ABSTRACT

This article is an overview of online virtual learning environments for discovery learning. The paper defines Virtual Learning Environments and discusses literature findings on the benefits of using web-based VEs for self-directed learning. It gives an overview of the latest technologies/platforms used to develop online VEs, discusses development and delivery challenges posed by complex, information-rich web-based 3D environments, and describes possible solutions that can be adopted to overcome current limitations. The paper also presents and discusses two 3D web-deliverable virtual learning environments that were recently developed by the authors: the “Virtual Tour of the Muscatatuck State Hospital Historic District (MSHHD)” and the “VELS: Virtual Environment for Learning Surveying”. The “Interactive 3D Tour of MSHHD” is a web-based digital heritage application that uses Virtual Reality as a tool to document and preserve historic sites and educate the public about them; the “VELS” is an online virtual learning environment whose objective is to help undergraduate students learn surveying concepts and practices.

Keywords: Digital Heritage Applications, Discovery Learning, Engineering Education, Self-Discovery Learning, Virtual Learning Environments

1. INTRODUCTION

An online interactive Virtual Environment (VE) is defined as a web-deliverable designed “information space in which the information is explicitly represented, educational interactions occur, and users are not only active, but actors, i.e., they co-construct the information space.” (Dillenburg, 2000). VEs offer three main benefits: (a) representational fidelity; (b) immediacy of control and high level of active user participation; and (c) presence. “(a) Representational fidelity refers to the degree of realism of the rendered 3D objects and the degree of realism provided by temporal changes to these objects. (b) User control and high level of participation refer to the ability to look at objects from different points of view, giving the impression of smooth movement through the environment, and the ability to pick up, examine and modify objects within the virtual world. (c) The feeling of presence, or immersion, occurs as a consequence of realism of representation and high degree of user control.” (Dalgarno et al., 2002).

DOI: 10.4018/ijssoe.2014010101
An online virtual world is a particular type of web VE where users can interact with each other. It is defined as “an electronic environment that visually mimics complex physical spaces, where people can interact with each other and with virtual objects, and where people are represented by animated characters” (Bainbridge 2007). The features of virtual worlds include shared space, graphical user interface, immediacy, interactivity, persistence, and community (Lesko & Hollingsworth, 2010; Duffy & Penfold, 2010).

Virtual Environments can be non-immersive (i.e. desktop VEs) or total immersion. Non-immersive virtual environments can be viewed on a PC with a standard monitor; interaction with the virtual world can occur by conventional means such as keyboards, mice, trackballs, and joysticks or may be enhanced by using 3D interaction devices such as a SpaceBall or DataGlove. Non-immersive VR has advantages in that it does not require special hardware; it can be delivered via web, and therefore can reach broad audiences. Immersive VR applications are usually presented on single or multiple screens, or through a stereoscopic head-mounted display unit. The user interacts with the 3D environment with specialized equipment such as a data glove, a wand or a 3D mouse. Sensors on the head unit and/or data glove track the user’s movements/gestures and provide feedback that is used to revise the display, thus enabling smooth, real time interactivity.

In this paper we focus on non-immersive, single-user VEs.

2. VIRTUAL ENVIRONMENTS AND LEARNING

2.1. Discovery Learning

Discovery learning is defined as a “self-directed way of learning in which the planning and monitoring of the learning process are in the hands of the learner” (de Jong, 2005, p. 218). Virtual environments support discovery learning as they are motivating, active experiences controlled by the individual (Coffman & Klinger, 2008). Immersion of students within a virtual environment can cultivate “learning by doing” as students use and apply their related prior experiences and further develop them by interacting with the environment (Land, 2000). The discovery learning provided by virtual environments also supports the upcoming generation of “digital natives” (Prensky, 2001, p.1) which think and learn in interactive, multimedia environments and need options for learning that are collaborative and creative (Loureteiro & Bettencourt, 2010). Learning is shifting from sets of knowledge transferred between teacher and students towards a more learner-centered approach focused on experience and exploration (De Freitas et al., 2009). Previously, a significant focus of education has been to teach the basics of literacy and mathematics, but now, with the advances of technology, it is becoming necessary to address 21st century workforce skills, such as digital literacy, which will ultimately impact productivity and creativity (Bavelier et al., 2010).

