Virtual Reality: An Emerging Technology for Learning

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Abstract—Better educational media that assist in learning have been constantly sought by researchers in the educational technology domain to enhance the outcomes of education. Virtual Reality (VR) has been identified as one of them. Proponents of VR believe that it is an excellent educational tool, which could help to improve performance and conceptual understanding on a specific range of tasks. Nonetheless, there is limited understanding of how VR could enhance the learning outcomes. This paper reviews the types of VR that have been used for teaching and learning, how does VR support constructivist learning and the theoretical framework for a VR learning environment. Further research is suggested for VR-based learning environment.

I. INTRODUCTION

The use of Virtual Reality (VR) as an educational tool is proliferating. Not only that it has been used in applied fields such as aviation and medical imaging, it has also been used in schools and colleges in the recent years [1]. The abilities to provide real time visualization and interaction within a virtual world that resembles the real world have made it widely used for educational and training purposes. With this technology, learners play a more active role in learning by exploring and manipulating three-dimensional (3-D) interactive environment to have a feel of “being there” in a virtual environment that is extremely close to reality. However, VR is just an educational tool which can be used to support learning, and should not be seen as a panacea that will work for all kinds 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 the relationships between VR and constructivist learning, and the theoretical model that has been developed specifically for VR-based learning environment.

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], and is usually termed as desktop VR. 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 computer systems might be needed in immersive VR environment. 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]. Though desktop VR is considered less immersive; however, Dalgarno, Hedberg & Harper [4] argue that “the sense of presence or immersion in a 3-D environment occurs as a consequence of the fidelity of representational and the high degree of interaction or user control, rather than just a unique attribute of the environment.” In the virtual world, users are able to become a participant in abstract spaces which are computer generated version of real world objects (for example, chemical molecules or geometric models) or processes (for example, population growth or cell division). These simulations could take many forms, ranging from computer renderings of 3-D geometric shapes to highly interactive, computerized laboratory experiments [1].

This paper will discuss the types of VR, the application of VR in educational settings, the capabilities of VR in supporting constructivist learning and the theoretical model of using VR in learning.

II. TYPES OF VR

According to Allen et al. [3], there are 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 a user’s body to detect, translate real movement into virtual activity. For example, CAVE, a projection-based VR system which is a room with multi walls where the stereoscopic view of the virtual
world is generated according to the user’s head position and orientation, and users can move around the ‘cave’ [7].

iii) Augmented Reality

A system where users can have access to a combination of VR and real-world attributes by incorporating computer graphics objects into real world 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.

On the other hand, Silva, Cardoso, Mendes, Takahashi & Martins [8] classify two types of VR based on the level of interaction and the complexity of the ambience: VR on-line and VR off-line. With VR off-line, more complex simulation and perfect modelling objects in terms of textures, materials and animations are possible. However, for VR on-line, there are more limitations in their multimedia aspects because care need to be taken for the size of files transmitted through the internet. VR on-line and VR off-line by Silva et al. [8] are somehow parallel to immersive and non-immersive VR respectively.

Due to the high cost of immersive VR systems and the inherent problems associated with them such as simulator sickness, desktop VR provides an alternative to immersive VR systems because it retains the benefits of real time visualization and interaction within a virtual world [9]. According to Youngbult [10], such non-immersive VR is much more mature and ubiquitously used in many different application areas as compared with the immersive technology.

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 Modelling Language) are used to generate 3-D interactive graphical representations that can be delivered over the World Wide Web [11], [12]. 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, [13]). Whilst X3D is the successor of VRML which was approved by the ISO in 2004 [13]. It is a powerful collection of open standards for 3-D visual effects, behavioural modelling and interaction. 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 [13]. On the other hand, Quick Time VR which is a type of image files that allows the creation and viewing of photographically captured panoramas can also be used [14]. Users can explore the objects through images taken at multiple viewing angles [14].

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 enters 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 [15], [16].

### III. 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 [17], 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.

#### A. Non Immersive VR Applications

The VRML-based 3-D objects used by Song and Lee [18] 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 [19] 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. [20] 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 [20].

#### B. 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 [21]. The Construct3D uses a stereoscopic head-mounted display and a Personal Interaction Panel developed by Kaufmann et al. [21] 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 [22]. 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 behaviours and social interactions [22]. These learning objectives normally cannot be achieved just by visiting the zoo [22].

Liu, Cheok, Lim and Theng [23] 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 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. [23] 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.

