Concepts, Applications, and Research of Virtual Reality Learning Environments

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Abstract**—**Educational virtual reality (VR) may result in a significant improvement over traditional instruction because it is not only an interactive multimedia tool but also a learning environment that is extremely close to *reality*. There have been few empirical studies on the use of VR for learning and it is necessary to investigate VR both in different scenarios and for different applications for learning. The present paper provides a critical discussion on the concepts, applications, and research of VR learning environments (VRLEs), touching upon VR and distance learning. Central to the discussion is a better understanding of scientific breakthroughs in human-computer interaction. VR further serves as a problem-solving tool or medium that lets people accomplish what was previously impossible. The targeted goal of the paper, therefore, is to stimulate the discussion of VRLEs based on current research and practical applications.

Keywords**—**interactive virtual reality learning, virtual reality learning environment, virtual field trips, interactive multimedia

I. Introduction

MANY learning systems have been employed over the course of years that propose to enhance the effectiveness of learning and increase proficiency within the complex technological world of today, but none have proven to significantly change the way people make meaning of a world with increasingly more complex machines with complicated operations and increased safety concerns; until the recent advent of *interactive virtual reality learning systems*. [1, ¶ 1]

Current educational systems have been designed for an era in which human minds, textbooks, and pencils were the major tools used to store and process information. In the 21st century, education must become responsive to changing social needs and become more effective in learning. Distributing knowledge via the Internet and World Wide Web (WWW or Web) has become standard for educational institutions. One of the clear realities is that online learning (also called as distance learning, mobile learning, or virtual learning) is an important and valuable *new* player in the educational world of today [2].

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The number of online programs at postsecondary schools has exploded especially in the past few years: “As more and more people participate in online learning, online programs will be accepted as equal in richness and quality to face-to-face classroom programs” [3, p. 42].

VR is indeed one of the ranges of more recent computer-based technologies that may increase the possibilities for interactivity [4]. Many theories and beliefs have suggested and predicted that educators can design the best curricula for students by using VR. Ashton [5] sees VR as helping educators break down barriers of race and gender because students are able to visit different countries and experience different cultures. Biocca [6] compares the introduction of VR to that of television in 1941. Nilan [7] defines the characteristics of the cognitive space where VR is used as distinguished from the physical space. Schwier [8] believes that, in the three-dimensional (3D) VR world, students and the system are mutually adaptive that is extremely important to the enhancement of learning.

More recently, Smedley and Higgins [9] argue that the term VR can mean *anything* (from a simple “simulation” program to full “immersion” involving special equipments) and that only by exploring the various levels of VR can one gain a true understanding of the term’s meaning. Learning through VR systems may result in a significant improvement over traditional instruction, primary because VR is not only an interactive multimedia tool but also a learning environment that is extremely close to *reality*. Compared the PowerPoint (PP) software program with the VR program, for instance, PP offers the user multimedia and interactive tools (importing pictures, and making animations and transitions between slides) and such features as narration, sound effects, and music greatly enhance the richness and quality of PP presentations [10] and, even so, “PP and VR are two very different multimedia tools. While PP presents images only in a liner way, VR creates the illusion of 3D” (¶ 15).

The present paper provides a critical discussion on the concepts, applications, and research of VR learning environments (VRLEs), touching upon VR and distance learning. Central to the discussion is a better understanding of scientific breakthroughs in human-computer interaction. VR further serves as a problem-solving tool or medium that lets people accomplish what was previously impossible. Research in VR is a relatively young field. The targeted goal of the paper is to stimulate the discussion of VRLEs based on current research and practical applications.

II. CONCEPTS AND APPLICATIONS

VR—a new computational paradigm that redefines the interface between human and computer—becomes a substantial and ubiquitous technology and subsequently penetrates applications for education and learning; VR systems allow the user to travel and navigate, and let the user manipulate objects and experience the consequences [11]. VR generally refers to a "technology" or an "environment" that provides artificially generated sensory cues sufficient to engender in the user some willing suspension disbelief. VR is further defined as a combination of high-end computing, human-computer interfaces, graphics, sensor technology, and networking [12]. In the VR world, the users believe that what they are doing is *real*, even though it is an artificially simulated phenomenon. Accordingly, VR for learning is "best used to give students experiences of things they cannot experience in the real world, like the bottom of Puget Sound or the inside of an atom" [13, ¶ 8].

