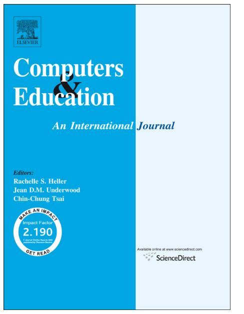
**Lee, E.A-L., Wong, K.W. and Fung, C.C. (2010) *How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach.* Computers and Education, 55 (4). pp. 1424-1442.**

# Accepted Manuscript




Title: How Does Desktop Virtual Reality Enhance Learning Outcomes? A Structural Equation Modeling Approach

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PII: S0360-1315(10)00166-1

DOI: 10.1016/j.compedu.2010.06.006

Reference: CAE 1664

To appear in: *Computers & Education*

Received Date: 15 December 2009

Revised Date: 5 May 2010

Accepted Date: 14 June 2010

Please cite this article as: Ai-Lim Lee, E., Wong, K.W., Fung, C.C. How Does Desktop Virtual Reality Enhance Learning Outcomes? A Structural Equation Modeling Approach, Computers & Education (2010), doi: 10.1016/j.compedu.2010.06.006

# HOW DOES DESKTOP VIRTUAL REALITY ENHANCE LEARNING OUTCOMES? A STRUCTURAL EQUATION MODELING APPROACH

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# HOW DOES DESKTOP VIRTUAL REALITY ENHANCE LEARNING OUTCOMES? A STRUCTURAL EQUATION MODELING APPROACH

**Abstract**

This study examined how desktop virtual reality (VR) enhances learning and not merely does desktop VR influence learning. Various relevant constructs and their measurement factors were identified to examine how desktop VR enhances learning and the fit of the hypothesized model was analyzed using structural equation modeling. The results supported the indirect effect of VR features to the learning outcomes, which was mediated by the interaction experience and the learning experience. 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 desktop VR-based learning environment. The moderating effect of student characteristics such as spatial ability and learning style was also examined. The results show instructional designers and VR software developers how to improve the learning effectiveness and further strengthen their desktop VR-based learning implementation. Through this research, an initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment is contributed.

Keywords: desktop VR-based learning environment, VR features, interaction experience, learning experience, learning outcomes

## 1. Introduction

Desktop VR has begun to gain its way and popularity in modern education because of its ability to provide real time visualization and interaction within a virtual world that closely resembles a real world (Chuah, Chen, & Teh, 2008; Inoue, 2007; Lee & Wong, 2008; Strangman & Hall, 2003). Moreover, a rapid and drastic fall in prices, a huge leap in the computer processing power, the proliferation of World Wide Web and the prevalence of broadband connections have aggravated the use of desktop VR in schools and colleges (Lee, Wong, & Fung, 2009a; McArdle, Monahan, & Mangina, 2004; McLellan, 2004). Therefore, today's VR systems can run on a relatively cheap system such as desktop personal computer. Such VR system is commonly known as desktop VR where user can interact with the virtual environment using keyboard, mouse, joystick or touch screen**.** Further, 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).

Desktop 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, Park, Lee, Yuk, & Lee, 2001). Constructivist learning model has been proposed by Reigeluth (1999). It is a philosophy of learning that believes knowledge is constructed by learners through experience and activity (Jonassen, Peck, & Wilson, 1999; Martens, Bastiaens, & Kirschner, 2007; Reigeluth, 1999). Constructivist learning is student-centric and focuses on meeting the learners' needs and helping them to construct and build on their own knowledge based on their prior experiences and knowledge (Mergel, 1998; Roblyer, 2003). Learners are active, able to control their learning pace and responsible for their learning. Chen and Teh (2000) have pointed out how the various technical capabilities of VR technology can support constructivist learning principles, which are congruent with the constructivist educational design principles by Dalgarno (1998). The constructivist learning principles focus on active learning and learner control over content, sequence and learning strategy to construct own knowledge;

authentic, contextual and discovery activity to encourage diverse ways of thinking; and interesting, appealing and engaging problem representation to provide intrinsic motivation.

Though VR could support constructivist learning and research has shown a positive array of learning outcomes with desktop virtual reality, for instance, better learning in geosciences (Li et al., 2002); better understanding in physic concepts (Kim et al., 2001); and positive effect on learning driving rules and regulations (Chen 2006), there is still a lack of research that addresses the issue of “How can desktop VR technology enhance learning outcomes” rather than just “Does desktop VR technology influence learning outcomes?” If desktop VR technology is to be used to support meaningful learning, then there is a need to examine the relevant constructs and their relationships that help to achieve this goal. To investigate how the attribute of desktop VR technology is able to support and enhance learning, the pedagogical benefits of VR as a learning tool need to be examined in a more comprehensive way. A broad framework that identifies the theoretical constructs and their relationships in this domain has yet to be developed for a desktop VR-based learning environment that supports constructivist learning model. Relevant constructs such as VR features, 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). Strangman & Hall (2003) also mention factors that influence computer simulations have not been extensively or systematically examined. Furthermore, there is a lack of greater-depth research in desktop VR-based learning that investigates the influence of psychological factors on learning outcomes. There are not many studies that explore and explain the effects of desktop VR in terms of theoretical prospective and models (Ausburn & Ausburn, 2008). Indeed, there have been limited attempts to introduce theoretical framework and models that considers 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.

For parsimony and feasibility of practice, this study intends to identify the relevant constructs and their relationships that play an important role in a desktop VR-based learning environment that supports constructivist learning principles. By understanding how these constructs work together to shape learning, we will be better to target learning and visualization problems with the appropriate affordances and to maximize the benefits of VR technology (Salzman et al., 1999, p. 42). The results will show instructional designers and VR software developer how to improve the learning effectiveness and further strengthen their desktop VR-based learning implementation. In other words, the findings will present guidelines for desktop VR-based learning development. Furthermore, academia can use the findings of this study as a basis to initiate other related studies in the desktop VR-based learning area. Through this research, a broad framework that identifies the relevant constructs and their relationships for a desktop VR-based learning environment is developed. Subsequently, an initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment is contributed.

## 2. Conceptual Background

Fig. 1 illustrates the conceptual framework of the outcomes and their causal relationships in a desktop VR-based learning environment. In this framework, VR features influence learning outcomes indirectly through the mediation of usability and psychological factors of learning experience such as presence, motivation, cognitive benefits, control and active learning, and reflective thinking. The model for immersive VR-based learning developed by Salzman et al. (1999) provides a starting point for this framework and is supported by the technology mediated learning models of Alavi and Leidner (2001); Piccolli, Ahmad, & Ives (2001); Benbunan-Fich and Hiltz (2003), Sharda et al. (2004) and Wan, Fang, & Neufeld (2007). The model of Salzman et al. (1999) describes the importance of scrutinizing how VR features work together with other factors such as the concept that is to be learned, 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). VR features influence not only learning, but the quality of the interaction experience and learning experience as well.

