A Review of Using Virtual Reality for Learning

Elinda Ai-Lim Lee and Kok Wai Wong

School of Information Technology, Murdoch University, South Street Campus, Murdoch, Western Australia 6150
{elinda.lee,k.wong}@murdoch.edu.au

Abstract. The major concern of educators is how to enhance the outcome of education. Better education media used to assist teaching has constantly been sought by researchers in the educational technology domain. Virtual Reality (VR) has been identified as one of them. Many have agreed that VR could help to improve performance and conceptual understanding on a specific range of task. However, there is limited understanding of how VR could enhance the learning outcomes. This paper reviews types of VR that have been used for learning, the theoretical framework for a VR learning environment, and instructional design for VR-based learning environment. Further research is suggested for VR-based learning environment.

1 Introduction

Virtual Reality (VR) has been used as education tools for some time in applied fields such as aviation and medical imaging, and it has also been used in schools and colleges in the recent years [1]. One of the main reasons why VR has been used for educational and training purposes is the support of high interactivity and the abilities to present a virtual environment that resembles the real world. With this technology, learners can explore and manipulate three-dimensional (3-D) interactive environment. However, VR is just an educational tool which can be used to support learning, which might not work for all kind of learning [2]. This paper reviews the types of VR that have been used for learning but does not attempt to cover all VR technologies mainly because this technology is developing rapidly and new methods are continually emerging everyday [3]. In addition, this paper also reviews theoretical and instructional design models that have been developed specifically for VR-based learning environment.

2 Definition and Types of VR

Basically, VR can be classified into two major types based on the level of interaction and immersive environment. In non-immersive virtual environment, computer simulation is represented on a conventional personal computer and is usually explored by keyboard, mouse, wand, joystick or touch screen [1, 2]. On the other hand, immersive VR environments are presented on multiple, room-size screen or through a stereoscopic, head-mounted display unit [1, 2, 4]. Special hardware such as gloves, suits and high-end

Z. Pan et al. (Eds.): Transactions on Edutainment I, LNCS 5080, pp. 231–241, 2008.

computer systems might be needed in immersive VR environment. Lately, VR computer simulation has been defined as a highly interactive, 3-D computer generated program in a multimedia environment which provides the effect of immersion to the users [5]. Users are able to become a participant in abstract spaces which is a computer generated version of real world objects (for example, chemical molecules or geometric models) or processes (for example, population growth or biological). These simulations could take many forms, ranging from computer renderings of 3-D geometric shapes to highly interactive, computerized laboratory experiments [1].

Allen et al. [3] have classified three levels of immersive VR:

i) Partially or semi immersive VR
A system that gives the users a feeling of being at least slightly immersive by a virtual environment [6] where users remain aware of their real world [3]. For example, a workbench that uses a table-top metaphor where special goggles are used to view the 3-D object on a table-top; a fish tank VR which uses monitor-based systems to display stereo image of a 3-D scene that is viewed by using shutter glasses; or a sensor-glove is used to interact with the world by using natural movement with the glove through a desk-top screen for visualization.

ii) Fully immersive VR
A system that uses special hardware where users are completely isolated from the physical world outside, to fully immerse in the virtual environment [6]. Head-mounted device, sensor gloves and sensors are attached to the user's body to detect, translate real movement into virtual activity. For example, CAVE, a projection-based VR system is a room with multi walls where the stereoscopic view of the virtual world is generated according to the user's head position and orientation, and users can move around the 'cave'[7].

iii) Augmented Reality
A system where users can have access to a combination of VR and real-word attributes by incorporating computer graphics objects into real world scene [3, 5]. It is also known as Mixed Reality. For example, a user dissects a virtual dummy frog using head-mounted device, or table-top display and a real scalpel.

Depending on the level of interaction and the complexity of the ambience, Silva, Cardoso, Mendes, Takahashi & Martins [8] classify two types of VR: VR on-line and VR off-line. With VR off-line, more complex simulation and perfect modeling objects in terms of textures, materials and animation is possible. As for VR on-line, there is more limitation in their multimedia aspect because care need to be taken for the size of files transmitted through the internet. VR on-line and VR off-line by Silva, Cardoso, Mendes, Takahashi & Martins [8] is somehow parallel to immersive and non-immersive VR respectively.