VR (also known as artificial reality, artificial worlds, virtual worlds, and virtualities) is a fully-immersive, absorbing, interactive experience of an alternate reality through the use of a computer structure in which a person perceives a synthetic (i.e., simulated) environment by means of special human-computer interface equipments and interacts with simulated objects in that simulated environment; also, several persons can see one another and interact in a shared synthetic environment [14]. VR simulation is relatively new and a valid VR simulation must be able to mimic visual-spatial ability and real-time characteristics of the procedure simulated, and preferably provide realistic haptic (which means of or relating to or proceeding from the sense of touch) feedback [15].

VR is a cutting-edge technology that allows the user to step through the computer screen into 3D interactive environments. There are *two* distinct categories of VR systems [16, p. 111]: (1) *immersive VR* (which is based on helmet-mounted or immersive display technologies); and (2) *non-immersive VR* or *desktop VR* (which presents images on a normal monitor and allows the user to interact with the computer-generated images. Although the user is not technically immersed, it is considered as a VR system because it is comparable to viewing a real world through a window). A promising new technology (desktop VR) has appeared in the form of VR on the Internet since the mid-1990s and, in essence, the new VR technology allows for the simulation of a 3D world on a 2D computer screen [17].

The most sophisticated VR level involves users manipulating an environment in which they fully immersed, wearing a special glove and a head-mounted display (HMD) [9]: "Together, these two pieces of equipments sense and register the user's movements, and using a series of fiber optic cables, send the information to the computer, which interprets the data and converts them into visual imagery" (p. 115). This type of VR started out as an improvement to the way users interact with computers; instead of using a keyboard and a mouse; users wear a helmet that completely encloses their eyes and ears, and the helmet contains two small video screens, one for each eye [13]: "The VR world is seen on these screens, stereoscopically. As the direction of gaze changes, the computer redraws what appears inside the helmet, creating the illusion that the user is looking around, just as in the real world" (¶ 5).

III. VIRTUAL FIELD TRIPS

Multimedia formats—such as VR, simulations, and virtual field trips (VFTs) (computer-based simulations of actual field trips)—can be used to present information in several modalities, thereby addressing different learning styles [9]. VFTs add variety to instruction and motivate students while preparing them for self-directed, lifelong learning. One of the advantages to using the VFT as a replacement for the regular field trip is that it is an inexpensive and readily accessible means to bring the world into the classroom [9]. VFTs can include all elements of a well-designed field trip and provide students with experiences that are beyond those that could be obtained from a pamphlet about or a photo display of the location [18]. At the same time, Clark et al. identify two major limitations to using VFTs: (1) the availability of VFTs that meets the objectives of the curriculum (e.g., commercially available and Web-based VFTs are designed for a large audience and may need to be adapted to meet an individual instructor's curriculum needs); and (2) the designer's expertise in the content area and appropriate pedagogy for VFTs.

VR is a unique computerized technology whose features are perhaps *not* available in other technologies. Therefore, teachers may help keep students' interest and curiosity by using VR programs to provide multi-sensory simulated learning environments occurring in real time. Students can *see* different parts of the world, can *feel* that they are there, and can *touch* things.

The following two scenarios by Wishnietsky [19] are still new and indicate the potentialities of VR to revolutionize the process of learning:

> **Scenario 1**: Students who enter the VR world could find themselves touring any city in the world. They could view the Washington Monument, the buildings of the Smithsonian Institution, and the Capitol in Washington, DC. Each student would decide which buildings to visit and what to explore. While one student visits the Capitol, another may be taking the elevator to the top of the Washington Monument. Each student decides a destination based on his or her interests and needs.
>
> **Scenario 2:** Students are also able to travel to VR destinations as a group. The teacher's and each student's HMD will be connected to the same computer. If the computer modeled Paris, a French teacher would be able to direct students through the streets of Paris. The group could travel by boat down the Seine and eat lunch at a French café where the students could order their meal in French. After the teacher finishes the tour, students are free to explore Paris on their own or exit VR and return to the physical world.

