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Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach

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A B S T R A C T

The use of animation and multimedia for learning is now further extended by the provision of entire Virtual Reality Learning Environments (VRLE). This highlights a shift in Web-based learning from a conventional multimedia to a more immersive, interactive, intuitive and exciting VR learning environment. VRLEs simulate the real world through the application of 3D models that initiates interaction, immersion and trigger the imagination of the learner. The question of good pedagogy and use of technology innovations comes into focus once again. Educators attempt to find theoretical guidelines or instructional principles that could assist them in developing and applying a novel VR learning environment intelligently. This paper introduces the educational use of Web-based 3D technologies and highlights in particular VR features. It then identifies constructivist learning as the pedagogical engine driving the construction of VRLE and discusses five constructivist learning approaches. Furthermore, the authors provide two case studies to investigate VRLEs for learning purposes. The authors conclude with formulating some guidelines for the effective use of VRLEs, including discussion of the limitations and implications for the future study of VRLEs.

1. Introduction

Virtual reality (VR) is a technology that has become extremely popular in recent years. VR technology has been successfully employed in educational applications and is at the core of what is known as Virtual Reality learning environments (VRLEs) (Chittaro & Ranon, 2007; John, 2007; Monahan, McArdle, & Bertolotto, 2008; Pan, Cheok, Yang, Zhu, & Shi, 2006; Rauch, 2007). A VRLE allows the visualization of three dimensional (3D) data and provides an interactive environment that reinforces the sensation of an immersion into computer-generated virtual world. Additionally, a VRLE offers the opportunity to simulate a realistic and safe environment for learners to perform specific tasks. A VRLE offers real-time simulation where three-dimensional computer graphics are used to mimic the real world (Burdea, 1999, pp. 87–96).

Traditional immersive VR systems are expensive, fragile, and not suitable for a long period of use (Limniou, Roberts, & Papadopoulos, 2008; Tax'en & Naeve, 2002), thus the developed applications are not accessible to many learners. Indeed, running VR systems are associated with high a high cost because of the special hardware is needed, such as head-mounted displays (HMD) or multiple projectors, and 3D input devices. These drawbacks make immersive HMDs difficult to use in large classroom settings (Tax'en & Naeve, 2002).

To invigorate students learning, a number of higher resolution displays with high quality audio systems can be useful. For example, CAVE, invented at the Electronic Visualization Laboratory of the University of Illinois at Chicago, is designed to project images on the surrounding walls around the users while an advanced audio sound system enhances the sense of immersion in the VR learning environment (Sherman & Craig, 2003). In addition, the option of offering 3D VR learning in a classroom setting is now feasible, given that VR learning environments are now run on low-cost personal computers. Although this type of VR environment has a low-cost advantage, users are not full sensual immersion the learning environment. However, learners using personal computer VR systems are less likely to feel motion sickness and experience fatigue than true immersive VR (Tax'en & Naeve, 2002).

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Research into VR has often focused on technical issues (Burdea & Coiffet, 2003; Capin, Pandzic, Magnenat-Thalmann, & Thalmann, 1999; Sherman & Craig, 2003). They include case studies of various VR technologies (Dimitropoulos, Manitsaris, & Mavridis, 2008; Lu, Pan, Lin, Zhang, & Shi, 2005; Moreno & Mayer, 2002), and discussions on how VR can be integrated into curriculum and relate to the learning process (Dickey, 2005; Mills & de Araújo, 1999). Although approaches such as using virtual reality for education promise among others student engagement, all whorthwhile educational innovation must begin with solid pedagogy (Huang, 2002; Huang & Liaw, 2004; Lok et al., 2006). Researchers and educators need to deploy a sound theoretical framework and supporting instructional principles to facilitate building novel VRLEs. It is the purpose of this paper is to explore how a constructivist principle can be applied in constructing VRLEs. We propose four design principles that should be considered when designing and building educational applications. Educators or instructional designers, as they apply a new VR technology to educational settings, need to consider carefully how a pedagogy or a learning theory may influence the learning process. Our research also provides two case studies to examine VRLEs for educational purposes. Lastly, we explore the limitations and implications of our findings for the future study of VRLEs.

2. Virtual reality features

For Burdea and Coiffet (2003), virtual reality has been defined as I^3 for "Immersion-Interaction-Imagination". Virtual reality (VR) is understood as the use of 3D graphic systems in combination with various interface devices to provide the effect of immersion in an interactive virtual environment (Pan et al., 2006). In order to allow learners to interact with VR environments, it is necessary to use special interfaces designed to input a learner's commands into the computer and to offer feedback from the simulation to the learner. Examples and functionalities of various commonly used VR interfaces are listed in Table 1.

For Sherman and Craig (2003), immersion can be classified into mental immersion and physical (or sensory) immersion. Thus, these two types of immersion play an important part in creating a successful personal experience with a VR world. When the user moves, the visual, auditory, or haptic devices that establish physical immersion in the scene change in response (Sherman & Craig, 2003). Users can interpret visual, auditory, and haptic cues to gather information while using their proprioceptive systems to navigate and control objects in the synthetic environment to accomplish physical immersion. On the other hand, mental immersion refers to the "state of being deeply engaged" within a VR environment (Sherman & Craig, 2003, p.7). For example, if a VR world is designed for entertainment purpose, the success in mental immersion is based on how involved the user becomes (Sherman & Craig, 2003). As a result, educators would like to take advantage of VR technology's immersive power which induces learners' intention to engage in learning activities (Hanson & Shelton, 2008).

Another feature of virtual reality is real-time interactivity. That is, a virtual reality system is able to detect a user's input (i.e., gesture) and respond to the new activity instantaneously. At the same time, users can see activity change on the screen based on their commands and captured in the simulation. Interactivity and VR's captivating power create for users a sensation of immersion and by reciprocating to user intervention with action on the screen. Moreover, users not only see and manipulate graphic objects on the screen; they also touch and feel them by using all human sensorial channels such as the visual, auditory, haptic, tactile, smell, and taste (Burdea, 1999).

Virtual reality is not only an immersive user interface, but it also has serves to present and solve real problems in fields such as engineering, medicine, and education. VR is especially helpful when it comes to address issues that require imagination creativity and high problem solving ability. For Jonassen (2000), technologies have intrinsic properties and activate cognitive tools that help learners to consciously elaborate on what they are thinking and to engage in meaningful learning. Therefore, a VR environment triggers the human mind's capacity to perceive, imagine in a creative sense, nonexistent things. In short, VR technology is well suited to convey difficult abstract concepts due to the visualization abilities (Burdea & Coiffet, 2003).

Since the interaction with VR technology seeks to simulate a more real, immersive learning environment, such learning might result in cognitive load reduction and a stimulated imagination assisting the mind's capacity to conceptualize (Wetzel, Radtke, & Stern, 1994). When educators design a course for delivery in a VRLE, it is not necessary to deploy all three features (interaction, immersion and imagination) in their learning environments. Weighting one over the other necessitates shifts in design. It is important for educators and instructional designers to understand of how emphasis on one or the other feature determines a choice when selecting a 3D VRLE (Dickey, 2005). Table 2

Table 1
Examples and functionality of various interfaces.