There are a number of methods to generate a non-immersive virtual environment on a personal computer. Web3D open standards, such as X3D (eXtensible 3D Graphics) and VRML (Virtual Reality Modeling Language) are used to generate 3-D interactive graphical representations that can be delivered over the World Wide Web [9, 10]. VRML provides a language that integrates 3D graphics, 2D graphics, text, and multimedia into a coherent model, and combines them with scripting languages and network capabilities (Carey & Bell 1997, cited in, [11]). Whilst X3D is the successor of VRML which was approved by the ISO in 2004 [11]. X3D inherits most of the design choices and technical features of VRML and improves upon VRML mainly in three areas: adds new nodes and capabilities; includes additional data encoding formats; and divides the language into functional areas called components [11]. On the other hand, Quick Time VR which is a type of image file that allows the creation and viewing of photographically captured panoramas can also be used [12]. Users can explore the objects through images taken at multiple viewing angles [12].

The virtual world used in learning could be of two types: virtual world that mimics the real world scenario (for example, a virtual museum is created to study the history, art and heritage of a place or a virtual scene shows how bacteria enter human body) or just computer simulation with 3-D geometry objects in an interactive multimedia environment (for example, ripping and unfolding a cube or generating a bottle design from a 2-D diagram). What makes VR an impressive tool for learning is in addition to multimedia, VR allows learners to immerse in a 3-D environment and feel 'in the middle of another environment' that extremely close to reality [13, 14] .

3 Application of VR in Educational Settings

VR is becoming increasingly popular for a variety of applications in today's society. It has become well suited and a powerful media for use in school [15], especially for science and mathematics which involve the study of natural phenomena and abstract concepts. The reason being the ability of this technology to make what is abstract and intangible to become concrete and manipulable [1]. Nevertheless, the application of VR in arts and humanities studies should not be ignored. For example, the ability to model on places that cannot be visited, such as historical cities and zoos could be beneficial in social studies, culture and foreign languages. Students could immerse themselves in historical or fictional events filled with foreign cultures and explore them first hand [1, 4].

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

3.1 Non-immersive VR Applications

The VRML-based 3-D objects used by Song and Lee [16] to teach geometry in middle school shows a positive effect on students' learning of geometric topics. And the VR Physic Simulation (VRPS) which is created by Kim, Park, Lee, Yuk, & Lee [17] helps students to learn physics concepts such as wave propagation, ray optics relative velocity and electric machines at the level of high school and college has also shown that students understand the subject matter better. An interactive VR distance learning program on stream erosion in geosciences is developed by Li et al. [18] with the aim to help motivate learners with concrete information which is perceptually easy to process and understand. In their project, VR is used to visualize the effects of related earth science concepts or phenomena, and the result shows that the VR of stream erosion may enhance students' learning in geosciences [18].

3.2 Immersive VR Applications

Complex spatial problems and relationships can be comprehended better and faster than with traditional method when Construct3D, a 3-D geometric construction tool is used [19]. The Construct3D uses a stereoscopic head-mounted display and a Personal Interaction Panel developed by Kaufmann et al. [19] for used in mathematics and geometry education at high school and university level. The Virtual Reality Gorilla Exhibit is an immersive VR developed at Georgia Institute of Technology for Zoo Atlanta to help educate people about gorillas, their lifestyle and their plight as an endangered species [20]. The positive reactions from the users suggest that it is possible to use VR as a general educational tool to teach middle school students the concepts about gorilla behaviors and social interactions [20]. These learning objectives normally cannot be achieved just by visiting the zoo [20].