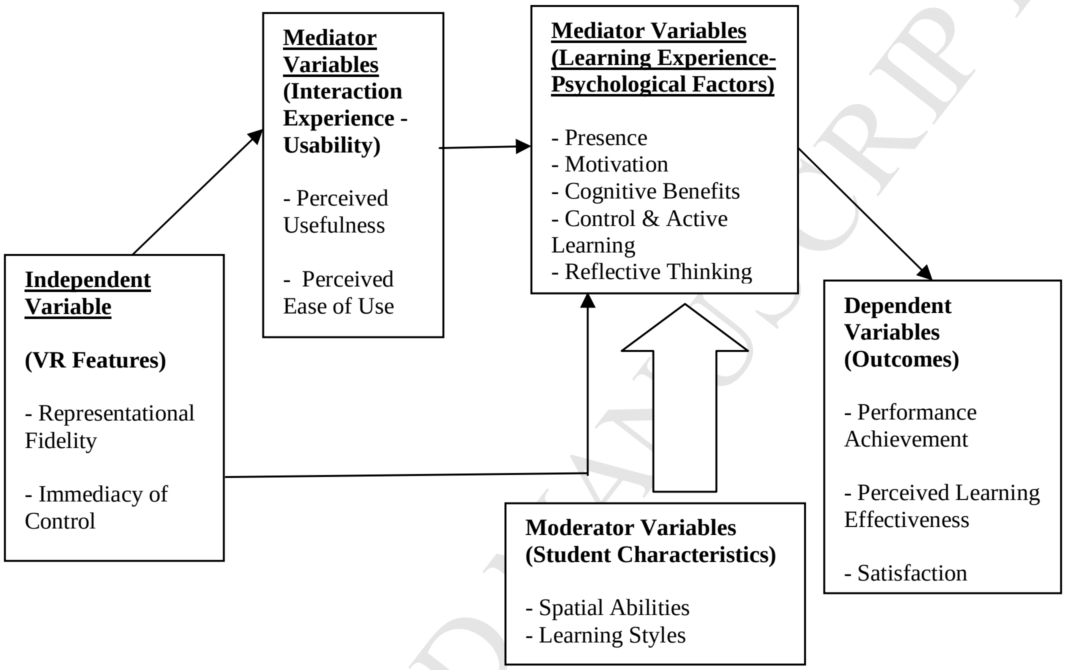



**Fig. 1. Conceptual framework of the outcomes and their causal relationships in a desktop VR-based learning environment**

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 the use of VR in web-based learning is proliferating, for instance, in studies of Li et al. (2002), Ong & Mannan (2004), Song & Lee (2002), Sharda et al. (2004), Kim et al (2001), Creddy et al (2007), and Monahan, McArdle & Bertolotto (2008). Thus, technology-mediated learning model could help to shed some light on the learning effectiveness with VR technology. More application of VR in web-based learning is expected with the emergence of Virtual Reality Modeling Language (VRML) and eXtensible 3D Graphic (X3D) to generate three-dimensional (3-D) interactive graphical representations that can be delivered over the web. Alavi and Leidner (2001, p. 2) define technology mediated learning as an environment in which 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 level 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 learners' interaction with learning content is mediated by the VR technology. Hence, technology mediated learning model is appropriate for this study.

**Table 1**
**Comparison between immersive VR theoretical Model by Salzman et al. (1999) and technology mediated models**

| Articles | Technology Features | Interaction Experience | Learning Experience | Participant Dimension | Learning Outcomes |
|---|---|---|---|---|---|
| Salzman et al. (1999) | x | x | x | x | x |
| Alavi and Leidner (2001) | x | | x | | x |
| Picolli et al. (2001) | | x | | x | x |
| Benbunan-Fich and Hilz (2003) | | x | x | x | x |
| Sharda et al. (2004) | x | x | | x | x |
| Wan et al. (2007) | x | x | x | x | x |

**Table 2**
**Related references about the factors relevant to desktop VR-based learning**

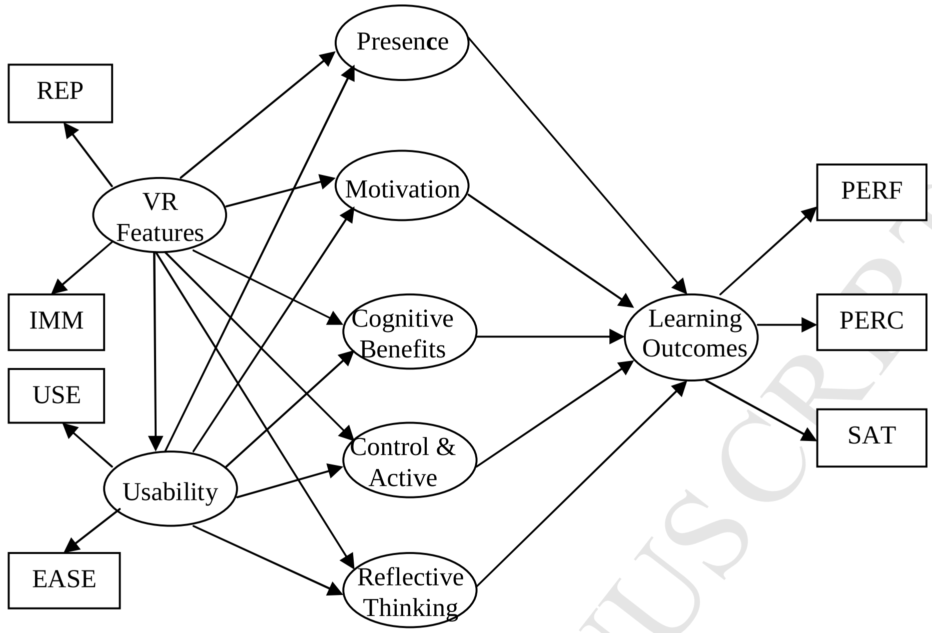
| Authors | Factors |
|---|---|
| Salzman et al. (1999) | VR features, ease of use, motivation, immersion, spatial ability, gender, computer experience |
| Picolli et al. (2001) | Maturity, motivation, previous experience, constructivist, technology quality and reliability, learner control |
| Benbunan-Fich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

The theoretical model of immersive VR-based learning by Salzman et al. (1999) and the theoretical framework for technology-mediated learning cover three main components: input, process and output. Most frameworks emphasize on the relevant independent variables such as technology factor and student characteristics, the mediating process such as psychological learning experience, and finally the output such as learning outcomes. It is noted that some technology-mediated models illustrate technology factor in terms of technology features while others illustrate in terms of quality and accessibility which is analogous to 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. Table 1 presents a summary of the comparison between the model of Salzman et al. (1999) and other technology mediated learning models. A summary of the literature relevant to the factors vital to the activities of desktop VR-based learning and could affect the learning outcomes is presented in Table 2.