Interfaces	Examples	*Functionality*
Input devices		
User monitoring	position tracking, videometric (optical) tracking, body tracking (posture and gestures)	Monitoring a users interaction with virtual world
VR navigation	Tracker-based navigation/manipulation(3D mouse), trackballs	Offering more functionality than measuring position/orientation
Output devices		
Visual displays	Stationary displays (projection VR), Head-based displays, Hand-based displays (Palm VR)	Providing visual feedback from the simulation in response to users input
Auditory displays	Stationary auditory displays (speakers-based 3D sound), Head-based auditory displays (headphones)	Providing synthetic sound feedback to users interacting with the VR world
Input/output devices		
Haptic displays	Tactile displays, end-effector displays, robotically operated shape displays	Achieving physical touch and force an virtual object to user operators

(Sources: Burdea & Coiffet, 2003; Sherman & Craig, 2003).

Table 2
A Summary of VR applications in education.

Research	Features of VR applied (eg,)	Technology employed
Dimitropoulos et al. (2008); John (2007); Karpouzis, Caridakis, Fotinea, and Efthimiou (2007); Sims (2007);	Interaction	Web 3D
Brenton et al. (2007)	Imagination	Web 3D
Tax'en and Naeve (2002)	Immersion	VR Juggler,C++
Wollensak (2002)	Immersion	WorldToolKit (C++, Sense8's VR library)
Chittaro and Ranon (2007); Ieronutti and Chittaro (2007)	Interaction, Imagination	Web 3D
Shih and Yang (2008);	Interaction, Immersion	Web 3D (Java 3D)
Keefe et al. (2008)	Interaction, Immersion	Cave Painting (artistic free-form modeling tool)
Limniou et al. (2008); Roussou, Oliver, and Slater (2008)	Interaction, Immersion	CAVE (3dsmax)
Rauch (2007)	Immersion, Interaction, Imagination	Croquet (open sources)

shows research by VR features in their learning settings. It also identifies the technology that was applied to create the virtual reality learning environment.

3. Theories reviewed – constructivism

Within a constructivist paradigm, learners take an active role in their learning, since they not only absorb information, but also connect it with previously assimilated knowledge to construct their new knowledge. For Dewey (1916), the environment will affect the learner and that an interaction will take place between the environment and the learner. Dewey believed that learning should be real and applicable for daily life. In other words, education should be experimental and experiential. Dewey argued that knowing was an active process of being in the environment (Dewey, 1916). Knowledge is based on active experience. Piaget and Dewey believed that the educator's role was to shape a learners' real experience and to understand what surroundings tend to promote positive learning experiences (Ornstein & Hunkins, 1998).

Dewey considered that the main function of education was to improve the reasoning process. He also recommended adapting his problem-solving method to many subjects. A learner who is not motivated will not really perceive a problem, so problems selected for study should be derived from learner interests (Ornstein & Hunkins, 1998). The constructivist approach emphasizes the development of a learner's abilities in solving a real-life problem. Problem solving and free discovery are joined together; in other words, knowledge is a dynamic quality, built around the process of discovery (Dewey, 1916).

Vygotsky in his theory of cognitive development emphasized the critical importance of interaction among people, including other learners and teachers, and pointed at the element of "social constructivism" underlying the learning process (Maddux, Johnson, & Willis, 1997). Vygotsky proposed that learning is a socially mediated activity. He also postulated that thinking and problem-solving skills can be classified into three categories (Maddux et al., 1997). First, some learning can be performed independently by the learner. Second, some learning cannot be achieved even with help from others. And third, between these two extremes are the tasks that learners can perform with the help from others such as teachers or fellow learners.

According to constructivist theory, learners actively construct meaningful knowledge from individual experiences. This theoretical approach focuses on the learner's control of learning processes and attempts to mitigate the gap between the knowledge as a concept real-life experience. That is, constructivists believed in learner-centered education. Without doubt, a constructivist understanding provides learners more freedom to select and coordinate their learning processes with other learners. As Jonassen (1994, p.35) stated, "constructivists emphasize the design of learning environments rather than instructional sequences". The learning environment should provide real world, case-based environments for meaningful and authentic knowledge.

4. Constructivist approach for VRLE

A growing body of research notes that constructivist principles are fundamental and underlying our understanding of learning in a virtual reality environment (Chittaro & Ranon, 2007; Dimitropoulos et al., 2008; John, 2007; Mills & de Araújo, 1999; Shih & Yang, 2008; Tax'en & Naeve, 2002; Virvou & Katsionis, 2008). As Burdea and Coiffet (2003) noted, (a) constructivist learning involves exploration and discovery of prebuilt artificial real worlds, and (b) constructivist learning process provided by VR technology requires educators to examine the learning models and how the technological features support learning.

The following section describes and analyses how a constructivist approach can be applied in developing VRLEs. Five learning strategies are proposed for instructional designers.

4.1. Situated learning

Dewey (1916) believed that students should learn in a real situation by doing, so students could improve their skills through practice on realistic tasks. VR environments enable the simulation for learners engaged in learning in a realistic-looking environment. Therefore, VR is an application that allows learners to interact with a simulated environment in real time (Pratt, Zyda, & Kelleher, 1995). VR offers richer perceptual cues and multimodal feedback (e.g., visual, auditory, and haptic) to enable the easy transfer of VR-based learning into real-world skills (Durlach & Mavor, 1995). Furthermore, VR is a new technology that provides interaction with learning content. For example, learners can view 3D objects from multiple viewpoints or zoom in/out the objects. This will potentially deepen the learning effect when the learners are actively constructing new knowledge (Hanson & Shelton, 2008).

Especially, immersive VR offers a variety of situated learning experience rather than what learners encounter in a traditional classroom learning. Immersive environments create a strong sense of presence, which in turn motivates and thereby causes the learner to cognitively process the learning material more deeply. Therefore, learners could acquire knowledge and skills in the context of reflecting how knowledge is obtained and applied in everyday situations. When learners become active learning in immersive VR, learners can construct knowledge through interaction with objects and events in the artificial world.

When learners interact with a VR environment, they do treat this as real world by using situated learning approaches (Chittaro & Ranon, 2007).VRLEs have been developed and applied in a variety of contexts and in different fields such as medicine education (Brenton et al., 2007) and language education (Shih & Yang, 2008). In other words, education based on virtual reality environments can be both, experimental and experiential. It follows that VR with immersion or simulation features might provide a good level of realism and interactivity and offer life-like situated learning experiences as formulated by Dewey.

4.2. Role playing

Learning through role playing takes advantage of the capability of a VRLE to provide learners with specific characteristics and personalities (Holmes, 2007). Due to VR's ability to mediate virtual world exploration and construction, learners can act through novel 3D graphical representations of the characters or avatars. Younger learners are very familiar with those representations of self (Burdea & Coiffet, 2003; Turkle, 2007). When they feel safe in a VRLE, younger learners will express what they think and feel through the characters. This stimulates their creativity and imagination (Pan et al., 2006).

The genre of computer games integrated with education is called edutainment. Since immersion and interactivity are the key added value of VR, and since computer games are an instance of VR, edutainment is appropriate for creating VR learning. By reviewing research about immersive VR worlds for learners, e.g., Rauch (2007) and Sims (2007), we observed that particular attention needs be directed to the role and nature of interactivity. As a result, learners prefer playing and engaging in multi-players gaming because it offers a context, a chance to role play and competitive interaction tasks (Shih & Yang, 2008). Especially for children and younger learners, combining computer game into the VR learning could be an appropriate way to motivate their learning.