To fully utilize the potential of educational technologies including VR, teachers must familiarize themselves with both the technology itself and the proven successful methods of its use. And, as teachers become more aware of the power of VR as a learning environment, they will be in the position to provide suggestions to developers as to what programs are needed and what works best with students including those with disabilities [9].

IV. CURRENT RESEARCH AND ANALYSIS

VR would *re-shape* the socio-cultural life in the 21st century because it has a wide diversity of practical applications; the advantages of incorporating VR and 3D technologies in science education are categorized into two domains [20]: (1) in the instructional domain, teachers employ visual cues to eliminate 2D illusions for explaining complicated science objects and abstract concepts; and (2) in the learning domain, students develop visual and psychomotor (hands-on) skills to conduct experiments or manipulate apparatus through the computer-mediated interactivity provided by those VR learning resources, which can help students develop scientific investigation skills through a deep level of constructivist approach for science learning as the students can freely explore or observe in detail on what they are in doubt.

The Science Department of the Hong Kong Institute of Education has developed self-learning materials (an array of innovative learning media such as VR to create seven sets of resource kits) to support effective training of science teachers (Table 1) [20].

TABLE I
VR AND 3D VISUALIZATION TECHNOLOGIES

Resource kits	Descriptions
3D Shutter Glasses	This is an inexpensive version for VR technologies originally developed in mainframe computers as a core part of the VR environment, but it is now growing with rapid popularity in the personal computer domain, especially for stereoscopic computer games.
Panoramic Scenes	This requires some free software plug-ins like the Apple QuickTime VR or Sun's Java virtual machine for display, and it can provide interactivity to the users for conducting scientific investigation because people can use mouse to rotate the scene by 360 degrees and to zoom in or zoom out the scenes.
3D Photo Objects	This is effective in helping students get familiar with new science specimen (the Internet website contains many resources or courseware such as *3D flowers*, *Lung Model*, *Cathode Ray Oscillation*, *Millikan's Oil Drop Experiment*, and *Microscope*).
VRML Objects	Since VRML (virtual reality modeling language) is a plain text scripting language constructed for describing 3D objects such lighting, texture and camera angle which can by themselves be used for direction illustration of the science concepts concerned.
Analgyph Images	This can by itself be used as a pedagogical example for demonstrating the application of complimentary colors in the study of color physics.
Random Dot Stereograms	The method of using a computer to generate dual image random dot stereograms was first invented in early 1960s and made a significant improvement to produce single image random dot stereograms, which are now found in many popular 3D pictures books around the world.
Lenticular 3D Photos	This is so-well established that there are many types of commercial 3D cameras available for home users. For taking 3D photos, each camera is equipped with 3 to 4 pupils placed on a horizontal line.

Innovative and practical applications of treatment systems based on VR have been published in literature pertaining to the field of psychology in Mexico [21]; specifically, the scarce research and technologic development in psychology "point out the relevance to count with the VR learning objects and teaching programs that might impulse the incorporation of VR systems to teach various topics and to disseminate novel modalities for psychological interventions among university students" (p. 248). The following five studies also document current research and analysis of VR for learning:

Research 1: The potential of VR (interactivity, engagement, and remote access for learners) in biology education is enormous. Shim et al. [4] examined the effect of the VR biology simulation (VRBS) on knowledge achievement, using two classes (one used the VRBS and the other used videos) of middle school students. Knowledge achievement scores at the pretest level were not significantly different between these two groups. At the posttest level, the scores of the VRBS group were significantly higher than the control group taught using videos. More than 50% of students said that studying biology using the VRBS provided enjoyment, having a sense of *reality* and an ease for understanding biological concepts.

