal view (view from the back side)
Part C: Choose the correct answer from the four alternatives (either A, B, C or D) below. Figure 4 and Figure 5 are on the last page (p. 5). Please refer to Figure 4 for Questions 1 to 5, and Figure 5 for Questions 6 to 8.

1. In Figure 4, “G” belongs to what system?
   A. digestive
   B. urogenital
   C. circulatory
   D. respiratory

2. In Figure 4, the letter “H” indicates the
   A. spleen
   B. stomach
   C. duodenum
   D. gall bladder

3. In Figure 4, the letter “I” indicates the
   A. pancreas
   B. kidney
   C. spleen
   D. gall bladder

4. In Figure 4, the letter “J” indicates the
   A. liver
   B. duodenum
   C. spleen
   D. colon

5. In Figure 4, which of the following functions as a blood storage organ associated with the immune system?
   A. G
   B. H
   C. I
   D. J

6. In Figure 5, the letter “P” indicates the
   A. right atrium
   B. left atrium
   C. ventricle
   D. pulmonary artery
7. In Figure 5, the function of “P” is
   A. to cleanse blood
   B. to receive blood from the pulmonary arteries
   C. to produce red blood cells
   D. to receive blood from the sinus venosus

8. Which description best describes structure “Q” in Figure 5?
   A. site of gas exchange when the frog is breathing air
   B. last chamber to contract during a heart beat
   C. receives blood from arteries
   D. receives blood from veins
Figure 4 – for Questions 1, 2, 3, 4 & 5

Figure 5 – The heart, ventral view (view from the front) – for Questions 6, 7 & 8

END OF QUESTION PAPER
Appendix D

Initial Questionnaire
(Actual Study)
Dear student:

This questionnaire is designed to investigate your learning styles and consists of two parts:

Part A: Background Information
Part B: Learning Styles

Completion of the questionnaires is entirely voluntary and you can decide not to participate at any time. All information given during the survey is confidential, no names or other information that might identify individuals will be obtained.

If you have any questions about this project please feel free to contact me (Elinda Lee, elinda.lee@murdoch.edu.au, Malaysia Mobile: +60128836361, Australia Mobile: +614 16713138), or my supervisors (Associate Professor Dr Kevin Wong, k.wong@murdoch.edu.au, +618 93606100). If you wish to talk to an independent person about your concerns, you can contact Murdoch University’s Human Research Ethics Committee on +618 9360 6677 or email ethics@murdoch.edu.au.
Please write down:

1) The last four digits of your Identification Card Number: __________________

2) Your home address number: ________________

**PART A. Background Information**

This portion is aimed to gather your background information. Unless specified in the question, please select and tick (✓) **only one appropriate** answer for each of the following questions.

A1. Please write down your age: __________________

A2. What is your gender?

☐ Male  ☐ Female

A3. What is your ethnic group?

☐ Malay

☐ Chinese

☐ Indian

☐ Others, please specify: ________________________

**PART B. Learning Styles**

Kolb Learning Style Inventory Version 3.1

Appendix E

Final Questionnaire for VR Mode
(Actual Study)
Dear student:

This questionnaire is designed to investigate your acceptance, learning processes and outcomes of using this type of computer software program for learning. It is a virtual reality software program. Virtual reality is an interactive three-dimension computer generated program in a multimedia environment which is implemented on a conventional personal computer.

This questionnaire consists of seven parts:

- Part A: Background Information
- Part B: Acceptance of the Computer Program
- Part C: Learning Process
- Part D: Features of the Computer Program
- Part E: Perceived Learning with the Computer Program
- Part F: Satisfaction with the Computer Program
- Part G: Suggestions and Comments

Completion of the questionnaire is entirely voluntary and you can decide not to participate at any time. All information given during the survey is confidential, and no names or other information that might identify individuals will be obtained.

If you have any questions about this project please feel free to contact me (Elinda Lee, elinda.lee@murdoch.edu.au, Malaysia Mobile: +60128836361, Australia Mobile: +614 16713138,) or my supervisor (Associate Professor Dr Kevin Wong, k.wong@murdoch.edu.au, +618 93606100.) If you wish to talk to an independent person about your concerns, you can contact Murdoch University’s Human Research Ethics Committee on +618 9360 6677 or email ethics@murdoch.edu.au.
Please write down:

1) The last four digits of your Identification Card Number: ________________

2) Your home address number: ________________

**PART A. Background Information**

This portion is aimed to gather your background information. Unless specified in the question, please select and tick (✓) only one appropriate answer for each of the following questions.

1. Do you have a computer at home?
   
   Yes ______ No ______

2. How often do you use computers at home or at school?
   
   Always _____ Frequently _____ Sometimes _____
   Seldom _____ Never _____

3. In what way do you use computers at home or at school? (Tick (✓) all appropriate answers)
   
   Word processing _____ Drill-and-practice _____ Internet _____
   Electronic mail _____ Games _____
   Others, please specify: ________________________________

4. Did you know about “virtual reality” before taking this lesson?
   
   I knew nothing about virtual reality. _____
   I had some knowledge about virtual reality. _____
   I had lots of knowledge about virtual reality. _____
   I had some experiences with virtual reality computer programs. _____

5. Would you like to use virtual reality programs in other school subjects?
   
   Yes ______ No ______

   If yes, in which school subjects would you like to use virtual reality support?
   