Liu, Cheok, Lim and Theng [21] have created a mixed reality classroom. Two systems are developed: the solar system and the plant system. In the solar system, users sit around an operation table and used a head-mounted device to view the virtual solar system. Cups are used for the interactions between the users and the virtual objects. For instance, users can use the cup to pick up part of the earth to observe its inner structure. As for the plant system, four topics regarding plant are created: Reproductive, Seeds Dispersal, Seeds Germination and Photosynthesis. For example, in seeds germination, users have to set the right conditions to see a bug growing. The preliminary study conducted by Liu et al. [21] indicates participants' intention to use mixed reality for learning which is influenced directly by perceived usefulness, and indirectly through perceived ease of use and social influence.

In spite of the positive findings of some research, it would be premature to make broad recommendations regarding the use of VR as a curriculum enhancement [1]. It should not be used indiscriminately in any educational program [22]. 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 or participant factors and their relationships in this domain should be developed further. Relevant constructs and their relationships need to be examined for the effective use of VR in education because all these constructs plays an important role in shaping the learning process and learning outcomes [23]. Strangman and Hall [1] also mention that factors that influence the effectiveness of computer simulations have not been extensively or systematically examined. Sanchez et al. [22] mention that it is a challenging and an outstanding task to study the right and applicable use of VR in education. Questions posed by them remained unanswered [22]: What are the appropriate theories and/or models to guide the design and development of a VR learning environment? What disciplines or subjects and what sorts of students require this technology? How are VR systems capable of improving the quality of student learning? When and why VR is irreplaceable?

Study on the use of VR for learning has been endeavoured with most of the efforts focus on implementing special-purpose systems or limited-scope prototypes [22]. Nevertheless, a matured framework still needs to be formalized to answer those questions mentioned above.

4 Reviews of Theoretical Model

The literature search shows only one model that has been developed to understand how VR influences the learning process and learning outcomes in a VR learning environment. Although designers and evaluators of VR systems know that this technology has significant potential to facilitate and improve learning, but little is known about the aspects of this technology that are best leveraged for enhancing understanding [23, 24]. In other words, we need to know when and how to use VR's features to support different learning tasks and various learners' needs to maximize the benefits of employing this technology in learning [23].

Knowing that VR's affordances and other factors of a learning environment all play a role in shaping learning process and the learning outcomes, through Project ScienceSpace, Salzman, Dede, Loftin and Chen [23] develop a model for understanding how VR aids complex conceptual learning in an immersive virtual learning environment. ScienceSpace project consists of three immersive virtual environments for science instruction: Newton World, Maxwell World and Pauling World. In Newton World, learners can become a ball that moving along an alley to learn Newton's laws of motion. Multisensory cues are used to direct users' attention to important variables such as mass, velocity and energy [23]. In Maxwell world, learners can build and explore electric fields. They can directly experience the field by becoming a test charge and be propelled through the field by the electric forces [25]. In Pauling World, learners explore the atoms and bonds of a simple and complex molecule for a lesson in chemistry [23].

This immersive virtual learning model describes how VR's features work together with other factors such as the concept that is to be learnt, learner characteristics, the interaction and learning experience that influence the learning process which, in turn, affect the learning outcomes (see Fig. 1). The learning process of this model is defined as the understanding development process that occurs while a person is completing lessons within the VR learning environment. In other words, it means the ability to do predictions, observations, and comparisons during the process of learning [23]. The assessment of the value of the VR's features is done through students' comments during the learning process, administrator observations during the lesson, usability questionnaires, interview feedback, and pre- and post-lesson knowledge assessments. The model stresses on the type of relationships that are important to examine rather than the direction (positive or negative) or strength (strong or weak) of the relationships which will differ depending on the specific nature of the virtual learning environment [23].

According to the model of Salzman et al. [23], before designing and developing an immersive VR learning environment, it is important to analyze the concepts to be mastered for the appropriate usage of VR's features because VR's features can support the learning of one concept, and at the same time hinder the learning of another. The three features afforded by the VR technology in this model are immersive 3-D representations, multiple frames of references and multisensory cues. The model shows that the relationships between the VR's features and learning may be moderated by the learner characteristics such as gender, domain experience, spatial ability, computer experience, motion sickness history and immersive tendencies. And these learner characteristics may also influence the learning and interaction experience as each individual has a unique experience in a learning environment. Finally, the VR's features also influence the quality of the interaction and learning experiences which,