In short, a greater depth of research in using technology is emphasized in which the mediating process is highlighted to understand how technology enhances learning, instead of merely knowing does technology influence learning. With such, a conceptual framework that based on an input, process and output metaphor that emphasizes on the psychology learning factors is developed to guide the research design for evaluating how desktop VR enhances learning as shown in Fig. 1. The input factors that could affect the learning process, which in turn would affect the learning outcomes are VR technology and student characteristics. VR technology is assessed in terms of its features and usability (quality and accessibility). The VR features such as representational fidelity and immediacy of control are the independent variables while student characteristics such as spatial ability and learning style are the moderator variables which would strengthen or weaken the relationships between variables. However, usability is an independent as well as a dependent variable which represents the interaction experience in the desktop VR-based learning environment. As for the process, the internal psychological learning experience such as presence, motivation, cognitive benefits, control and active learning and reflective thinking 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. According to Yaman, Nerdel & Bayhuber (2008), the impact of learner's psychological perspective on its learning effects has hardly been studied in computer simulation-based learning. Finally, the effectiveness of desktop VR-based learning is measured in terms of cognitive domain through performance achievement and affective domain through students' perceived learning effectiveness and satisfaction in using desktop VR for learning. This conceptual framework does not emphasize the direct influence of VR features to the learning outcomes, but emphasizes on the indirect effect through mediating factors such as interaction experience and learning experience as supported by the model of Salzman et al (1999) and the technology-mediated models.

## 3. Research Model

Based on the conceptual framework, a research model is developed for evaluating how VR enhances learning as shown in Fig. 2. The fit of the hypothesized model is assessed using structural equation modeling (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 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 could help make an opaque construct (i.e., all psychological factors are 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 their measurement variables are described as follows.




Notes: REP = Presentational fidelity; IMM = Immediacy of control; USE = Perceived usefulness; EASE = Perceived ease of use; PERF = Performance achievement, PERC = Perceived learning Effectiveness; SAT = Satisfaction

**Fig. 2. Research model**

### 3.1 VR features

Research has shown that technology features could influence learning outcomes (Alavi & Leidner, 2001; Salzman et al., 1999; Sharda et al., 2004; Wan et al. 2007). In this study, it is hypothesized that VR features have an indirect effect on the learning outcomes which are mediated by the interaction experience and learning experience. In other words, the qualities of the medium are regarded as determinants of 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 and 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 and immediacy of control.

Representational fidelity is the degree of realism provided by the rendered 3D 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, Hedberg, & Harper, 2002). In short, representational fidelity (scene realism) 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).

### 3.2 Usability

Based on the model of Salzman et al. (1999), VR features are the antecedents to interaction experience which covers the construct of usability. Two aspects of usability are emphasized in this study, the quality and accessibility. The issue that learning outcomes depends on the quality and accessibility of the technology used is highlighted in the model of Salzman et al (1999) and the model of technology mediated learning (Benbunan-Fich & Hiltz, 2003; Piccoli et al. 2001; Sharda et al., 2004; Wan et al., 2007). The quality aspect is assessed through the perceived usefulness while the accessibility aspect is assessed through the perceived ease of use.

Davis (1989) theorizes the widely accepted Technology Acceptance Model (TAM) that posited two beliefs – perceived usefulness and perceived ease of use 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. 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 deems 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 content (Dalgarno et al., 2002).

### 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. According to Dalgarno et al. (2002), the sense of presence in a 3D 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) mentions 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 processes of the users in a virtual environment determine the extent to which they will be compelled by what they see, hear and feel and thus become immersed into the virtual world (Usoh, Alberto, & Slater, 1996). Furthermore, it may influence the learning outcomes of an individual (Salzman et al., 1999).

Generally, the more immersive a virtual environment is, the greater sense of presence users tend to experience in it (Schuemie, Van Der Straaten, Krijin, & Van Der Mast, 2001). However, recently, there was a debate that the low-immersion systems such desktop VR are capable of providing high-presence experience to users (Nunez, 2004).

### 3.4 Motivation

This psychological factor has found to have effect on learning effectiveness by many researchers (Alavi & Leidner, 2001; Benbunan-Fich & Hiltz, 2003; Piccoli et al., 2001; Salzman et al., 1999; Wan et al., 2007). Student motivation is a potentially important but understudied factor in virtual reality-based learning environment. According to Rezabek (1995), motivation study has long been neglected in instructional technology. This is supported by Yaman, Nerdel & Bayrhuber (2008) 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.

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 (e.g. rewards) (Deci & Ryan, 2000). To maintain those behaviors, they require satisfaction of basic psychological needs such as autonomy and competence (Deci & Ryan, 2000).

One of the assumptions of the currently accepted social cognitive motivational theories is that motivational is situated and contextualized (Linnenbrink & Pintrich, 2002). It is not an individual's stable trait but 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, and 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).

### 3.5 Cognitive Benefits

Antonietti, Rasi, Imperio, & Sacco (2000) have 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 level of Bloom's taxonomy, memorization is synonym to the knowledge level which emphasizes on 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) asserts 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 VR-based learning environment, students have the freedom to explore, and view the environment from any vantage point desired." Thus, the VR-based learning environment allows students to analyze their problems and evaluate possible alternatives in ways that are 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 & Riempp, 2004).

### 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 degrees of learner control are important in a learning process. This is because students may better learn how to learn through making instructional choices and may feel more motivated to learn, which lead to better performance (Kinzie, Sullivan, & Berdel, 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 a total internal control by the learners, learners can better learn how to learn because they make their own instructional decisions, experience and responsible for the consequences and results of those decisions, and in the process discover the best tactics for different situation (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).

Research has found that computer-simulated experiments permit more student active involvement in the learning process and thus lead to more understanding of science concepts (Choi & Gennaro, 1987; Rivers & Vockell, 1987; Yang & Heh, 2007). This is in agreement with the principle of constructivist that the more opportunity of active learning, the more positive results the students would gain (Roblyer, 2003; Yang & Heh, 2007).

### 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 desktop VR-based environments is relatively 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 lead to a new understanding (Fitzpatrick, 2008). 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 includes: 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 in which people are aware of why 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 to construct new knowledge is aligned with 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 if VR-based learning environment engages learners in some forms of reflective thinking such as understanding and reflection advocated by Mezirow (1991, 1998) that promote deep learning, which is consistent with the constructivist approach of learning. In addition, to determine if reflective thinking leads to greater perceived learning effectiveness and satisfaction.

### 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) classify learning outcomes into three groups: psychomotor outcomes, cognitive outcomes, and affective outcomes. Psychomotor outcomes include efficiency, accuracy, and response magnitude. Cognitive outcomes include comprehension, knowledge, application and analysis. Affective outcomes include students' perception of satisfaction, attitude, and appreciation for the learning experience (Sharda et al., 2004). Indeed, research suggests that technology-mediated learning environments may improve students' achievement (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 affective domain in terms of perceived learning effectiveness and satisfaction with the desktop VR-based learning environment.

### 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. 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, 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 SpaceScience 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 such as spatial abilities and learning styles was investigated in this study. These student characteristics may serve to moderate the relationship between the learning experience and the learning outcome as advocated by Salzman et al. (1999).

## 4. Research Hypotheses

Based on the hypothesized theoretical model, the following hypotheses were thus developed to answer the research questions of (1) What are the constructs that play an important role in a desktop VR-based learning environment? (2) How do these constructs interrelate to enhance the learning with desktop VR? Fig. 3 represents the hypothesized relationships in the model.