4.3. Cooperative/collaborative learning

Much of a collaborative learning strategy is built on Vygotsky's zone of proximal development (ZPD). In groups, learners are able to cooperate, exchange ideas and share experiences to obtain knowledge within the learning process (Dimitropoulos et al., 2008). Tax'en and Naeve (2002) suggested that educators should adapt their teaching style to collaborative virtual reality environments.

VR technologies that support immersive learning are seen as having great potential for social scaffolding in cooperative/collaborative learning (Hodge, Tabrizi, Farwell, & Wuensch, 2008; Sherman & Craig, 2003). The collaborative VR learning environment can be created as multiple users interact within the same virtual space or simulation. Learners perceive of others existence within the simulation by using avatars that act as users' proxies (Sherman & Craig, 2003).

With VRLE as virtual shared space, avatar and chat rooms enable users to be aware of each other and to share the common learning environment. The VRLE stimulates users' motivation and aspiration toward collaborative learning. A collaborative VR learning environment is called "multipresence or multiparticipant" (Sherman & Craig, 2003, p.12). Visuals of lectures and text chats are two tools to enable mutual communication between instructors and learners. This collaborative environment fosters adaptability and sociability of younger learners (Pan et al., 2007). Moreover, increasing interest among learners and promoting critical thinking are major benefits of collaborative learning (Dimitropoulos et al., 2008). As a result, participants in the collaborative learning group develop greater social skills. The collaborative learning style challenges a group of learners to solve problems collaboratively among themselves.

4.4. Problem-based learning

Problem-solving ability is a critical skill for learning. Thus, many educators adopt a variant of problem-based learning (PBL) to improve learners' problem-solving skills. PBL is a learner-centered approach that encourages learners to solve a problem by outlining a problem, e.g., a case study and then discussing the case in a small group with minimal intervention from an outside facilitator. In comparison, VR learning environments pose authentic problems often in vaguely-structured tasks. In order to create a problem (e.g., medical problem) realistically (for example, a serious head injury problem), VRLE can be applied to simulate the situation. By using VRLE, designers were able to achieve individualization of the level of difficulty with immediate feedback which provides greater realism than purely didactic instructions (Brenton et al., 2007; Holmes, 2007).

Problem-based learning (PBL) aims to improve the weaknesses in didactic instruction by encouraging learners to develop independent thinking ability and collaborative learning (Brenton et al., 2007). A VRLE allows learners to observe the simulated situation, and then motivate learners to learn and solve problem adequately through the immersive and interactive environment. Each group can alter some environmental parameters to change the simulation instantly (Holmes, 2007). Thus, the VRLE provides learners a rich and focused learning environment and allows learners to collectively understand and solve visualization problems in a group (Wollensak, 2002).Therefore, problem-solving helps learners appreciate different facets of a problem and lets them compare their thinking to others. As the result, a VRLE based on a PBL strategy leads learners to immerse themselves into a context that prompts the exploration of the constructs of the problem. Eventually, learners are encouraged by free discovery in the VRLE, and then they can construct their new knowledge actively by the problem-solving process. It is a reflexive yet collaborative and dynamic learning process.

4.5. Creative learning

Since knowledge is a dynamic property, progressive educators not only facilitate a self reflexive learning, but also lead students to tap in their own creativity. For Claxton (1999), creativity can be learned. Therefore, educators can advocate integrating creativity into curriculum which offers a subject oriented basis for reflective learning activities. According to Hsiao et al. (2006), creativity is one of the core resources for problem solving, and Isaksen and Parnes (1985) state that problem solving, creative thinking and creativity learning are correlated. Most problems need creative thinking to solve. Thus learners can promote their own creativity by using elaborate thinking ability to solve problems.

Creative imagination allows learners to visualize new ideas and concepts in their minds not immediately presented to the senses (Singer, 2000). The imagination aspect of VR promotes learners in developing problem-solving capacity for open-ended problems. Creative visualization is the technique of helping learners to develop imagination in what learners want to learn in VR learning environments. Creative learners can apply their knowledge gleaned from imaginative play (i.e., games) and appropriately employ both divergent and convergent thinking to construct a new knowledge (Turvey, 2006). As the result, VR technology deserves extensive attention as an instructional tool.

Deriving from a constructivist framework, the instructional designer chooses different instructional strategies or combines one or more strategies into one virtual reality course design. For example, Sims (2007) applies role playing and collaborative learning into the VR learning environment to improve learners' motivation and retention.

5. Case study

5.1. Case study 1: web-based 3D VR interactive learning system

5.1.1. Web-based 3D VR interactive learning system

WVBS-ATS, Web-based Virtual Body Structures Auxiliary Teaching System, is a Web-based 3D VR interactive learning system that is designed for undergraduate medical students to obtain knowledge about the structure of human body. The Web-based VR learning system is designed in three parts: Website design, Web server setup, and Database setup. The developer used PHP, Java Script to design the web page and utilizes Autodesk 3DMax, VR4MAX to create 3D course contents. 3DMax is a commercial software package used to create 3D models. With 3DMax, users can quickly and easily visualize the 3D objects without knowing any special computer language or having to export application-specific files. VR4MAX provides high performance real-time interactive virtual reality environment. For the Web server part, the website administrator used Apache and PHP to establish a web server and the MySQL database to access text data. In addition, we built an FTP Server to store the 3D module files. Students feel free to study any medical subjects by using VR learning system as they wanted. Moreover, learners can discuss with others by using discussion boards in the VR learning system. Fig. 1 shows the main screen of the WVBS-ATS.

5.1.2. Research hypotheses

The three critical factors of VR applications for motivating students' learning are the intuitive interaction, the sense of physical imagination, and the feeling of immersion. VR applications should aim to simulate reality as faithfully as possible (Stone, 2002). Sutcliffe and Gault (2004) stated that successful VR application should have the following characteristics: (a), natural engagement, interaction should approach the user's expectation of interaction in the real world as far as possible. (b), natural expression of action. The representation of the imagination in the VR should allow users to act and explore in a natural manner and not restrict normal physical actions. (c), realistic feedback. The effect of the user's actions on virtual world should be immediately visible and conform to the laws of physics and the user's perceptual expectations. It means that realistic feedback provides effective interaction. (d), navigation and orientation support. The users should always be able to find where they are in the VR environment and return to known, preset positions. In other words, navigation and orientation

Fig. 1. The main screen of the VBS-ATS.

support high immersion. And lastly (e), a sense of imagination. The user's perception of engagement and being in a 'real' world should be as natural as possible.

Web-based anatomy instructions are generally perceived by medical students to be enjoyable and interested (Nicholson, Chalk, Funnell, & Daniel, 2006). Students can explore or navigate in a VR learning environment, and manipulate the 3D learning objects. VR experiences may motivate learners to participate in VRLEs. Thus, VRLEs may be used as a tool to enhance, motivate and stimulate learners' understanding of certain knowledge (Shim et al., 2003). As a result, learners have a positive attitude toward VRLEs because of interest, enjoyment, reality and easily understood learning concepts (Shim et al., 2003). Furthermore, VRLEs allow learners to observe the simulated situation, and enhance learners to learn and solve problem adequately through the immersive and interactive environment. Thus, VRLEs provide learners a rich learning environment and allows learners to collectively understand and solve visualization problems (Wollensak, 2002).