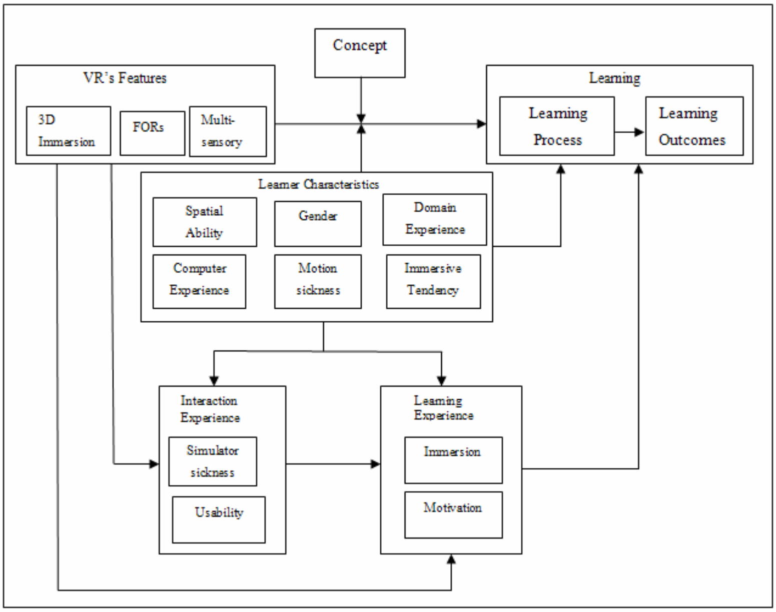

Fig. 1. Model describing how VR's features, the concept one is being asked, learner characteristics, and the interaction and learning experiences work together to influence the learning outcomes in VR learning environments [23]

in turn, affect the learning. The learning experience such as motivation and presence, and interaction experience such as usability and simulator sickness are the identified variables that can be affected by VR's features. Additionally, the interaction experience may also influence the learning experience which, in turn, affects the learning.

The model by Salzman et al. [23] can be a useful guide in designing, developing and evaluating VR learning environment. For instance, which concepts to address, which features are appropriate, and how interfaces should be designed to support usability. This model might have shed some light on what sort of students might gain benefits through VR learning and how VR enhances learning by looking into the interaction and learning experience. Nevertheless, more research is definitely needed to look into the appropriate theories and/or models to guide the design and development of a VR learning environment; how are VR systems capable of improving the quality of student learning by investigating the psychological learning process of the learners; and to investigate how other relevant constructs or factors work together to influence VR learning environment. Further investigation on the role of individual characteristics in VR learning environment is also needed.

5 Instructional Design Theoretical Framework

In order to use VR as a learning tool, an appropriate instructional design that guides the development of a VR-based learning environment is imperative because it is the

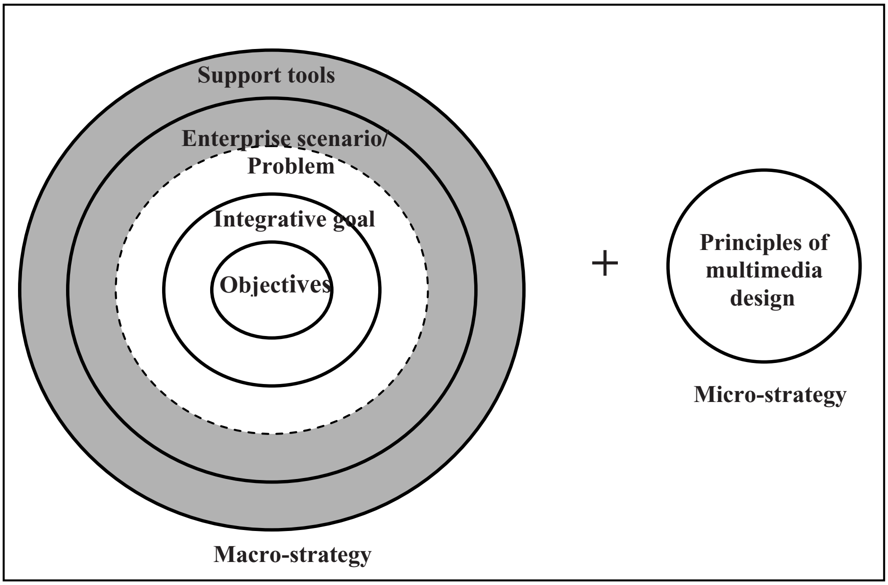

Fig. 2. Theoretical framework for designing a desktop VR-based learning environment [28]