### 4.1 Hypotheses for the relationships between constructs

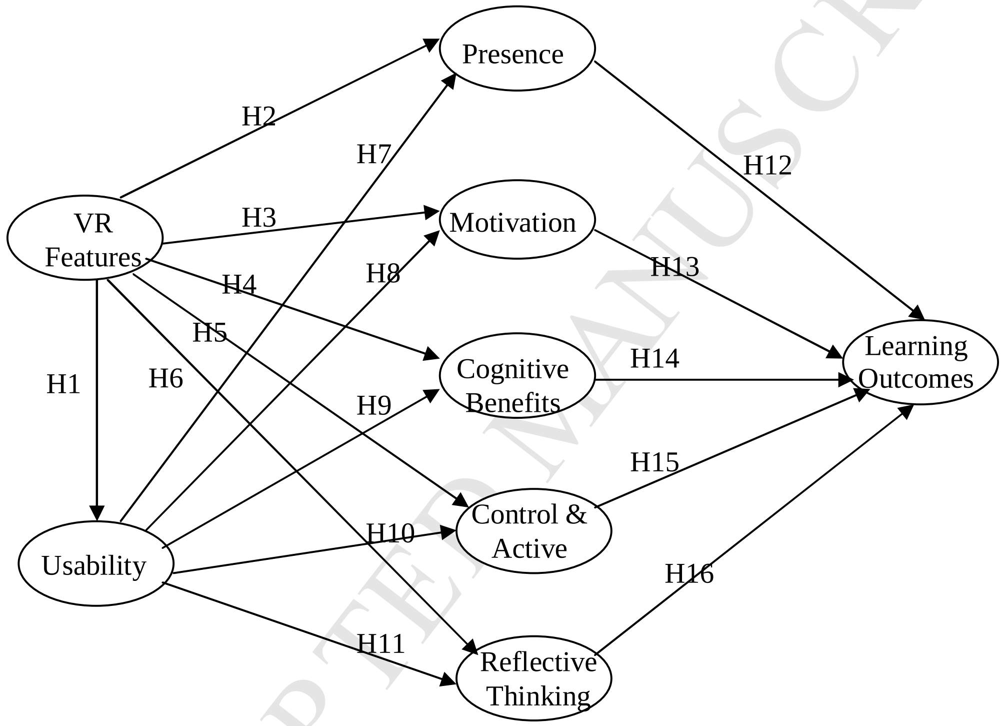



**Fig 3. Hypothesized relationships between constructs**

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 & active learning is positively related to learning outcomes.

H16: Reflective thinking is positively related to learning outcomes

### 4.2 Hypotheses for the moderating effect of student characteristics

$H_{01}$: Spatial ability moderates the influence of presence on learning outcomes.

$H_{02}$: Spatial ability moderates the influence of motivation on learning outcomes.

$H_{03}$: Spatial ability moderates the influence of cognitive benefits on learning outcomes.

$H_{04}$: Spatial ability moderates the influence of control and active learning on learning outcomes.

$H_{05}$: Spatial ability moderates the influence of reflective thinking on learning outcomes.

$H_{06}$: Learning style moderates the influence of presence on learning outcomes.

$H_{07}$: Learning style moderates the influence of motivation on learning outcomes.

$H_{08}$: Learning style moderates the influence of cognitive benefits on learning outcomes.

$H_{09}$: Learning style moderates the influence of control and active learning on learning outcomes.

$H_{10}$: Learning style moderates the influence of reflective thinking on learning outcomes.

## 5. Methodology

### 5.1 Subjects and Procedures

The sample consisted of 232 students from four randomly selected co-education secondary schools in East Malaysia. The sample was senior high science stream students, aged between 15 and 17 years old. They were Form Four students in Malaysian education system. These students were chosen because they have started to learn biology in Form Four. The sample underwent a lesson on frog anatomy with a desktop VR software program, V-Frog™. Two weeks before the treatment with the VR software program, students answered the Kolb Learning Style Inventory, the spatial ability test and the pretest. The detail of the pretest and its results were reported in

Lee, Wong & Fung (2009b). During the treatment, each student was assigned to an individual computer to learn the lesson on frog anatomy that took approximately 1.5 hours to complete. Three modules were selected for this lesson: internal anatomy, digestive system and circulatory system. After the treatment, students sat for the posttest which was submitted immediately after the test and answered a set of questionnaires. After completing the experiment, a few participants from each selected schools were asked to provide additional qualitative feedback during debriefing sessions.

### 5.2 Measurement

Kolb Learning Style Inventory (KLSI) Version 3.1 was used to categorize students' learning style. Each student needs to complete 12 sentences that describe learning. Studies have reported that KLSI Version 3.1 scales show good internal consistency reliability (Kolb & Kolb, 2005). The internal consistency for the scale scores of KLSI Version 3.1 is within the range of 0.52 – 0.84 (Kolb & Kolb, 2005). Based on the method of Chen, Toh & Wan (2005), instead of categorizing into four learning styles: accommodator, assimilator, diverger and converger, a dash diagonal line was introduced to equally separate the grid into two halves as shown in Fig. 4. 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.

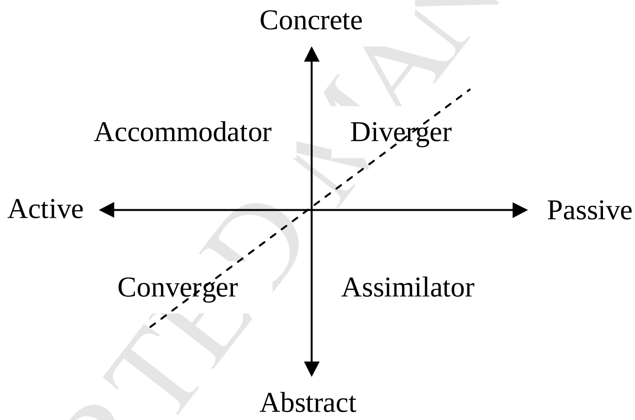



**Fig. 4. Types of Learning Styles (Adapted from Kolb (2007))**

Spatial ability test from Barrett & Williams (2003) was used to test the spatial visualization ability of the students. It consists of 75 patterns that could be folded or formed into figures. The Cronbach's alpha for the spatial ability test from the pilot study was 0.76. One mark was given to each correct answer and zero to incorrect answer. The total mark was then converted to percentage score. The learners were then categorized to high and low spatial groups based on median split.

Posttest was developed to measure the performance achievement of the students. The assessment was based on the modules covered in this study. The posttest questions include: sentence completion with the correct word(s); organs labeling and drawing; and multiple-choice questions. Content validity of the posttest 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. Based on the result of a pilot test with forty-seven students from one co-education school in the same city, six items were deleted in which five were deleted because of poor discrimination and one was removed due to a low corrected item-total correlation (r = 0.010). As a result, the final version of the posttest contains 32 items with an alpha coefficient of 0.846. The item difficulty index was ranging from 0.27 – 0.85 which was of moderate difficulty (Hopkins, 1988). One mark was given to each correct answer and zero to incorrect answer for the posttest. The total mark was then converted to percentage score.

Items to measure representational fidelity, immediacy of control, motivation, cognitive benefits, reflective thinking, perceived learning effectiveness and satisfaction were developed based on previous studies as listed in Appendix A. Items to measure presence, and control and active learning were self developed by the researchers. All items were measured with a five-point Likert scale with (1) strong disagree and (5) strongly agree. The internal consistency of these measurements was determined with the pilot data and again with the actual data. (see Appendix B.)