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________
PART B. Acceptance of the Computer Program

This portion relates to your acceptance of the computer program for learning. Please circle only one answer for each of the following questions that best describes your opinion.

1. Using this type of computer program as a tool for learning in classroom increases/will increase my learning and academic performance.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

2. Using this type of computer program enhances/will enhance the effectiveness on my learning.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

3. This type of computer program allows/will allow me to progress at my own pace. (I can use as much time as needed to practice and master the skills required).
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

4. This type of computer program is useful in supporting my learning.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

5. Learning to operate this type of computer program is easy for me.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

6. Learning how to use this type of computer program in classes is too complicated and difficult for me.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

7. It is easy for me to find information with the computer program.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

8. Overall, I think this type of computer program is easy to use.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

PART C. Learning Processes

This portion relates to the aspects of learning processes while using this type of computer program for learning. Please circle only one answer for each of the following questions that best describes your opinion.

1. I enjoyed this type of computer program very much.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree
2. I think I am pretty good at this type of computer program.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

3. I put a lot of effort into this type of computer-based learning environment.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

4. It was important for me to do well at this type of computer program.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

5. Learning with this type of computer program was fun.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

6. I would describe this type of computer program as very interesting.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

7. I was satisfied with my performance in this type of computer-based learning environment.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

8. I felt pressured while learning with this type of computer program.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

9. I didn’t try very hard while learning with this type of computer program.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

10. While learning with this type of computer program, I was thinking about how much I enjoyed it.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

11. After trying this type of computer program for a while, I felt pretty competent.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

12. I was very relaxed while learning with this type of computer program.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

13. I am pretty skilled at this type of computer program.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree
14. This type of computer program did not hold my attention.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

15. I couldn’t learn much using this type of computer program.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

16. This type of computer program makes the comprehension easier.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

17. This type of computer program makes the memorization easier.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

18. This type of computer program helps me to better apply what is learned.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

19. This type of computer program helps me to better analyze the problem.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

20. This type of computer program helps me to have a better overview of the content learned.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

21. This type of computer program allows me to be more responsive and active in the learning process.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

22. This type of computer program allows me to have more control over my own learning.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

23. This type of computer program promotes self-paced learning (can easily repeat learning steps and processes as many times as required)

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

24. This type of computer program helps to get myself engaged in the learning activity.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>

25. I was able to reflect on how I learn.

<table>
<thead>
<tr>
<th>1 Strongly Disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly Agree</th>
</tr>
</thead>
</table>
26. I was able to link new knowledge with my previous knowledge and experiences.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

27. I was able to become a better learner.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

28. I was able to reflect on my own understanding.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

29. There is a sense of presence (being there) while learning with this type of computer program.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

### PART D. Features of the Computer Program

This portion investigates your opinions about the features of this type of computer program. Please circle **only one answer** for each of the following questions that best describes your opinion.

1. The realism of the three-dimensional (3-D) images in this type of computer program motivates me to learn.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

2. The smooth changes of images in this type of computer program make learning more motivating and interesting.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

3. The realism of the 3-D images in this type of computer program helps to enhance my understanding.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

4. The ability to change the view position of the 3-D objects in this type of computer program allows me to learn better.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

5. The ability to change the view position of the 3-D objects in this type of computer program makes learning more motivating and interesting.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

6. The ability to manipulate the objects (eg: pick up, cut, change the size) within the virtual environment makes learning more motivating and interesting.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree
7. The ability to manipulate the objects in real time helps to enhance my understanding.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

**PART E. Perceived Learning Effectiveness with the Computer Program**

This portion investigates your perception on learning with this type of computer program. Please circle **only one answer** for each of the following questions that best describes your opinion.

1. I was more interested to learn the topics.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

2. I learned a lot of factual information in the topics.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

3. I gained a good understanding of the basic concepts of the materials.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

4. I learned to identify the main and important issues of the topics.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

5. I was interested and stimulated to learn more.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

6. I was able to summarize and conclude what I learned.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

7. The learning activities were meaningful.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree

8. What I learned, I can apply in real context.

1 Strongly Disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly Agree
PART F. Satisfaction with the Computer Program

This portion investigates your satisfaction with this type of computer program for learning. Please circle **only one answer** for each of the following questions that best describes your opinion.

1. I was satisfied with this type of computer-based learning experience.
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

2. A wide variety of learning materials was provided in this type of computer-based learning environment.
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

3. I don’t think this type of computer-based learning environment would benefit my learning achievement.
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

4. I was satisfied with the immediate information gained in this type of computer-based learning environment.
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

5. I was satisfied with the teaching methods in this type of computer-based learning environment.
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

6. I was satisfied with this type of computer-based learning environment.
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

7. I was satisfied with the overall learning effectiveness.
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

PART G. Suggestions and Comments

1. In what ways do you think this type of computer program is effective as an educational tool?

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

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2. Do you have any other comments on the use of this type of computer program for learning?