instructional implementation of the technology that determines learning outcomes [26]. Clark [27] claims that "*if learning occurs as a result of exposure to any media, the learning is caused by the instructional method embedded in the media presentation.*" Chen, Toh and Wan [28] have proposed an instructional design theoretical framework that offers design guidelines for desktop VR-based learning environment. Based on this instructional design theoretical framework, Chen et al. [28] have designed and developed a VR-based learning environment to assist novice car drivers to better comprehend the traffic rules. The framework comprises macro-strategy and micro-strategy (see Fig. 2). The macro-strategy combines the concept of integrative goals proposed by Gagné and Merill [29] and the model of designing constructivist learning environment proposed by Jonassen [30]. Whilst the micro-strategy is based on the cognitive theory of multimedia derived by Mayer [31] which is used to guide the design of the instructional message.

Goals that are to be achieved from learning are presumed to be the starting point of the instructional design process [29]. Thus, this framework starts with identifying the instructional goal which is a combination of several individual objectives that are to be integrated into a comprehensive purposeful activity known as enterprise. This is the concept of integrative goal proposed by Gagné & Merill [29]. These individual objectives may fall in the category of verbal information, labels, intellectual skills, or cognitive strategies (Gagné 1985, cited in [28]). The instructional designer then needs to design instruction that enables the learners to acquire the capability of achieving this integrated outcome, which is called the enterprise scenario [28].

VR is capable of affording constructivist learning because it provides a highly interactive environment in which learners are active participant in a computer-generated world [17, 32]. Winn [33] mentions that constructivism provides the best learning theory on which to develop educational applications of VR and Jonassen [30] has provided a useful guidance for designing constructivist learning environment which focuses on problems because learners learn through their attempt in solving problems. Thus, in the macro-strategy, the framework of Chen et al. [28] stresses on the importance of posing an appropriate problem which includes three integrated components: the problem context, problem presentation, and problem manipulation. Basically, this means that in order to achieve the integrated outcome or enterprise scenario, the instructional designer needs to select the appropriate problem context, problem presentation, and problem manipulation space.

In a constructivist learning environment, the problem statement must describe all the contextual factors that surround the problem to enable the learners to understand the problem; the problem representation must be interesting, appealing and engaging which is able to perturb the learner; and the problem manipulation space must enable learner to manipulate or experiment with the problem for them to assume some ownership of the problem [28].

Constructivist learning emphasizes on learners to construct knowledge themselves and be an active learner. Constructivists believe that individual's knowledge is a function of one prior's experiences, mental constructs, and beliefs that are used to interpret events and objects [34]. Therefore, the instructional design has to provide various supports that may assist the learners to construct their knowledge and engage in meaningful learning in the learning environment. These support tools include related cases, information resources, cognitive tools, conversation and collaboration tools, and social or contextual support [28]. Related cases refer to a set of related experiences or knowledge that the learner can refer to. Information resources refer to the rich sources of information that help learners to construct their mental models and comprehend the problems. Cognitive tools are tools that can scaffold the learners' ability to perform the task. Conversation and collaboration tools allow learners to communicate, collaborate and share ideas. Whilst social or contextual support stresses on the importance of considering contextual factors, such as physical, organizational, and cultural aspects of the environment [2].