Except for single item measurement, an exploratory factor analysis was also conducted on the actual data to provide evidence of unidimensionality of the indicators of each measurement. After the unidimensionality and reliability were determined, the average of the raw items of all measurements was taken as their composite measure. Motivation was measured by 15 items of the Intrinsic Motivation Inventory (IMI) by McAuley, Duncan & Tammen (1989) which was categorized into four sub-dimensions: Interest-enjoyment dimension, perceived competence dimension, effort-importance dimension and tension-pressure dimension. However, the overall scale was used to measure motivation factor in this study. The results of the factor analysis are shown in Table 2 in Appendix B. The results revealed unidimensionality was achieved for all indicators in the respective constructs. Based on the criteria suggested by Nunnally (1978), the measurements have good internal consistency as their Cronbach's alpha coefficient was greater than 0.7.

### 5.3 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 by Tactus Technologies, Inc., New York. This virtual reality-based dissection simulator was developed using virtual surgery technology. Students 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 scalpel and tweezers for students to cut and peel the skin are provided. Moreover, there are also query tool that allows students to get information about a part of the specimen; magic wand tool that activates and brings parts of the specimen to life; and 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 lab report icon on the screen indicates to students that information on the current screen can assist them to complete their lab report successfully. A screenshot from V-Frog™ is shown in Fig. 5.

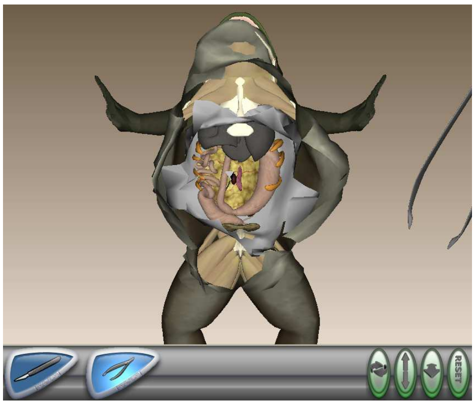


**Fig. 5. The skin was being pulled back with the tweezer (Courtesy of Tactus Technologies)**

## 6. Data Analysis and Results

The relationships in the model were tested using Analysis of Moment Structures (AMOS) Version 16. A two-step model building approach was used to analyze the two conceptually distinct models: the measurement model followed by the structural model. The fit and construct validity of the proposed measurement model was first tested and once a satisfactory measurement was obtained, the structural paths of the SEM were estimated. The evaluation of the measurement models and structural models was done using maximum likelihood estimation.

Analytic strategy of Singh (1995) was used to examine the existence of moderating effect on the structural model by using a subgroup analysis. First, an "unconstrained" simultaneous multi-group estimation of path coefficient was conducted where path coefficients were allowed to vary across the cross-group dataset. This will serve 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-square ($\chi^2$) value for the "unconstrained" and "partially constrained" models, a $\chi^2$ difference test was then used to examine the hypotheses.

### 6.1 Demographic Statistics

Among a total of 232 students, only 210 results could be analyzed because 22 students did not fully complete all measurements. Among the respondents, 41.9% (88) were male and 58.1% (122) were female. The mean age of the participants was 16 years old. Descriptive statistics of the students' VR knowledge can be found in Appendix C. To improve the normality of the data, two cases of outliers were removed. Hence, a total of 208 sample data was analyzed with AMOS.

### 6.2 Measurement Model

The measurement models were assessed based on the significance of each estimated coefficient or loading, the convergent validity and discriminant validity. All items loaded significantly on their latent construct ($p < 0.01$). Convergent validity was assessed using composite reliability and average variance extracted. A commonly used threshold value for composite reliability is 0.7 whereas for average variance extracted is 0.5 (Hair, Black, Babin, Anderson, & Tatham, 2006). The composite reliability and average variance extracted met or were very close the guidelines. (see Table 3.) The scales were therefore considered satisfactory for SEM. For single-item constructs, reliability estimation was not possible. Their measurement paths and error variance terms should be set based on the researcher's best judgment (Hair et al., 2006). In this study, it was assumed 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.

Correlational method was used to determine the discriminant validity. The implied correlations between the variables can be found in Appendix D. Discriminant validity appeared to be satisfactory for all operationalizations as the estimated correlations were not excessively high except for usability and learning outcomes. The correlation between them was slightly higher than 0.9. However, it was evidenced that both indicators of usability correlated more highly with usability than with learning outcomes. Likewise, indicators of learning outcomes correlated more highly with itself than with usability. (see Appendix D.) Discriminant is achieved if 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 these operationalizations.

**Table 3**
**Summary of measurement scales**

| Construct | Composite Reliability | Average Variance Extracted |
|---|---|---|
| VR Features | 0.88 | 0.78 |
| Usability | 0.67 | 0.51 |
| Presence | NA* | NA* |
| Motivation | NA* | NA* |
| Cognitive Benefits | NA* | NA* |
| Control and Active Learning | NA* | NA* |
| Reflective Thinking | NA* | NA* |
| Learning Outcomes | 0.70 | 0.48 |

*Notes*: NA = Not applicable
* The composite measure was treated as a single item measure in these constructs.

### 6.3 Structural model

Fig. 6 shows the results of the structural model. The test yields the standardized path coefficients, which indicate the positive and negative relationships between the constructs, and their statistical significance. The test also provides the squared multiple correlation ($R^2$), which indicates the amount of variance of the dependent constructs that can be explained by the independent constructs. In addition, the goodness-of-fit measures are provided to assess the fit of the model.

The overall goodness of fit measures indicated an acceptable fit of the model (Normed $\chi^2$ = 1.825, GFI = 0.942, CFI = 0.979, TLI = 0.968, RMSEA = 0.063). All estimates were within the admissible range (i.e., correlation coefficient less than 1 and no negative covariances) and in the theoretically expected directions. For the relationships between the constructs, all hypotheses except H4, H6 and H7 were supported. For the moderating effect of student characteristics on the structural model, only one hypothesis was supported, that is, $H_{04}$, $\chi^2$ difference = 3.277, $p < 0.10$.

(see Table 4 and Table 5.) This indicates that the influence of control and active learning on learning outcomes was moderated by spatial ability.

Overall, the model explained 97% of the variance in learning outcomes, 59% in usability, 42% in presence, 79% in motivation, 68% in cognitive benefits, 72% in control and active learning, and 63% in reflective thinking. VR features were 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 was 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 were 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, $p < 0.001$) and reflective thinking (beta = 0.36, $p < 0.001$).