Based on immersion, interaction, and imagination, we propose the following hypotheses:

H1: With the increased immersion, interaction, and imagination provided by a VR environment, the motivation of the environment increases.

H2: With the increased immersion, interaction, and imagination of a VR environment provides, the problem-solving capability of the environment increases.

5.1.3. Participants and measurement

This study surveys learners' attitudes toward the VR leaning environments. A total of 190 university students have been taught on how to use the VR system. Students were allowed to use the system anytime for a period of one month. After that, a questionnaire survey was distributed to participants during class to explore their understanding of VRLEs. Participants were invited to complete the questionnaire. All subjects were asked to respond to the questionnaire and their responses were guaranteed to be confidential. All 190 students filled the questionnaire survey. There were 23 uncompleted responses which left 167 responses included for analysis. Therefore, the study group comprised of 167 students which includes 68 male students and 99 female students.

The questionnaire has 16 questions that are to be evaluated using 7-point Likert scale (ranging from 1 which means "strongly disagree" to 7 which means "strongly agree").

The questionnaire is based on a constructivist theoretical approach; thus, the content validity of the questionnaire is carefully design to query learners' attitudes toward the VRLE. To ensure validity of the instrument we conducted a content validity study involving four steps: determining who will review the questionnaire, preparing the reviewers for the validity test, setting up the survey, and analysis whether the survey is a valid instrument (Rubio, Berg-Weger, Tebb, Lee, & Rauch, 2003).

When determining who will review the questionnaire, we firstly invited three experts as participants. The second step was to prepare the content validity study. This step included providing the questionnaire to be used, and providing the purpose of the questionnaire and relevant factors related to previous studies (Brenton et al., 2007; Burdea & Coiffet, 2003; Holmes, 2007; Mantovani, 2003; Nicholson et al., 2006; Sherman & Craig, 2003; Shim et al., 2003; Tax'en & Naeve, 2002). These dimensions, along with source of references, are listed in Table 3. The third step in the content validation process was to prepare the content validity survey. The response form contains three columns (Rubio et al., 2003) that including representation, clarity, and comprehension for measuring each item. Representation will permit the participant to express whether or not they believe the question is accurately representing the content domain of the theoretical definition. Clarity will help reviewers to determine how clearly the question is to the participant. Comprehension will permit participants to decide if they desire to delete or keep the individual question. The final step in conducting content validity is to analyze the measure to determine if the survey is valid. This step consists of Content Validity Index (CVI), to determine if the instrument as a whole is valid. The CVI was conducted by counting the number of participants who have rate the question as a crucial item or not. When a question is rated to be crucial by more then one participant, we kept the question. The final questionnaire included 16 questions to investigate learners' attitudes toward VR learning environments.

Table 3
Dimensions of measurements.

Dimensions	References
Interaction	Burdea & Coiffet, 2003; Mantovani, 2003
Immersion	Burdea & Coiffet, 2003; Sherman & Craig, 2003; Tax'en & Naeve, 2002
Imagination	Burdea & Coiffet, 2003;
Motivation	Nicholson et al., 2006; Shim et al., 2003
Problem–solving capability	Brenton et al., 2007; Holmes, 2007
Collaborative learning	Pan et al., 2007; Sherman & Craig, 2003; Tax'en & Naeve, 2002
Intention to use	Davis, 1989; Lai, Huang, Liaw, & Huang, 2009; Liaw, Huang, & Chen, 2007

5.1.4. Results

The internal consistency reliability was assessed by computing Cronbach's αs. The alpha reliability was highly accepted ($\alpha = 0.94$) and coefficients of questionnaire items are presented in Table 4. Given the exploratory nature of the study, reliability of the scales was deemed adequate.

For investigating hypotheses H1 and H2, the predictive model is an acceptable statistical method. The results of stepwise multiple regressions for the path associated with the variables are presented in Table 5. To investigate H1, a regression analysis was performed to check the effects of immersion, interaction, and imagination on motivation of using VR. The result showed that three factors were all predictors and immersion had more contribution than other two ($F(3, 164) = 69.72$, $\underline{p}<0.001$, $R^2 = 0.55$). To examine H2, a regression analysis was performed to check the effects of immersion, interaction, and imagination on enhanced problem-solving capability after using VR. The result showed that three factors were all predictors and interaction had more prediction than other two ($F(3, 164) = 142.87$, $\underline{p}<0.001$, $R^2 = 0.72$).

Table 4
The mean, standard deviation, item-total correlations of VR from 1 which means "strongly disagree" to 7 which means "strongly agree".

Items	M	S.D.
Immersion		
The 3D simulation system creates a realistic-looking learning environment.	5.26	1.26
I pay more attention when using the 3D simulation system.	5.51	1.11
I feel immersed in the 3D simulation system.	5.29	1.23
Interaction		
I would like to share my VR learning experience with other learners.	4.79	1.30
The system can enhance teacher–learner interaction.	5.43	1.12
The system can enhance learner–learner interaction.	5.45	0.93
Imagination		
The system gives me more engagement to help me understand the learning content.	6.15	0.83
I feel the system improves my understanding by the imagination of the body structure.	6.11	0.87
I feel the system helps me better understand by the imagination the relative positions among organs.	5.92	1.15
Motivation		
It is impressed using the VR system for learning purposes.	5.74	1.05
The system can enhance my learning interest.	5.58	1.19
The system can enhance my learning motivation.	5.67	1.07
Enhanced problem-solving capability		
The system can enhance my learning capability.	5.40	1.20
The system can enhance my problem-solving capability.	5.50	1.12
The system can enhance my capability of knowledge construction.	5.38	1.14
The system can enhance my capability of knowledge management.	5.24	1.21

Table 5
Regression results of VR.

H*	Dependent variable	Independent variables	β	R^2	P
H1	Motivation	Immersion	0.32	0.46	<0.001
		Interaction	0.31	0.07	<0.001
		Imagination	0.24	0.02	$= 0.001$
H2	Enhanced problem-solving capability	Interaction	0.49	0.60	<0.001
		Immersion	0.26	0.10	<0.001
		Imagination	0.24	0.02	<0.001

H*: hypothesis.

5.2. *Case study 2: collaborative virtual reality learning environment*

The collaborative virtual reality environment for medical education, a Java-based program, is named 3D Human Organ Learning System – 3D-HOLS. With Java's cross-platform capability, 3D-HOLS runs in various system platforms. 3D-HOLS was being developed under both Windows and Linux environments. 3D-HOLS has been tested to be compatible with Windows XP, Vista, Mac OS X, and Red Hat Linux. 3D-HOLS provides two operating modes. The first mode is single user self-learning mode. In this mode, individual learners interact with 3D organs and read course web pages. The second mode is collaborative learning mode. This mode allows multiple learners to interact, practice and discuss in a virtual space. Fig. 2 depicts a typical classroom scenario. To begin collaborative learning, the instructor may initiate a 3D-HOLS server instance. Learners input instructor's IP address to connect to the server. The server instance has power to assign control privilege to a learner. These operations are shown in Fig. 2.