To complement the macro-strategy, Mayer's [31] principles of multimedia design is served as the micro-strategy to guide the design of instructional message in the

Table 1. Principles of Multimedia Design (Mayer, 2002)

Principle	Description
Multimedia Principle	Learners learn better from words and pictures than from words alone.
Spatial Contiguity Principle	Learners learn better when corresponding words and pictures are presented near rather than far from each other on the page or screen.
Coherence Principle	Learners learn better when extraneous words, pictures, and sounds are excluded rather than included.
Modality Principle	Learners learn better from animation and narration than from animation and on-screen text.
Redundancy Principle	Learners learn better from animation and narration than from animation, narration, and on-screen text.

learning environment for a more effective learning. The five principles of multimedia adopted by Chen et al. [28] are multimedia principle, spatial contiguity principle, coherence principle, modality principle and redundancy principle. A description of these five principles is shown in Table 1.

The instructional design theoretical framework by Chen at al. [28] can be used to guide the design of a desktop VR-based learning environment that fits the constructivist learning environment. Empirical findings by Chen [2] show that this framework may function as an initial structure to guide the instructional design of a VR-based learning environment which can be further refined and/or revised to generate a more robust model.

6 Conclusions

This paper has given a review of the VR used for learning. We first started by examining the definition and types of VR available to be used for learning. From literature search, it can be observed that there are already some applications of VR for learning that have been implemented. However, implementing VR for learning without examining the pedagogical theories and the effect of using VR for learning would not be convincing. We have reviewed frameworks that have been applied in this domain. However, we realized that the framework is still immature. There is a need of a detailed theoretical framework for VR-based learning environment that could guide future development efforts. Key factors related to learning effectiveness in a VR-based learning environment and the influence of VR technology on psychological learning process should not be ignored. A critical step towards achieving an informed design of a VR-based learning environment is the investigation of the relationship among the relevant constructs or participant factors, the learning process and the learning outcomes. And only through this investigation that we would be able to answer to those implementation questions.

References

1. Strangman, N., Hall, T.: Virtual reality/simulations. National Center on Accessing the General Curriculum, Wakefield (2003), http://www.cast.org/publications/ncac/ncac_vr.html
2. Chen, C.J.: The design, development and evaluation of a virtual reality-based learning environment: Its efficacy in novice car driver instruction. Centre for Instructional Technology and Multimedia. University Science Malaysia (2005)
3. Allen, K., Austin, T., Beach, R., Bergstrom, A., Exon, S., Fabri, M., Fencott, C., Fernie, K., Gerhard, M., Grout, C., Jeffrey, S.: Creating and using virtual reality: A guide for the arts and humanities (2002), http://vads.ahds.ac.uk/guides/vr_guide/sect11.html
4. Dalgarno, B., Hedberg, J., Harper, B.: The contribution of 3D environments to conceptual understanding. In: ASCILITE 2002, Auckland, New Zealand, pp. 149–158 (2002)
5. Pan, Z., Cheok, A.D., Yang, H., Zhu, J., Shi, J.: Virtual reality and mixed reality for virtual learning environments. Computers & Graphics 30, 20–28 (2006)