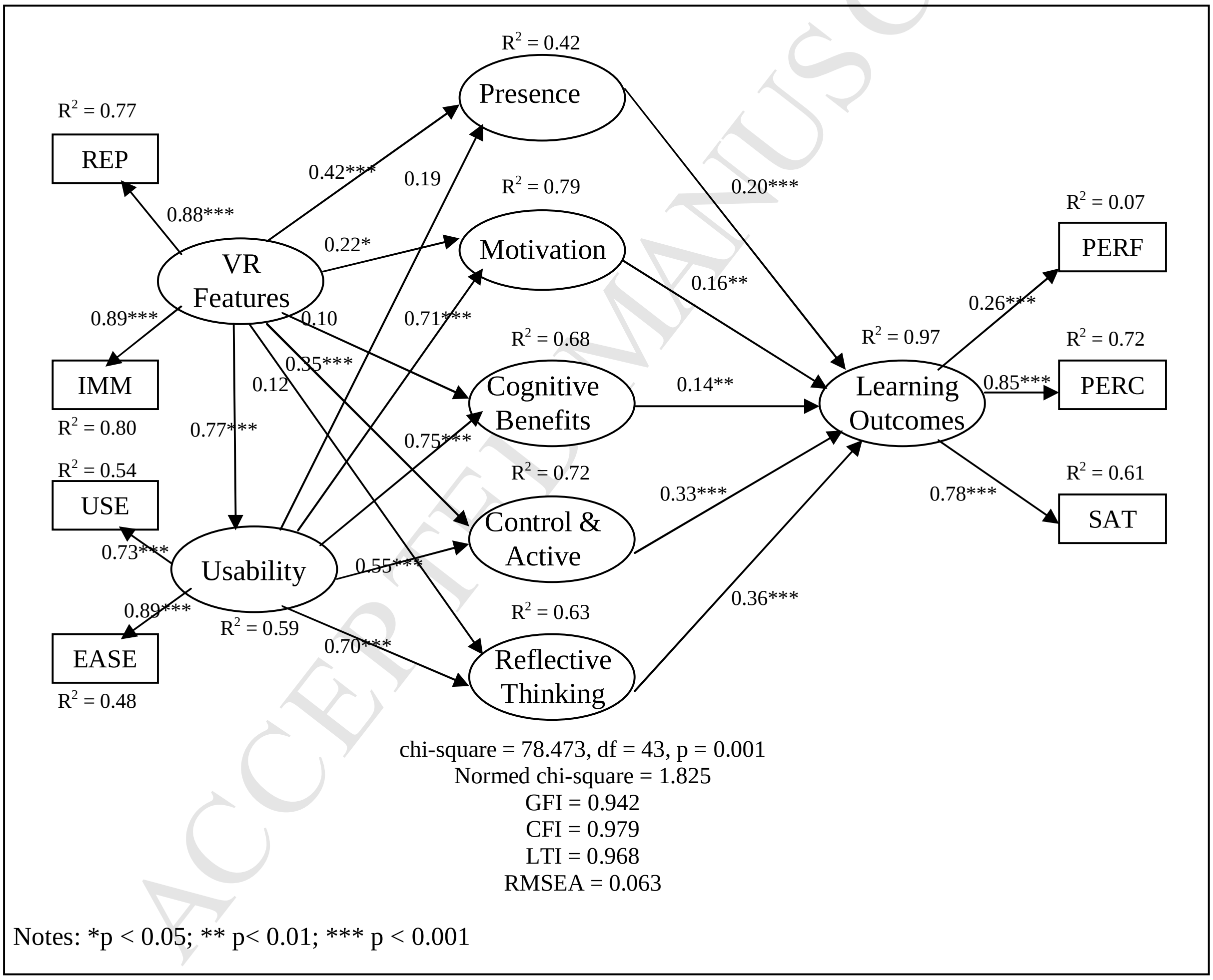



**Fig. 6: Structural model results**

**Table 4**
**Spatial ability moderating effects**

| Hypothesis | High Spatial Ability Group | | Low Spatial Ability Group | | Subgroup comparison (unconstraint) $\chi^2$ (86) =149.603 | | Result |
|---|---|---|---|---|---|---|---|
| | Standardized Coefficient | C.R. | Standardized Coefficient | C.R. | Constrained $\chi^2$ (87) | $\chi^2$ difference | |
| $H_{01}$ | 0.19** | 2.484 | 0.19* | 1.406 | 151.003 | 1.400 | H = L |
| $H_{02}$ | 0.10 | 1.096 | 0.17 | 1.207 | 149.767 | 0.164 | H = L |
| $H_{03}$ | 0.21** | 2.078 | 0.13 | 1.148 | 151.951 | 2.348 | H = L |
| $H_{04}$ | 0.39*** | 2.932 | 0.30* | 1.439 | 152.880 | 3.277* | H > L |
| $H_{05}$ | 0.25*** | 2.390 | 0.43* | 1.534 | 149.871 | 0.268 | H = L |

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

**Table 5**
**Learning style moderating effects**

| Hypothesis | Accommodator Learner | | Assimilator Learner | | Subgroup comparison (unconstraint) $\chi^2$ (86) =171.483 | | Result |
|---|---|---|---|---|---|---|---|
| | Standardized Coefficient | C.R. | Standardized Coefficient | C.R. | Constrained $\chi^2$ (87) | $\chi^2$ difference | |
| $H_{06}$ | 0.13** | 1.902 | 0.27* | 1.588 | 171.529 | 0.046 | AC = AS |
| $H_{07}$ | 0.19** | 1.748 | 0.10 | 1.010 | 172.547 | 1.064 | AC = AS |
| $H_{08}$ | 0.09 | 0.975 | 0.19* | 1.416 | 171.548 | 0.065 | AC = AS |
| $H_{09}$ | 0.38*** | 2.595 | 0.30* | 1.574 | 172.266 | 0.783 | AC = AS |
| $H_{10}$ | 0.33*** | 2.390 | 0.41* | 1.621 | 171.588 | 0.105 | AC = AS |

*Note*: C.R. = Critical Ratio; AC = Accommodator Learner; AS = Assimilator Learner
*p < 0.10; ** p < 0.05; *** p < 0.01

## 7. Discussion

This study examined how VR enhances the learning outcomes. In other words, the determinants and their relationships for effective desktop VR-based learning in a learning environment that supports constructivism model was examined. Using AMOS, the results supported the causal path from VR features to usability, presence, motivation, and control and active learning; 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, i.e., presence, motivation, cognitive benefits, control and active learning, and reflective thinking took central stage in affecting the learning outcomes in the desktop VR-based learning environment.

### 7.1 Presence

The finding that presence was found to be significantly and positively related to learning outcomes in the VR-based learning environment is consistent with the study of Salzman et al. (1999) and Mania and Chalmers (2000). The results indicate that low-immersion systems such as desktop VR are capable of providing a sense of presence to users. A possible explanation is high quality and high resolution information; interaction with the virtual environment; and anticipated effect of action in the virtual environment that contribute to presence have a positive impact on the learning effectiveness of desktop VR-based learning (Slater & Usoh, 1993). This study provides empirical evidence on the causality relationship between presence and learning outcomes which until today is relatively scarce. Most of the research findings were analyzed with correlation analysis which does not imply causality relationship.

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 relationship between VR features and presence indicates that the better the VR features in terms of realism and control factors, the higher level of presence the users experienced. The higher the level of presence, the better the learning outcomes.

### 7.2 Motivation

Motivation was found to be a significant psychological factor that positively related to learning outcomes. This is in line with the model proposed by Salzman at al (1999) and Benbunan-Fich & Hiltz (2003). Similar with the findings by Rezabek (1995) and Virvou, Katsionis, and Manos (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.