5.2.1. *Research hypotheses*

In order to examine users' attitudes and intentions of using 3D-HOLS system, the three features (immersion, interaction and imagination) of VR should be considered. The research model served as a guideline for formulating questionnaire and systematically performing statistical analyses to test the hypotheses. First, the three features were investigated to see whether they have positive influence on the collaborative learning. Thus, the hypothesis was proposed as follows:

H3: When using the 3D-HOLS system, the three features of interaction, immersion, and imagination will have positive impacts on collaborative learning.

Having investigated the relationships between the three features of interaction, immersion, and imagination and collaborative learning, the predictive relationship between collaborative learning and behavioral intention of using 3D-HOLS system was then examined. Therefore, a hypothesis was proposed:

H4. There is a positive correlation between collaborative learning and students' behavioral intention to the 3D-HOLS system.

5.2.2. *Participants and measurement*

Participants included students from school of Medicine, school of Pharmacy, college of Chinese Medicine and college of Health Care. All participants have taken at least one medical informatics course. There were 48 males and 28 females of a total of 76 valid responses. The data for this study were gathered by means of a paper-and-pencil survey. The questionnaire included 25 questions and used a 7-point Likert scales (ranging from 1 which means "strongly disagree" to 7 which means "strongly agree").

Fig. 2. Collaborative set up in a typical classroom setting. The instructor initiates a 3D-HOL server instance.

The questionnaire was initially drafted by referencing survey questions used in published literature (e.g., Lai et al., 2009; Liaw et al., 2007) that served as the basis of the conceptual model in this research. These dimensions, along with source of references, are listed in Table 3 (Burdea & Coiffet, 2003; Davis 1989; Lai et al., 2009; Liaw et al., 2007; Mantovani, 2003; Pan et al., 2007; Sherman & Craig, 2003; Tax'en & Naeve, 2002). A total of 40 items were first proposed. To enhance the content validity, three experts in the field were invited to review the questionnaire. Each item was assessed against the following criteria: (1) relevance to the objectives of this research, (2) appropriateness of the wording and (3) clarity of question. Items with assessed scores below a certain level were deleted. Unclear questions were modified or rephrased. To increase the validity of the measures used, a pre-test of 35 items was conducted. A total of 30 learners attended the pre-test. After pre-test, the questionnaire was revised to 25 items.

5.2.3. Results

The internal consistency reliability was assessed by computing Cronbach's αs. The alpha reliability was highly accepted ($\alpha = 0.92$) and coefficients of questionnaire items are presented in Table 6.

Multiple regression analysis has been widely adopted for empirically examining sets of linear causal relationships. For testing H3, a regression analysis was conducted to check the effect of interaction, immersion, and imagination on collaborative learning. The results explained that imagination, interaction and immersion variables were all predictors for the collaborative learning ($F(3,72) = 21.32$, $\underline{p} = 0.000$, $R^2 = 0.47$). The imagination was the biggest contributor (37%). On the other hand, the result of testing H4 was collaborative learning can predict intention to use the VR learning system ($F(1,74) = 105.71$, $\underline{p} = 0.000$, $R^2 = 0.59$) as shown in Table 7. The factor of

Table 6
The means, standard deviations of each question.

Items	M	S.D.
Interaction		
By using this system, I can easily translate and move 3D objects.	5.97	0.94
By using this system, I can easily rotate 3D objects.	6.00	0.92
By using this system, I can easily zoom in or zoom out 3D objects.	6.08	0.90
By using this system, I can easily observe 3D objects from various perspectives.	5.96	1.03
It is easy to interact with other team members by using this system.	5.47	1.04
Imagination		
I feel that it is easier to understand anatomical structures by using this system.	6.11	0.81
I feel that I have developed better understanding of structures and orientations of organs by using this system.	6.12	0.78
I feel that I have developed better understanding of relative positions of organs by using this system.	5.99	0.77
Using this system has helped me develop better understanding of shapes of every organ.	5.82	0.88
It is easy to use the collaborative learning functionality to help memorize the relative positions of organs.	5.67	0.86
It is useful to use the collaborative learning functionality to help memorize the relative positions of organs.	5.71	0.83
Immersion		
I feel the 3D simulated environment provided by this system is realistic.	5.34	1.07
I feel the 3D simulated environment provided by this system is immersive.	5.18	1.14
I feel that the 3D simulated environment makes me concentrate more while learning.	5.24	1.03
Collaborative learning		
I can immediately ask questions when problems arise.	5.46	0.94
I can immediately obtain help or solutions when necessary.	5.36	0.98
The collaborative learning system allows me to discuss with team members.	5.63	0.89
I am able to complete organ assembly exercises with team members.	5.61	0.94
It is useful to use the collaborative learning environment to study human anatomy.	5.57	0.85
I am indeed working with team members and solving problems together.	5.45	0.92
This system allows me to interact with classmates more frequently.	5.43	1.01
Intention to use the system		
I think this system can strengthen my intentions to learn.	5.26	0.87
I am willing to continue using this system in the future.	5.29	0.92
I wish that other classes also adopt 3D collaborative virtual system to facilitate my learning.	5.51	0.93
Overall, I think this system is worth to be a good learning tool.	5.76	0.83

Table 7
Regression analysis result.

H*	Dependent variables	Independent Variable	β	R^2	P
H3	Collaborative learning	Imagination	0.38	0.37	<0.001
		Immersion	0.25	0.07	<0.001
		Interaction	0.18	0.03	<0.001
H4	Intention to use the system	Collaborative learning	0.77	0.59	<0.001

H*: hypothesis.

collaborative learning by itself provides 59% of contributions for students' intention to use the 3D-HOLS. In addition, all *p*-values are below 0.1% significance levels.

6. Discussion

The VRLE may fail to meet learners' needs if learning activities and tasks are designed inside an inappropriate pedagogical approach (Shih & Yang, 2008). Instructional designers or educators face the challenge of deploying features of virtual reality into their 3D VR courses. Some principles that assist course design are as follows:

6.1. Learning from interacting with an artificial real environment

The ability of providing highly interactive learning experiences is one of the best-valued features of VR. Since Constructivism advocates that interaction with an "other" is relevant for a learning process, interaction in a VRLE can be a reasonable and valuable substitute for real experience. Learners can undertake activities that allow them to put new understanding and new skills into practice. Furthermore, VRLEs allow learners to acquire knowledge with less of a cognitive effort than that of traditional learning process (Chittaro & Ranon, 2007).

Moore (1989) proposed three types of interactions that are essential in a virtual learning environment. They are learner-to-instructor, learner-to-learner, and learner-to-content interactions. First, learner-to-instructor interaction is highly desirable by many learners. In a VRLE, an instructional avatar can trigger motivation, and provide feedback and support by interactions with learners. Next, learner-to-content interaction is the process of obtaining intellectual information and results in learners' understanding in the course content. Due to rich devices as shown in Table 1, VRLEs provide learners with faster and more realistic ways to interact with the learning contents. In some cases, role playing is a good strategy to try a different character in order to understand different point of views of the course content. Finally, learner-to-learner interaction is the exchange of information, ideas and interactions among learners. To collaborate in a VR learning environment, a shared space is established to help immerse participants work together. This space may have avatar representing learners added to the scenery of the virtual world (Sherman & Craig, 2003). From case study 1 and case study 2, it is shown that interaction is a crucial factor to affect learning performance.