IV. VR AND CONSTRUCTIVIST LEARNING

A new paradigm of instructional design which focuses on the learners has been proposed by Reigeluth [24]. Whilst the current paradigm of instructional design focuses on presenting material and conveying information from instructors to learners, the new paradigm is student-centric. It focuses on helping learners to construct and build on their own new knowledge based on their prior experiences and knowledge. Technological advances in the past decade have had considerable impact on the way teaching and learning is being carried out in academic institutions. A rapid and drastic fall in prices, a huge leap and improvement in the processing power of personal computers and the proliferation of World Wide Web have unleashed new opportunities for educational applications to support this new paradigm of instructional design that supports the constructivism learning theory. Some authors use the term “new learning” when they refer to the joint influence of constructivism and information and communications technology on learning [25].

VR is capable of affording constructivist learning because it provides a highly interactive environment in which learners are active participants in a computer-generated world [19]. Apart from being able to navigate and manipulate the virtual objects in the virtual world, the interaction can be observed by learners in real time. Therefore, VR is not only well suited for providing exploratory learning environments in which learners learn through experimentation, it is also able to support situated learning where learners learn in the actual context where the learning is to be applied [2], [19]. Moreover, technologies that promote interaction such as VR can be effectively used to develop higher-order thinking skills and build conceptual knowledge when following a constructivist learning model [26]. Chen and Teh [27] have pointed out how the various capabilities of VR technology can support constructivist learning principles as how shown in Table 1.

<table>
<thead>
<tr>
<th>Constructivist Learning Principles</th>
<th>VR</th>
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<tbody>
<tr>
<td>Intrinsic motivation with interesting, appealing and engaging problem representation that describes the contextual factors of the problem</td>
<td>- can present problem in a shared-three dimensional environment that simulate real aspect of the real world</td>
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<td>Multiple perspectives, themes, or interpretations of a problem to encourage diverse ways of thinking and discovery learning</td>
<td>- can provide unlimited number of viewpoints of the three dimensional environment</td>
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<td>- can provide an independent controlled viewpoint for each learner</td>
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<td>- can exclude secondary elements that may divert learner’s attention from important primary elements</td>
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<td>Active Learning – learners use sensory input and construct meaning out of it</td>
<td>- can provide a problem manipulation space that allows free exploration and manipulation. Feedback/interaction can be observed by other participant learners</td>
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<tr>
<td>Understanding is tracked by experience, gradually built up step-by-step</td>
<td>- can provide virtual experience instead of words or pictures. Virtual experience has natural semantics that provide meaning to the learner without any explanation</td>
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<tr>
<td>Instruction cannot be designed – learners control over learning strategy and construct their own knowledge</td>
<td>- instruction is designed without a specific sequence – permit any kind of interaction the system is capable of</td>
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<td>Rich sources of information</td>
<td>- contains needed information - can also be complemented with other computer-supported collaborative learning tool to provide other relevant information (e.g. World Wide Web)</td>
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<tr>
<td>Cognitive tools – intellectual devices used to visualize, organize, automate, and/or supplant information processing</td>
<td>- can act as visualization tool, modelling and design tool, dynamic modelling tool, and automation tool.</td>
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<td>Conversation and collaboration tools – access to shared information and knowledge building tools to help learners collaboratively construct socially shared knowledge</td>
<td>- can provide a shared place for a group of learners, either co-located or at a distance, to collaboratively construct knowledge through synchronous and/or asynchronous communication</td>
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In spite of the ability of VR to support constructivist learning and 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 [28]. 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 play an important role in shaping the learning process and learning outcomes [29]. 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. [28] mention that it is a challenging task to study the right and applicable use of VR in education. Questions posed by them remained unanswered [28]: 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 endeavored with most of the efforts focus on implementing special-purpose systems or limited-scope prototypes [28]. Nevertheless, a matured framework still needs to be formalized to answer those questions mentioned above.

V. REVIEW OF THEORETICAL MODEL

The literature search shows only one model 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 [29], [30]. 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 [29].

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 [29] 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 [29]. 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 [31]. In Pauling World, learners explore the atoms and bonds of a simple and complex molecule for a lesson in chemistry [29].

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 [29]. 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 [29].

According to the model of Salzman et al. [29], before designing and developing an immersive VR learning environment, it is important to analyse 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, 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. [29] 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.

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 [29].

VI. CONCLUSIONS

This paper has reviewed the use of VR for learning. We first started by examining the definition and types of VR available to be used for learning and the ability of VR to support constructivist learning. The literature search has shown that there are already some applications of VR for learning in academic institutions. However, implementing VR for learning without examining the pedagogical theories, learning processes and learning effectiveness would not be convincing. We have reviewed framework 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 and actual 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