VR features were a significant antecedent to motivation. The result is consistent with the finding of Virvou, Katsionis, and Manos (2005) where their VR game educational software 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. The realism of the scene, dynamic displays and close-loop interaction where user have control over the contents viewed in the VR software used have 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 why the desktop VR program was effective as an educational tool in the open-ended sections of the survey, students reported the desktop VR program was interesting and motivated them to put in more efforts in the related subjects. One student wrote in the survey, "The realism of the image will make students easier 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. 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 are more motivated to learn with the system provided. It may eventually influence the intention of the students to adopt this system for learning.

### 7.3 Cognitive Benefits

Cognitive benefits were positively related to the 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 in a desktop VR-based learning environment. This finding is in agreement with the study of Antonietti et al. (2000) 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 the effect was mediated by usability. A possible explanation 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, the learning content and instructional strategy. 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 which the students undertake have a positive impact on cognitive benefits (Dalgarno et al., 2002).

### 7.4 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 results corroborate those of Stipek and Weisz (1981), Choi & Gennaro (1987), Rivers & Vockell (1987), Yang & Heh (2007), and Jang, Jyung & Black (2007). However, is in contrast with the research by Keehner & Khooshabeh (2002) that active learning did not contribute to the improvement of performance. Nevertheless, it was argued that only those science experiments that cover hands-on and minds-on activities and in which students could actively involved in the learning process can enhance the effect of computer assisted learning (Berger, Lu, Belzer, & Voss, 1994; Chang & Barufaldi, 1999). 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 in 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 indicated that control and active learning could positively affect learning effectiveness in a desktop VR-based learning environment.

Both VR features and usability were 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 are 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."

### 7.5 Reflective thinking

Reflective thinking was another significant antecedent to learning outcomes. 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.

VR features were indirectly related to reflective thinking, which was mediated by usability. Similar with cognitive benefits, a possible explanation is that reflective thinking is caused by the instructional method embedded in the media presentation. 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 (Rami, Piccolli, & Ives, 1998). As mentioned by Collins (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) that a virtual learning environment that modeled on a real world system with high degree of fidelity and immediacy of control will not necessarily facilitate better learning and understanding. This must be a suitable set of learning tasks and activities that are considered to be useful and easy to use by learners that help to facilitate reflective thinking, which in turn affects the learning outcomes.

Learners must be able to reflect on their activities and observations to learn the lesson that the activity has to teach. It is believed the requirement to complete the lab report had helped learners to reflect on their activity and observation, to integrate new experiences with their prior knowledge to construct new knowledge and learn 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 have 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.

### 7.6 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 with the unique desktop VR features alone is 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 learners' learning experience. In short, the design dimension of the desktop 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 a significant antecedent to usability, as predicted by the model. This is consistent with the findings of Salzman et al. (1999). VR features that were measured by the representational fidelity and the ability to control, manipulate and interact with the virtual objects in the desktop VR-based learning environment collectively influenced the interaction experience of the users. The positive relationship between VR features and usability indicates 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, student 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 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 these help 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."

### 7.7 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 experience and learning experience, which in turn influence the learning outcomes (Barnett, Yamagatah-Lynch, Keating, Barab, & Hay, 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 (scene realism) 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 the learners which eventually enhance the learning outcomes.

### 7.8 Spatial ability moderating effect

The influences of presence, motivation, cognitive benefits and reflective thinking on learning outcomes being similar for high and low spatial ability groups indicate that these psychological factors to learning outcomes are not spatial ability specific. The phenomenon implies that these psychological factors are the common success factors, regardless of the learners' spatial ability. Thus, a desktop 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 for learners with different spatial abilities.

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 sensitively to control and active learning rather than to other psychological factors. The difference between both groups may result from the phenomenon that the high spatial ability learners generate a higher level of performance achievement, perceived learning and satisfaction if control and active learning is provided. This shows that control and active learning is a more 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 they perceive the learning process as effective and satisfying.

### 7.9 Learning style moderating effect

The influences of presence, motivation, cognitive benefits, control and active learning and reflective thinking on learning outcomes being similar for accommodator learners and assimilator learners indicate that these psychological factors to learning outcomes are not learning style specific. The phenomenon implies that these psychological factors are the common success factors, regardless of the learners' learning style. Thus, a desktop VR-based learning environment that is able to provide such learning experiences is crucial to achieve good learning outcomes.

The implication of this findings is desktop 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, desktop 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 for the path of control and active learning to learning outcome. Thus, the efforts to improve the learning outcomes are only subjected to very minimal influence of spatial ability. Consequently, desktop VR is an educational tool that could accommodate individual differences in terms of learning styles and spatial abilities.

## 8. Future Research and Implications

It is noted 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 was 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 score 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. Thus, studying students in 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.

Replication of the study in 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. The subjects were confined to the context of Malaysia. There is evidence that cultural backgrounds of students from different cultures could influence how they use and think about learning with computer based technologies (Colis, 1999; Lai, 2002; Palma-Rivas, 2002). Thus, it is recommended that similar study to be carried out for students with different cultural backgrounds from different geographically areas to generalize the result findings.

Nevertheless, the findings have important implications to instructional designers, desktop VR software developers and educators. 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 experiences that play a significant role in improving the learning outcomes. 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 considered to be useful and easy to use by learners that are afforded by the VR technology is crucial in enhancing the learning outcomes. For educators, individualized learning is possible with desktop VR-based learning. 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 desktop VR-based learning environment.

## 9. Conclusions

This research makes a significant contribution by bringing us one step closer to understand the potential of desktop VR technology to support and enhance learning. Through this research, an initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment is contributed. 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 desktop VR-based learning environment. Moreover, the framework and model have enlightened practitioners the capability of desktop VR to enhance learning and to support practitioners using desktop VR-based learning. Taken together, the findings from this study not only tell us what has occurred but also how the learning has occurred in a desktop VR-based learning environment.

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**Appendix A. Questionnaire items and sources**

| Measurements | Items | Sources |
|---|---|---|
| Representational Fidelity | 1. The realism of the 3-D images motivates me to learn.<br>2. The smooth changes of images make learning more motivating and interesting.<br>3. The realism of the 3-D images helps to enhance my understanding. | Dalgarno et al. (2002) |
| Immediacy of Control | 1. The ability to change the view position of the 3-D objects allows me to learn better.<br>2. The ability to change the view position of the 3-D objects makes learning more motivating and interesting.<br>3. The ability to manipulate the objects (e.g.: pick up, cut, change the size) within the virtual environment makes learning more motivating and interesting.<br>4. The ability to manipulate the objects in real time helps to enhance my understanding. | Dalgarno et al. (2002) |
| Perceived Usefulness | 1. Using this type of computer program as a tool for learning in classroom increase/will increase my learning and academic performance.<br>2. Using this type of computer program enhances/will enhance the effectiveness on my learning.<br>3. This type of computer program allows/will allow me to progress at my own pace.<br>4. This type of computer program is useful in supporting my learning. | Davis (1989) |
| Perceived Ease of Use | 1. Learning to operate this type of computer program is easy for me.<br>2. Learning how to use this type of computer program in classes is too complicated and difficult for me. (**R**)<br>3. It is easy for me to find information with the computer program.<br>4. Overall, I think this type of computer program is easy to use. | Davis (1989) |
| Presence | 1. There is a sense of presence (being there) while learning with this type of computer program. | Self-development |
| Motivation | 1. I enjoyed this type of computer program very much.<br>2. I think I am pretty good at this type of computer program.<br>3. I put a lot of effort into this type of computer-based learning environment.<br>4. It was important for me to do well at this type of computer program.<br>5. Learning with this type of computer program was fun.<br>6. I would describe this type of computer program as very interesting.<br>7. I was satisfied with my performance in this type of computer-based learning environment. | McAuley, Duncan, &Tammen, (1989) |