6.2. Learning from problem solving to promote creativity

Many educators or researchers are concerned that new learning technology is changing too quickly. Therefore, learners should have the ability to transfer their skills into and apply them to whatever technology is salient. VRLEs that require imagination and immersion are good tools to train for problem solving abilities. A VRLE promotes learners to conceptualize experience at an abstract level and stimulates spontaneous and imaginative elaboration. As a result, VRLE not only provide rich teaching opportunities, but also help to improve learners' ability to analyze problems and explore new concepts. Based on case study 1, immersion, interaction, and imagination are all positive factors to enhance problem-solving capability in VRLEs.

6.3. Motivating learners to learn

Motivation is defined as an internal state or condition that activates, guides, and maintains or directs behavior (Kleinginna & Kleinginna, 1981). Motivation is a major cognitive factor influencing learning and thus better-motivated students can learn more effectively (Sutcliffe, 2003). Limniou et al.'s (2008) research results showed that 3D full immersive VRLEs will elevate a learner's interest and motivation compared with learning in a 2D animated environment. In addition, the novelty of VR technology as multisensory user interface promotes a learner's motivation by representing personality traits, by engaging media, and by stimulating dialogue. That is, features of interaction, imagination, and immersion are the main characteristics to attract and motivate students to learn in a VR learning environment.

Through the interactive and potential high repetition, VR can help to improve knowledge retention and student's motivation (Burdea & Coiffet, 2003). Sims's (2007) study noted that "lifelike, interactive digital characters, serving as mentors and role-playing actors, have been shown to significantly improve learner motivation and retention" (p.75). One of the great challenges to instructional designers of VRLE is how to integrate the VR features into curriculum in order to motivate students to learn (Shih & Yang, 2008). To promote motivation to learn in a VRLE, learners may participate in delivering instruction, or assist peers in collaborative learning. Additionally, in a comparison between immersive and non-immersive treatment groups, immersive learners showed better retention of symbolic information and revealed more interest in a VR class (Roussos et al., 1999). As the result, there is a general agreement that VRLEs can have a strong motivational impact (Bricken, 1991). Based on case study 1, immersion, interaction, and imagination have positive effects on increasing learners' motivation in VRLEs.

6.4. VR as a scaffolding tool for learners to learn

Based upon Vygotsky's ZPD, learners' ability can be improved if guidance or a scaffolding tool is provided. For example, avatars that replace real-life images have simple facial expressions such as smiles, frowns, and surprise. This has led to more realistic representations of the learner (Sutcliffe, 2003). In addition, VRLEs support immersive learning as they provide multisensory stimuli. 3D visualization helps to improve a learner's imagination by developing a learner's' capacity to detect and follow near invisible cues. Moreover, 3D visualization also provides a low-cost training environment (Chittaro & Ranon, 2007). Barab et al. (2000) found that 3D virtual worlds are an effective tool to foster undergraduate students' understanding of course contents. Through the use of VRLE, we are able to research what cognitive properties are associated with immersion, how immersion is generated in synthetic environments, and what its benefits are. The level and depth of immersion might influence the long-term retainable knowledge acquired through VRLEs (Tax'en & Naeve, 2002). From the case study 1 and case study 2 it follows that VR are effective as a scaffolding tool for learners to learn.

A summary of desirable constructivist strategies and designs embedded in educational VRLEs is included in Appendix A

7. Conclusions

As more theories and disciplines focus on VR technology, VR applications for education will get easier to use and create. In order to widely deploy VR for learning, educators need to understand the challenges of using VR technology for instruction rather than counting on the novelty of the approach. There are five issues to consider when employing VRLEs.

First, the usability of the VR interface design. As with many emerging technologies, VRLEs may be designed from a functionality point of view rather than ease of use in practical educational applications. The most common difficulties are VR navigation in using a 3D interface. Learners may easily get lost or unable to navigate their VRLEs (Chittaro & Ranon, 2007). Poor usability severely limits the effectiveness to deliver instruction, since VR applications may have problems ranging from creating motion sickness to users getting lost inside the application (Sutcliffe, 2003). Therefore, it is necessary to research why some user responses lead to simulation sickness, what their causes are, and what can be done to minimize their effects (Burdea & Coiffet, 2003).

Secondly, educators may be challenged by the skill levels required to design a VR course. VR tools require higher programming skills than traditional 2D tools. The educators may lack experience in using VR-based course design or having the difficulties in classroom practice (Chittaro & Ranon, 2007). In particular, an immersive VR learning systems requires high level of programming skills (Mantovani, 2003). For educators who lack a programming background, the process to create a VR learning system for educational application has been extremely challenging. Although there are an increasing number of applications that support teaching and learning in a VR space, perhaps the largest determining factor for user acceptance is how easily accessible a VR interface is for non-technical instructors. Thus, institutional support is necessary for educators without programming backgrounds.

Thirdly, a simulated world is not a real world. Learners may have a negative attitude toward learning in a VRLE since current VRs only approximate reality (Chittaro & Ranon, 2007). Recent advances in the design of interactive technologies have allowed the possibility of designing mixed reality environments in which realty is augmented by a virtual element. These mixed reality spaces provide exciting opportunities for designing innovative learning environments that hopefully make learning more interactive, effective, relevant and powerful especially for younger learners.

Next, cost effectiveness is an important factor in the design of a successful VR course. One of the biggest challenges remains the high cost of building a VRLE. The VR developers need to consider that an expensive system in the early development stage will be out-of-date due to rapid technology advance (Hanson & Shelton, 2008). VR technology is expensive when using hardware such as head-mounted displays. Most schools cannot afford such an expense (Chittaro & Ranon, 2007). VR technology does not currently offer compatible immersive hardware and special peripherals, and many researchers work to overcome this limitation (Chittaro & Ranon, 2007). For example, Soares and Zuffo (2004) designed an X3D browser that can run on a desktop computer.

Finally, the effectiveness of using VR learning environments should be further explored. It is important to measure the user's performance when engaging such an innovative technology. Likewise, user responses serve to iteratively improve the VR system or the particular application design (Burdea & Coiffet, 2003). There are some of the crucial factors to evaluate: which VR devices are most suitable for average learners; how VR technologies should be improved to better meet learners' needs, and what kind of designs will enhance a learner's performance (Burdea & Coiffet, 2003).

8. Limitations and future research

There are three limitations in this research we would like to mention. First, this research attempts to investigate learners' attitude toward VRLEs but does not compare the effectiveness of 3D vs 2D environments. There are not a lot of empirical studies or clear evidence that shows that student learning using 3D anatomical structures in VRLEs (i.e.WVBS-ATS) yields an improvement over the standard teaching modalities of text or 2D media. With respect to the educational effectiveness of 3D VR learning contents, a variety of results emerge. One study (Nicholson et al., 2006) shows support for a hypothesis that students are more receptive to understanding of anatomical relationships by using learning materials in 3D rather than 2D. The equivocal and negative results of previous studies may be due to the limitations of small sample size or a lack of full interactivity (Nicholson et al., 2006). Future research into the benefits and educational effectiveness of 3D virtual learning is warranted.

Secondly, designing VR learning environments takes time and is a complex task. Learners maybe confused about 3D related application features. A study by Levinson, Weaver, Garside, McGinn, and Norman (2007) shows that offering multiple view points simultaneously may impede learning, particularly for those with relatively poor spatial ability. VR products have a wide catalogue of usability problems ranging from motion sickness to navigation difficulty. Learners should expect that VR instruction decreases the extraneous cognitive load so that available cognitive resources can be devoted fully to learning (van Merrïenboer & Sweller, 2005). However, this needs to be supported by further research to evaluate the impact of multimedia resources upon student learning.