Research 2: Chen, Toh, and Fauzy [22] investigated the effect of a VRLE on learners with different learning styles. The findings of this aptitude-by-treatment interaction study have shown that learners benefit most from the VR mode, irrespective of their learning styles, indicating that VR offers promise in accommodating individual differences in terms of learning styles. The significant positive effect of the VR (guided exploration) mode (which provides additional navigational aids) over the VR (non-guided exploration) mode (which does not provide additional navigation aids) also implies the importance of providing VRLEs with proper instructional designs to achieve the desired educational outcomes.

Research 3: VR labs at the Ohio State University allow students to probe Newton's 2nd law using the Linear Motion VR software [23]. Students at the University responded positively to the VR labs stating that the joystick was more useful for understanding forces than the normal lab equipment. This VRLE is manipulated using a touch-sensitive joystick. If the student pushes harder, a larger force is applied to the object in the simulation. The VRLE allows students to apply a controlled force at a distance and instantly see how their force affects the motion of an object. Unlike typical computer-based activities, the VR output is not authoritative information; it is a direct, real-time response to student input. This provides a true complement to traditional lab experiments.

Research 4: The thrust of the use of games within the domain of computer-assisted instruction (CAI) is to increase students' motivation to learn by presenting the material in a form that encourages engagement and thereby increases practice. Children from one public elementary school (N = 44) in Florida participated in a quasi-experimental study by Vogel, Greenwood-Ericksen, Cannon-Bowers, and Bowers [24]. The control group used the CAI (3D figures on a computer to represent accurate objects and scenarios) program while the experimental group used the program with gaming attributes. The results of this study showed that significant improvement in the population for math skills in the non-game CAI control condition was observed but not in the game-based experimental condition.

Research 5: The use of VR environments with HMDs offers unique assets to the evaluation and therapy of clinical populations. Understanding how wearers interact with the HMD is vital. Simone, Schultheis, Rebimbas, and Millis's [25] study is a post-hoc analysis of the relationship between HMD use and HMD comfort in order to determine contributing factors for a high incidence of simulator sickness observed in an HMD-based driving simulator. Pearson correlation analysis was used to evaluate both objective and subjective measures of HMD performance and self-reported user comfort ratings. The results of the study indicated weak correlations between the two variables (HMD use and HMD comfort), revealing the complexity of quantifying "user discomfort" and "HMD performance."

Meaningful learning derived from learner-centered approaches, as documented in the above studies, takes place when students are engaged in tasks that embrace action and reflection on action, and students can achieve high levels of learning in VRLEs by being actively involved in the execution of tasks required for performing specific complex operations [1].

Learner-centered approaches to VR require a research-based theory of how students learn in VRLEs, and it is necessary to continuously search for empirically-based principles for the design of VRLEs. Shim et al. [4] provide four design guidelines concerning VR simulations:

1. Selection of a topic suitable for exploration using the application of VR technologies
2. Design of a suitable learning activity to include in the simulation
3. Maximization of the sense of the reality of the simulation context
4. Maximization of the opportunities for the student to interact with the simulation enhancing learner control within the (learner-centered) simulation

V. VR AND DISTANCE LEARNING

Based on the notion that personalized learning tailored to individual learners' continuously changing requirements is becoming a widely accepted education model in the knowledge age of today, Anani [26] has divided the public searching for knowledge and learning opportunities into four classifications: *lifelong* learners search for answers to specific questions for knowledge and enrichment; *discovery* learners search for answers to specific questions for knowledge and enjoyment; *formal* learners access formal learning settings for formal educational purposes; and *skill* learners access information to create knowledge pertinent to working environments.

With the emergence of the knowledge society in the current environment of information globalization, increasing volumes of information are being created, captured, or converted into digital forms—thus documents are first drafted on personal computers while hand-drawn figures are encoded through digital scanners, traditional works of art are transformed into electronic images, and the rapid interconnection of previously isolated computers has led to the accessibility of public and private information through electronic networks [16].