6. Fällman, D.: Virtual reality in education: On-line survey (2000), http://www.informatik.umu.se/~dfallman/projects/vrie
7. Cruz-Neira, C., Sandin, D.J., DeFanti, T.A.: Surround-screen projection-based virtual reality: the design and implementation of the cave. In: 20th Annual Conference on Computer Graphics and Interactive Technique, pp. 135–142. ACM Press, New York (1993)
8. Silva, L.F., Cardoso, A., Mendes, E.B., Takahashi, E.K., Martins, S.: Associating non-immersive virtual reality and cognitive tools for Physics Teaching. In: 9th International Conference on Engineering Education, San Juan, Puerto Rico (2006)
9. Ashdown, N., Forestiero, S.: A guide to VRML 2.0 and an Evaluation of VRML Modelling Tools (1998), http://www.agocg.ac.uk/train/vrml2rep/cover.htm
10. Ieronutti, L., Chittaro, L.: Employing virtual humans for education and training in X3D/VRML worlds. Computers & Education 49, 93–109 (2007)
11. Chittaro, L., Ranon, R.: Web3D technologies in learning, education and training: Motivations, issues, opportunities. Computers & Education 49, 3–18 (2007)
12. Wikipedia: Quick time VR (2008), http://en.wikipedia.org/wiki/QuickTime_VR
13. Inoue, Y.: Effects of virtual reality support compared to video support in a high-school world geography class. Campus - Wide Information Systems 16, 95 (1999)
14. Kommers, P.A.M., Zhao, Z.M.: Virtual reality for education, http://projects.edte.utwente.nl/proo/trend4.htm
15. Roussou, M.: Learning by doing and learning through play: An exploration of interactivity in virtual environments for children. Computers in Entertainment 2, 10–23 (2004)
16. Song, K.S., Lee, W.Y.: A virtual reality application for geometry classes. Journal of Computer Assisted Learning 18, 149–156 (2002)
17. Kim, J.H., Park, S.T., Lee, H., Yuk, K.C., Lee, H.: Virtual reality simulations in physics education (2001), http://imej.wfu.edu/articles/2001/2/02/index.asp
18. Li, F.C., Angelier, J., Deffontaines, B., Hu, J.C., Hsu, S.H., Lee, C.H., Huang, C.H., Chen, C.H.: A virtual reality application for distance learning of Taiwan stream erosion in Geosciences. In: International Conference on Computers in Education (2002)
19. Kaufmann, H., Schmalstieg, D., Wagner, M.: Construct3D: A virtual reality application for mathematics and geometry education. Education and Information Technologies 5, 263–276 (2000)
20. Allison, D., Hodges, L.F.: Virtual reality for education. In: ACM Symposium on Virtual Reality Software and Technology, pp. 160–165. ACM Press, NY, USA, Seoul, Korea (2000)
21. Liu, W., Cheok, A.D., Lim, C.M.L., Theng, Y.L.: Mixed reality classroom - learning from entertainment. In: Second International Conference on Digital Interactive Media in Entertainment and Arts, Perth, Australia (2007)
22. Sanchez, A., Barreiro, J.M., Maojo, V.: Design of virtual reality systems for education: a cognitive approach. Education and Information Technologies 5, 345–362 (2000)
23. Salzman, M.C., Dede, C., Loftin, R.B., Chen, J.: A model for understanding how virtual reality aids complex conceptual learning. Presence: Teleoperators and Virtual Environments 8, 293–316 (1999)
24. Barnett, M., Yamagatah-Lynch, L., Keating, T., Barab, S.A., Hay, K.E.: Using virtual reality computer models to support student understanding of astronomical concepts. Journal of computers in Mathematics and Science Teaching 24, 333–356 (2005)
25. Salzman, M.C., Loftin, R.B.: ScienceSpace: Lessons for designing immersive virtual realities. In: CHI 1996, Vancouver, Canada (1996)
26. Collins, A.: Anticipating the impact of multimedia in education: Lessons from the literature. computers in Adult Education and Training 2, 136–149 (1995)

27. Clark, R.E.: Media will never influence learning. Educational Technology, Research and Development 42, 21–29 (1994)
28. Chen, C.J., Toh, S.C., Wan, M.F.: The theoretical framework for designing desktop virtual reality-based learning environment. Journal of Interactive Learning Research 15, 147–167 (2004)
29. Gagné, R.M., Merrill, M.D.: Integrative goals for instructional design. Education Technology Research and Development 38, 23–30 (1990)
30. Jonassen, D.H.: Designing constructivist learning environment. In: Reigeluth, C.M. (ed.) Instructional-design theories and models: A new paradigm of instructional theory, vol. 2, pp. 215–239. Merrill Prentice Hall, NJ (1999)
31. Mayer, R.E.: Multimedia learning. Cambridge University Press, Cambridge (2002)
32. Salis, C., Pantelidis, V.S.: Designing virtual environments for instruction: concepts and considerations. VR in the Schools 2, 6–10 (1997)
33. Winn, W.: A conceptual basis for educational applications of virtual reality (1993), http://www.hitl.washington.edu/projects/learning_center/winn/winn-R-93-9.txt
34. Mergel, B.: Instructional design & learning theory (1998), http://www.usask.ca/education/coursework/802papers/mergel/brenda.htm