Finally, 3D VR technologies cannot yet offer easy and flexible support to the adoption of immersive hardware and special peripherals (Chittaro & Ranon, 2007). Much work is done to overcome this limitation. More flexible application support should be developed to improve both the realism and the usefulness of immersive virtual reality practice in the future (Chittaro & Ranon, 2007).

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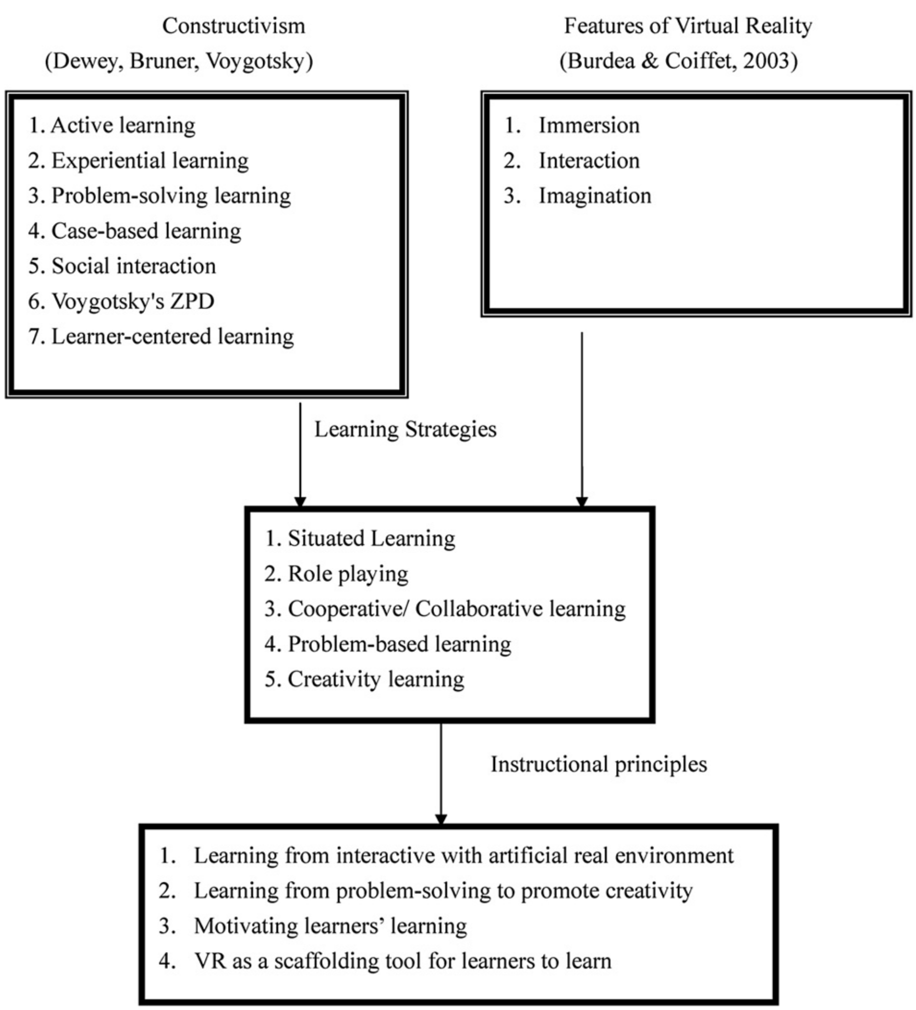
Appendix A

Constructivism applied in virtual reality learning.



References

Barab, S. A., Hay, K. E., Squire, K., Barnett, M., Schmidt, R., & Karrigan, K. (2000). Virtual solar system project: learning through a technology-rich, inquiry-based, participatory learning environment. *Journal of Science Education and Technology, 9*, 7–25.

Brenton, H., Hernandez, J., Bello, F., Strutton, P., Purkayastha, S., Firth, T., & Darzi, A. (2007). Using multimedia and Web3D to enhance anatomy teaching. *Computers & Education, 49*, 32–53.

Bricken, M. (1991). Virtual reality learning environments: potentials and challenges. *Computer Graphics, 25*(3), 178–184.

Burdea, G. C. (1999, May). *Haptic feedback for virtual reality, keynote address of Proceedings of International Workshop on Virtual prototyping*. Laval: France.

Burdea, G. C., & Coiffet, P. (2003). *Virtual reality technology* (2nd ed.). , New York: John Wiley & Sons.

Capin, T. K., Pandzic, I. S., Magnenat-Thalmann, N., & Thalmann, D. (1999). *Avatars in networked virtual environments*. New York: John Wiley & Sons.

Chittaro, L., & Ranon, R. (2007). Web3D technologies in learning, education and training: motivations, issues, opportunities. *Computers & Education, 49*, 3–18.

Claxton, G. (1999). *Wise up: The challenge of lifelong learning*. London: Bloomsbury.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*, 319–340.

Dewey, J. (1916). *Democracy and education*. New York: The Free Press. (1966).

Dickey, M. D. (2005). Brave new (interactive) worlds: a review of the design affordances and constraints of two 3D virtual worlds as interactive learning environments. *Interactive Learning Environments, 13*(1–2), 121–137.

Dimitropoulos, K., Manitsaris, A., & Mavridis, I. (2008). Building virtual reality environments for distance education on the web: a case study in medical education. *International Journal of Social Sciences, 2*(1), 62–70.