The benefits of distance learning or mobile learning (M-learning) (which is a term coined to cover a complex array of possibilities opened up by the convergence of new mobile technologies, wireless infrastructure and e-learning developments referring to the use of mobile and handheld IT devices, such as mobile phones, laptops and tablet PCs, in learning) include [27]: (1) portability (students can interact with each other and the teacher instead of hiding behind large monitors); (2) anytime, anywhere (mobile devices can be used at home, on the train, and in hotels); and (3) just-in-time learning (accessing step-by-step guides to help students achieve a task). But disadvantages include: (1) small screens limit the amount and type of information that can be displayed, the storage capacities are also reduced, and batteries require regular charging; (2) a common platform is lacking (different sized screens—horizontal screens with some handheld computers, small square screens with mobile phones) and it is difficult to develop content that will work anywhere; and (3) accessing wireless networks puts problems linked to security issues and to bandwidth that may degrade with a larger number of users.

During the past decade, various new and emerging technologies have been designed and adapted as environments for distance learning. Among the more interesting contenders of adapted technologies are 3D virtual worlds that provide three important features [28, p. 105]: (1) the illusion of a 3D space; (2) avatars that serve as visual representations of users; and (3) an interactive chat environment for users to communicate with one another. There is a great enthusiasm for promoting 3D virtual worlds as a collaborative medium for online distance education and project collaboration—thus 3D virtual worlds allow for students and the instructor to engage in distributed meetings, seminars, and tutorials [29].

Distributed VR environments (DVREs) allow a group of geographically separated users to interact in real time. The

DVRE in which a user is immersed is 3D to the eye and ear, and moving in the DVRE changes the user's visual and auditory perspective. Unlike a video conferencing system (where an attendee's screen shows other attendees in their own video-conferencing rooms), DVRE users assemble in a virtual world—they are all seen, for example, seated together around a conference table in one room [29, ¶ 2].

Course designs in the DVRE or the VRLE are very important to maximize distance learning: "Design research has grown in importance since it was first conceptualized in the early 1990s… but many researchers continue to conduct studies that principally seek to determine the effectiveness of the delivery medium, rather than the instructional strategies and tasks" [30, p. 96]. Design research requires that teachers should:

- define pedagogical outcomes and create learning environments that address them;
- emphasize content and pedagogy rather than technology;
- give special attention to supporting human interactions and nurturing learning communities;
- modify the learning environments until the pedagogical outcomes are reached; and
- reflect on the process to reveal design principles that can inform other instructors and researchers, and future development projects. [30, pp. 109-110]

Additionally, experience has shown that the successful online courses are those that actively engage students; therefore, teachers should get trained by going through rigorous online training sessions and get a taste of what the students will experience [2].

The use of well-designed online modules has pedagogical benefits and there are opportunities for increased interactive learning and for making for a more satisfying learning environment, but Wake and Lisgarten [31] maintain the following challenges to online teaching and learning: (1) the standard of students' work does not always improve; (2) plagiarism can increase; (3) synchronous interaction and student experience can suffer; (4) teachers and students must be computer literate; (5) computers with high specification are usually required, both on and off campus, with associated high costs; (6) technical problems with computers (crashing and slow online connection) can delay study and cause frustration; and (7) providing adequate "reading around" support material—virtual library—for core course work can be difficult.

Concurrent with the development of new instructional tools for distance learning has been an epistemological shift in paradigms of learning from an *objectivist* perspective to a *constructivist* perspective (the belief that knowledge is constructed, not transmitted) [28]. Dickey [28] conducted an evaluative case study of the pedagogical implications of using 3D virtual worlds for synchronous distance education. The data were collected through participatory observations, class logs, and interviews with the instructor of the course. The results of this case study have revealed that although VR provides tools that support constructivist learning environments, the affordances and constraints of the tools (discourse, experiential, and resource) may impact the pragmatic use of this medium. Basically, a 3D virtual world is an emerging technology and does not as yet offer the *immersive*, *interactive*, and *experiential* opportunities of VR learning systems, although it does afford multi-user discourse options for geographically distant learners.