**Appendix A.** *(continued)*

| Measurements | Items | Sources |
|---|---|---|
| | 8. I felt pressured while learning with this type of computer program. (**R**)<br>9. I didn't try very hard while learning with this type of computer program. (**R**)<br>10. While learning with type computer program, I was thinking about how much I enjoyed it.<br>11. After trying this type of computer program for a while, I felt pretty competent.<br>12. I was very relaxed while learning with this type of computer program.<br>13. I am pretty skilled at this type of computer program.<br>14. This type of computer program did not hold my attention. (**R**)<br>15. I couldn't learn much using this type of computer program. (**R**) | |
| Cognitive Benefits | 1. This type of computer program makes the comprehension easier.<br>2. This type of computer program makes the memorization easier.<br>3. This type of computer program helps me to better apply what was learned.<br>4. This type of computer program helps me to better analyze the problems.<br>5. This type of computer program helps me to have a better overview of the content learned. | Antonietti, Ras, Imperio, & Sacco (2000) |
| Control and Active Learning | 1. This type of computer program allows me to be more responsive and active in the learning process.<br>2. This type of computer program allows me to have more control over my own learning.<br>3. This type of computer program promotes self-paced learning.<br>4. This type of computer program helps to get myself engaged in the learning activity. | Self-development |
| Reflective Thinking | 1. I was able to reflect on how I learn.<br>2. I was able to link new knowledge with my previous knowledge and experiences.<br>3. I was able to become a better learner.<br>4. I was able to reflect on my own understanding. | Maor & Fraser (2005) |
| Perceived Learning Effectiveness | 1. I was more interested to learn the topics<br>2. I learned a lot of factual information in the topics.<br>3. I gained a good understanding of the basic concepts of the materials.<br>4. I learned to identify the main and important issues of the topics.<br>5. I was interested and stimulated to learn more.<br>6. I was able to summarize and concluded what I learned.<br>7. The learning activities were meaningful.<br>8. What I learned, I can apply in real context | Benbunan-Fich & Hiltz (2003), Marks , Sibley, & Arbaugh (2005), Martens, Bastiaens, & Kisrcher (2007) |

**Appendix A** . *(continued)*

| Measurements | Items | Sources |
|---|---|---|
| Satisfaction | 1. I was satisfied with this type of computer-based learning experience.<br>2. A wide variety of learning materials was provided in this type of computer-based learning environment.<br>3. I don't think this type of computer-based learning environment would benefit my learning achievement. (**R**)<br>4. I was satisfied with the immediate information gained in this type of computer-based learning environment.<br>5. I was satisfied with the teaching methods in this type of computer -based learning environment.<br>6. I was satisfied with this type of computer-based learning environment.<br>7. I was satisfied with the overall learning effectiveness. | Chou & Liu (2005) |

Note: (**R)** reverse coded

**Appendix B.**

**Table 1. Internal consistency analysis with pilot data**

| **Measurement** | **Cronbach's alpha** |
|---|---|
| Motivation | 0.738* |
| Cognitive Benefits | 0.915 |
| Control and Active Learning | 0.888 |
| Reflective Thinking | 0.836 |
| Representational Fidelity | 0.838 |
| Immediacy control | 0.900 |
| Satisfaction | 0.835 |
| Perceived Usefulness | 0.899 |
| Perceived Ease of Use | 0.636 |
| Spatial ability test | 0.757 |

*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.

**Table 2: Exploratory principal component and internal consistency analysis with actual data**

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

* Single item measurement

** Exploratory principal component analysis with varimax rotation

**Appendix C**

**Table 1. Virtual reality knowledge of the students**

| | | **Frequency** | **Percent** | **Valid Percent** | **Cumulative Percent** |
|---|---|---|---|---|---|
| Valid | Know Nothing | 96 | 45.7 | 46.2 | 46.2 |
| | Some Knowledge | 85 | 40.5 | 40.9 | 87.0 |
| | Lots of Knowledge | 8 | 3.8 | 3.8 | 90.9 |
| | Some Experience | 19 | 9.0 | 9.1 | 100.0 |
| | Total | 208 | 99.0 | 100.0 | |
| Missing | System | 2 | 1.0 | | |
| Total | | 210 | 100.0 | | |

**Appendix D.**

**Table 1. Implied correlation between the variables in the model**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.000 | | | | | | | | | | | | | | |
| 2 | .777 | 1.000 | | | | | | | | | | | | | |
| 3 | .660 | .792 | 1.000 | | | | | | | | | | | | |
| 4 | .772 | .819 | .666 | 1.000 | | | | | | | | | | | |
| 5 | .675 | .825 | .658 | .689 | 1.000 | | | | | | | | | | |
| 6 | .766 | .879 | .707 | .750 | .733 | 1.000 | | | | | | | | | |
| 7 | .566 | .513 | .427 | .480 | .440 | .488 | 1.000 | | | | | | | | |
| 8 | .816 | .906 | .864 | .875 | .803 | .854 | .648 | 1.000 | | | | | | | |
| 9 | .878 | .676 | .579 | .678 | .529 | .672 | .497 | .716 | 1.000 | | | | | | |
| 10 | .893 | .688 | .590 | .690 | .603 | .684 | .506 | .729 | .784 | 1.000 | | | | | |
| 11 | .564 | .733 | .580 | .600 | .604 | .644 | .376 | .664 | .495 | .504 | 1.000 | | | | |
| 12 | .534 | .694 | .549 | .568 | .572 | .609 | .356 | .628 | .469 | .477 | .508 | 1.000 | | | |
| 13 | .693 | .769 | .734 | .743 | .682 | .725 | .550 | .849 | .608 | .619 | .564 | .534 | 1.000 | | |
| 14 | .637 | .708 | .675 | .683 | .627 | .667 | .506 | .781 | .559 | .569 | .519 | .491 | .663 | 1.000 | |
| 15 | .208 | .231 | .221 | .223 | .205 | .218 | .165 | .255 | .183 | .186 | .170 | .161 | .217 | .200 | 1.000 |

Note:
1 = VR features; 2 = Usability; 3 = Reflective Thinking; 4 = Control and Active Learning; 5 = Cognitive Benefits; 6 = Motivation; 7 = Presence; 8 = Learning Outcomes; 9 = Representational Fidelity; 10 = Immediacy of control; 11 = Perceived Usefulness; 12 = Perceived Ease of Use; 13 = Perceived Learning Effectiveness; 14 = Satisfaction; 15 = Performance Achievement