Durlach, N. I., & Mavor, A. S. (Eds.). (1995). *Virtual reality: Scientific and technological challenges*. Washington DC: National Academy Press.
Hanson, K., & Shelton, B. E. (2008). Design and development of virtual reality: analysis of challenges faced by educators. *Educational Technology & Society, 11*(1), 118–131.
Hodge, E. M., Tabrizi, M. H. N., Farwell, M. A., & Wuensch, K. L. (2008). Virtual reality classrooms strategies for creating a social presence. *International Journal of Social Science, 2*(2), 105–109.
Holmes, J. (2007). Designing agents to support learning by explaining. *Computers & Education, 48*, 523–547.
Hsiao, H.-S., Wong, K.-H., Wang, M.-J., Yu, K.-C., Chang, K.-E., & Sung, Y.-T. (2006). Using cognitive affective interaction model to construct on-line game for creativity. *Lecture Notes in Computer Science, 3942*.
Huang, H. M. (2002). Toward constructivism for adult learners in online learning environments. *British Journal of Educational Technology, 31*(1), 27–38.
Huang, H. M., & Liaw, S. S. (2004). Guiding distance educators in building web-based instructions. *International Journal of Instructional Media, 31*(2), 1–12.
Ieronutti, L., & Chittaro, L. (2007). Employing virtual humans for education and training in X3D/VRML worlds. *Computers & Education, 49*, 93–109.
Isaksen, S. G., & Parnes, S. J. (1985). Curriculum planning for creative thinking and problem solving. *The Journal of Creative Behavior, 19*(1), 1–29.
John, N. W. (2007). The impact of Web3D technologies on medical education and training. *Computers & Education, 49*, 19–31.
Jonassen, D. H. (1994). Thinking technology: toward a constructivist design model. *Educational Technology, 34*(2), 34–37.
Jonassen, D. H. (2000). Transforming learning with technology: beyond modernism and post-modernism or whoever controls the technology creates the reality. *Educational Technology, 40*(2), 21–25.
Karpouzis, K., Caridakis, G., Fotinea, S.-E., & Efthimiou, E. (2007). Educational resources and implementation of a Greek sign language synthesis architecture. *Computers & Education, 49*, 54–74.
Keefe, D. F., Acevedo, D., Miles, J., Drury, F., Swartz, S. M., & Laidlaw, D. H. (2008). Scientific sketching for collaborative VR visualization design. *IEEE Transactions on Visualization and Computer Graphics, 14*(4), 835–847.
Kleinginna, P., Jr., & Kleinginna, A. (1981). A categorized list of emotion definitions, with suggestions for a consensual definition. *Motivation and Emotion, 5*, 345–379.
Lai, C. M., Huang, H. M., Liaw, S. S., & Huang, W. W. (2009). A study of user's acceptance on three-dimensional virtual reality applied in medical education. *Bulletin of Educational Psychology, 40*(3), 341–362.
Levinson, A. J., Weaver, B., Garside, S., McGinn, H., & Norman, G. R. (2007). Virtual reality and brain anatomy: a randomized trial of e-learning instructional designs. *Medical Education, 41*, 495–501.
Liaw, S. S., Huang, H. M., & Chen, G. D. (2007). Surveying instructor and learner attitudes toward E-learning environments. *Computers & Education, 49*(4), 1066–1080.
Limniou, M., Roberts, D., & Papadopoulos, N. (2008). Full immersive virtual environment CAVETM in chemistry education. *Computer & Education, 51*, 584–593.
Lok, B., Ferdig, R. E., Raij, A., Johnsen, K., Dickerson, R., Coutts, J., et al. (2006). Applying virtual reality in medical communication education: current findings and potential teaching and learning benefits of immersive virtual patients. *Virtual Reality, 10*(3–4), 185–195.
Lu, J., Pan, Z., Lin, H., Zhang, M., & Shi, J. (2005). Virtual learning environment for medical education based on VRML and VTK. *Computers & Graphics, 29*, 283–288.
Maddux, C. D., Johnson, D. L., & Willis, J. W. (1997). *Educational computing, learning with tomorrow's technologies* (2nd ed.). Needham Height, MA: Allyn & Bacon.
Mantovani, F. (2003). VR learning: potential and challenges for the use of 3D environments in education and training. In G. Riva, & C. Galimberti (Eds.), *Towards cyberpsychology: Mind, cognitions and society in the internet age* (pp. 208–225). Amsterdam: IOS Press.
Mills, S., & de Araújo, M. M. T. (1999). Learning through virtual reality: a preliminary Investigation. *Interacting with Computers, 11*, 453–462.
Monahan, T., McArdle, G., & Bertolotto, M. (2008). Virtual reality for collaborative e-learning. *Computers & Education, 50*, 1339–1353.
Moore, M. G. (1989). Editorial: three type of interaction. *The American Journal of Distance Education, 3*(2), 1–6.
Moreno, R., & Mayer, R. E. (2002). Learning science in virtual reality multimedia environments: role of methods and media. *Journal of Educational Psychology, 94*(3), 598–610.
Nicholson, D. T., Chalk, C., Funnell, W>R. J., & Daniel, S. J. (2006). Can virtual reality improve anatomy education? A randomized controlled study of a computer-generated three-dimensional anatomical ear model. *Medical Education, 40*, 1081–1087.
Ornstein, A. C., & Hunkins, F. P. (1998). *Curriculum: Foundations, principles, and issues* (3rd ed.). Needham Heights: Allyn and Bacon.
Pan, Z., Cheok, A. D., Yang, H., Zhu, J., & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & Graphics, 30*, 20–28.
Pratt, D. R., Zyda, M., & Kelleher, K. (1995). Virtual reality: in the mind of the beholder. *IEEE Computer Society, 28*(7), 17–19.
Rauch, U. (2007). Who owns this space anyway? The Arts 3D VL Metaverse as a network of imagination, In. *Proceedings of ED-MEDIA, 2007*, 4249–4253.
Roussos, M., Johnson, A., Moher, T., Leigh, J., Vasilakis, C., & Barnes, C. (1999). Learning and building together in an immersive virtual world. *Presence, 8*(3), 247–263.
Roussou, M., Oliver, M., & Slater, M. (2008). Exploring activity theory as a tool for evaluating interactivity and learning in virtual environments for children. *Cognition Technology and Work, 10*, 141–153.
Rubio, D. M., Berg-Weger, M., Tebb, S. S., Lee, E. S., & Rauch, S. (2003). Objectifying content validity: conducting a content validity study in social work research. *Social Work Research, 27*, 94–104.
Sherman, W. R., & Craig, A. B. (2003). *Understanding virtual reality*. New York: Morgan Kaufmann Publishers.
Shih, Y.-C., & Yang, M.-T. (2008). A collaborative virtual environment for situated language learning using VEC3D. *Educational Technology & Society, 11*(1), 56–68.
Shim, K.-C., Park, J.-S., Kim, H.-S., Kim, J.-H., Park, Y.-C., & Ryu, H. I. (2003). Application of virtual reality technology in biology education. *Journal of Biological Education, 37*(2), 71–74.
Sims, E. M. (2007). Reusable, lifelike virtual humans for mentoring and role-playing. *Computers & Education, 49*, 75–92.
Singer, J. (2000). Imagination. In A. Kazdin (Ed.), *Encyclopedia of psychology, Vol. 4* (pp. 227–230). New York: Oxford University Press.
Soares, L. P., & Zuffo, M. K. (2004). Jinx: an X3D browser for VR immersive simulation based on clusters of commodity computers. In Proceedings of the 9th international conference on 3D web technology, 79–86.
Stone, R. J. (2002). Applications of virtual environments: an overview. In K. Stanney (Ed.), *Handbook of virtual environments: Design, implementation and applications* (pp. 827–856). Mahwah NJ: Lawrence Erlbaum Associates.
Sutcliffe, A. (2003). *Multimedia and virtual reality*. New York: Lawrence Erlbaum Associates.
Sutcliffe, A., & Gault, B. (2004). Heuristic evaluation of virtual reality applications. *Interacting with Computers, 16*, 831–849.
Tax'en, G., & Naeve, A. (2002). A system for exploring open issues in VR-based education. *Computers & Graphics, 26*, 593–598.
Turkle, S. (2007, Aug). Constructions and reconstructions of self in virtual reality: playing in the MUDs. http://web.mit.edu/sturkle/www/constructions.html Access: 2007/August.
Turvey, K. (2006). Towards deeper learning through creativity within online communities in primary education. *Computers & Education, 46*, 309–321.
Van Merrïenboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: recent developments and future directions. *Educational Psychology Review, 17*(2), 147–171.
Virvou, M., & Katsionis, G. (2008). On the usability and likeability of virtual reality games for education: the case of VR-ENGAGE. *Computers & Education, 50*(1), 154–178.
Wetzel, D., Radtke, P., & Stern, H. (1994). *Instructional effectiveness of video media*. Hillsdale, NJ: Erlbaum.
Wollensak, A. (2002). Curricular modules: 3D and immersive visualization tools for Learning. *Computers & Graphics, 26*, 599–602.