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

Thank you for your participation. Your contribution to this survey is greatly appreciated.

Do you want to receive a summary of this report by email?
If Yes, please supply your email address: _______________________________
Alternatively, you may contact me at the given email address below.
elinda.lee@murdoch.edu.au
Appendix F

Final Questionnaire for
Non-VR Mode
(Actual Study)
Dear student:

This questionnaire is designed to investigate the learning outcomes of using the conventional classroom learning method for learning. This questionnaire consists of three parts:

- Part A: Background Information
- Part B: Perceived Learning Effectiveness with the Conventional Classroom Learning Method
- Part C: Satisfaction with the Conventional Classroom Learning Method

Completion of the questionnaire is entirely voluntary and you can decide not to participate at any time. All information given during the survey is confidential, no names or other information that might identify individuals will be obtained.

If you have any questions about this project please feel free to contact me (Elinda Lee, elinda.lee@murdoch.edu.au, Malaysia Mobile: +60128836361, Australia Mobile: +614 16713138), or my supervisors (Associate Professor Kevin Wong, k.wong@murdoch.edu.au, +618 93606100). If you wish to talk to an independent person about your concerns, you can contact Murdoch University’s Human Research Ethics Committee on +618 9360 6677 or email ethics@murdoch.edu.au.
Please write down:

1) The last four digits of your Identification Card Number: __________________

2) Your home address number: ________________

**PART A. Background Information**

This portion is aimed to gather your background information. Unless specified in the question, please select and tick (✓) **only one appropriate** answer for each of the following questions.

A1. Do you have a computer at home?
   
   Yes ______ No ______

A2. How often do you use computers at home or at school?
   
   Always ____ Frequently ____ Sometimes ____
   Seldom ____ Never ____

A3. In what way do you use computers at home or at school? (Tick ✓ all appropriate answers)
   
   Word processing _____ Drill-and-practice _____ Internet _____
   Electronic mail _____ Games _____
   Others, please specify: ________________________________

**PART B. Perceived Learning Effectiveness with the Conventional Classroom Learning Method**

This portion investigates your perception on learning with this type of conventional classroom learning method. Please circle **only one answer** for each of the following questions that best describes your opinion.

1. I was more interested to learn the topics.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

2. I learned a lot of factual information in the topics.
   
   1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree
3. I gained a good understanding of the basic concepts of the materials.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

4. I learned to identify the main and important issues of the topics.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

5. I was interested and stimulated to learn more.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

6. I was able to summarize and conclude what I learned.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

7. The learning activities are meaningful.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

8. What I learned, I can apply in real context.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

**PART C. Satisfaction with the Conventional Classroom Learning Method**

This portion investigates your satisfaction with this type of conventional classroom learning method. Please circle **only one answer** for each of the following questions that best describes your opinion.

1. I was satisfied with this type of conventional classroom learning experience.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

2. A wide variety of learning materials was provided in this type of conventional classroom learning environment.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

3. I don’t think this type of conventional classroom learning method would benefit my learning achievement.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

4. I was satisfied with the immediate information gained in this type of conventional classroom learning environment.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree
5. I was satisfied with the teaching methods in this type of conventional classroom learning environment.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

6. I was satisfied with this type of conventional classroom learning environment.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

7. I was satisfied with the overall learning effectiveness.

1 Strongly Disagree  2 Disagree  3 Neutral  4 Agree  5 Strongly Agree

______________________________

**Thank you for your participation. Your contribution to this survey is greatly appreciated.**

Do you want to receive a summary of this report by email?

If Yes, please supply your email address: _______________________________

Alternatively, you may contact me at the given email address below.

elinda.lee@murdoch.edu.au
Appendix G

Posttest Item Analyses
(Pilot Test)
Item Discrimination Index and Difficulty Index for Each Item

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<th>Item</th>
<th>Group</th>
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<th>Proportion of Correct Responses</th>
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Appendix H

Latent Mean Testing
Chi-square = 205.443  
df = 116  
p = .000  
Ratio = 1.771  
CFI = .949  
RMSEA = .061

Notes: 
REP = Presentational fidelity; IMM = Immediacy of control; USE = Perceived usefulness, EASE = Ease of use; PRES = Presence; MOT = Motivation; COG = Cognitive benefits; CONT = Control and active learning; REF = Reflective thinking; PERF = Performance achievement; PERC = Perceived learning effectiveness; SAT = Satisfaction

**Figure I.1:** Latent mean testing across high and low spatial ability groups
Chi-square = 210.235
df = 116
p = .000
Ratio = 1.812
CFI = .947
RMSEA = .063

Notes:
REP = Presentational fidelity; IMM = Immediacy of control; USE = Perceived usefulness, EASE = Ease of use; PRES = Presence; MOT = Motivation; COG = Cognitive benefits; CONT = Control and active learning; REF = Reflective thinking; PERF = Performance achievement; PERC = Perceived learning effectiveness; SAT = Satisfaction

Figure 1.2: Latent mean testing across accommodator and assimilator groups
References


Sweller, J. (1999). *Instructional design in technical areas*: Camberwell, Australia: ACER.