Since certain criticisms of VR have been indirectly addressed by entertainment software designs, it is proposed that modifying game-style interaction to suit the virtual reconstruction of a cultural site may allow for a more culturally immersive learning environment; nevertheless, this proposal raises serious concerns in designing educational VR that in some way depict the values of past cultures or exotic places as summarized below [32]:

- *Place vs. Cyberspace*: What creates a sensation of place (as a cultural site) in a virtual environment in contradistinction to a sensation of a virtual environment as a collection of objects and spaces?
- *Cultural Presence vs. Social Presence*: Which factors help immerse people spatially and thematically into a cultural learning experience? Virtual Presence has been defined as 'being-there.' Is it fully understood what 'being' means in this context?
- *Realism vs. Interpretation*: Does an attempt to perfect fidelity to sources and to realism improve or hinder the cultural learning experience?
- *Education vs. Entertainment*: Does an attempt to make the experience engaging improve or hinder the cultural learning experience?

VI. SUMMARY AND CONCLUSION

VR places students inside of a simulated environment that looks and feels like the real world, allowing them to be fully involved in their learning process instead of being passive observers. There has been a steady increase in the potential for VR techniques for learning—thus VR has the potential to be the most effective technology or environment for helping students accelerate their learning and retention of information. But, VR needs to be accepted by teachers before it can be used effectively and productively in educational and learning purposes.

VRLEs, as discussed in the present paper, offer a truly new and inventive way to teach and engage students. That is, VRLEs offer teachers and students unique *experiences* that are consistent with successful instructional strategies: hands-on learning, group projects and discussions, virtual field trips, simulations, and concept visualization. In Winograd's [33] words, "No longer is learning based on experts conveying messages to novices, but it centers on experiences. These are not reusable because all knowledge is situated in a specific context….The medium isn't the message, but the medium shapes both the message and the participants" (p. 42). Certainly VR will create a valuable learning environment for teachers and students; however, the vast majority of the research into virtual environments for instructional use is technology-driven, rather than taking into account the human factor. Also, there has been little research on how learner characteristics interact with the features of VR either to aid or to inhibit learning.

After decades of its development, it is true that VR remains largely misunderstood [34]: Why do people have such misconceptions and unreasonable expectations? Mainly because, according to Burdea, (1) to some extent this can be blamed on "media hype" (Hollywood movies such as "The Matrix" lead the public to believe VR can do *everything* but this is pure fantasy), (2) the VR community is small and has not been taught adequately at the college level (the vast majority of universities worldwide offer no VR courses), and (3) to some extent this used to be due to the specialized equipment needed to teach the subject.

VR is still expensive to produce and use, and it seems most likely that VR, especially in education, will only be cost-effective for remediation or enrichment; it is much harder to produce highly realistic simulations in VR than it is to make simple, cartoon-like worlds [13]. In this regard, Winn's following words tell all about VR—virtually *everything*:

> As the technology improves and we learn more about how people learn by interacting with virtual worlds, VR will be seen more frequently in our schools and colleges. It is unlikely that we will build virtual worlds with "holodeck" fidelity in our lifetimes. But people are working to create virtual touch and texture, virtual smell and virtual taste. Sounds in the environment can already be made to come from places that are stable relative to the user, regardless of how the head is turned. The quality of visual displays is increasing as their weight and cost come down. Educators have an uncanny ability to work creatively with new technologies. VR will be no exception. (¶ 9)

A website, *Virtual Reality and Education: Information Sources; A Bibliography*, developed by Pantelidis [35] is useful to access VR publications and resources linked on the Web that can be found on the Virtual Reality and Education Laboratory website at http://vr.coe.ecu.edu/vrel.htm. Finally, VR is not without its problems (Winn, 2001), but interactive VR learning system approach may be the next wave of education reform in high-tech learning.

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