2.1.1. Pedagogical Benefits of Interactive Virtual Learning Environments

The pedagogical benefits of interactive Virtual Learning Environments have been examined by researchers in the areas of computer graphics, cognitive psychology, visual cognition, and educational psychology. In general, research findings show that Virtual Learning Environments are often more effective than traditional teaching tools (Dalgarno 2004; Shin 2003; Winn 2002). More specifically, learning affordances include: “the facilitation of tasks that lead to enhanced spatial knowledge representation, greater opportunities for experiential learning, increased motivation and engagement, improved contextualization of learning and more effective collaborative learning as compared to tasks made possible by 2-D alternatives” (Dalgarno & Lee 2010, p.10). Technologies, such as VR, can be used to create interactive learning environments where learners can visualize abstract concepts easily and receive...
feedback to build new knowledge and understanding (Hmelo 1998; Kafai 1995; Schwartz 1999; Bransford 1999). VR is also effective in teaching students how to be critical and creative thinkers as it supports learning in a nonlinear fashion (Strangman 2003). VR environments are intrinsically motivating and engaging as they give the users the illusion of being part of the reconstructed world, and allow them to focus entirely on the task at hand. In addition, several studies have shown that VR applications can provide effective tools for learning in both formal and informal settings (Dalgaro & Harper 2004; Winn 2002; Shin 2003).

Reviews have concluded that technology has great potential to enhance young student achievement, but there is a need for additional research (Cognition and Technology Group at Vanderbilt 1996; Dede 1998; President’s Committee on Advisors on Science and Technology 1997). Although the availability of technology has increased dramatically and is impacting how children learn, develop and behave, it is still not clear how to best use the technology for desired learning outcomes (Bavelier et al., 2010; Linebarger & Walker, 2005; Owen 2010; Zimmerman 2007). Different behavioral effects have been observed as the media changes in “content, task requirements, and attentional demands” and “some products designed to benefit cognitive development actually hinder it while some products designed purely for entertainment purposes have been shown to lead to long-lasting benefits” (Bavelier et al., 2010, p. 693).

Interactive 3D animations have been shown to increase student interest and make material more appealing (Korakakis et al., 2008). Computer simulations can be an effective approach to improve student learning and may help students develop more accurate conceptions (Jiang 1994; Kangassalo 1994; Zietsman 1986; Brna 1987; Gorsky 1992). Virtual environments can also provide situated learning that is effective in generating useful knowledge for the real world (Dede, 2009). The potential for learning in virtual worlds, especially for providing a real world quality for role-play activities has been noted by other researchers (Broadribb & Carter 2009). Virtual worlds allow students to “go places that cannot be visited, overcome stereotypes, role-play, collaborate in groups, conduct scenario simulations and interact with a global audience” (Lesko & Hollingsworth 2010, p.9).

2.1.2. Interactive Virtual Learning Environments and Engineering Education

Though progress has been less evident in Engineering Education, some researchers argue that Virtual Reality is mature enough to be used for enhancing communication of ideas and concepts, stimulate the interest of engineering students and improve learning (Richardson & Adamo-Villani 2010). Some noticeable examples of engineering interactive virtual environments exist. For instance, Del Alamo (Mannix 2000) a professor of electrical engineering at MIT, created a web-based microelectronics lab for his students in 1998. At Johns Hopkins University, Karweit (2005) simulated various engineering and science environments on the web. At the University of Illinois Urbana-Champaign (UIUC), researchers developed a virtual environment for earthquake engineering (Gao et al., 2005). At Purdue University, Richardson and Adamo-Villani (2010) developed a photorealistic 3D computer-simulated laboratory environment for undergraduate instruction in microcontroller technology.

In the area of surveying, Kuo et al. (2007) have recently developed a virtual survey instrument (SimuSurvey) for visualizing and simulating surveying scenarios in a computer-generated VE, and studied the feasibility of introducing SimuSurvey in regular surveyor training courses. Results of the study indicated improved student learning outcomes and positive attitude toward including SimuSurvey in regular surveyor training courses. At Leeds Metropolitan University, UK, Ellis et al. (2006) have developed an undergraduate VR surveying application. The interactive environment includes 360-degree panoramic images of sites and makes use of QuickTime VR technology. The application was evaluated with 192
undergraduate students; findings suggest that the interactive tool complements traditional learning approaches, maintains student interest, and reinforces understanding. At University of New Castle, UK, Mills and Barber (2008) have implemented a virtual surveying field course which includes both a virtual fieldtrip and a virtual interactive traverse learning tool (VITLT). The goal of the tool is to improve understanding of surveying methods for first year students in the Geomatics degree. The application was evaluated by several Geomatics students; all subjects highlighted the potential of VITLT to help the learning and understanding of a traverse. However, the students did not see the e-learning tool as a replacement for a traverse observation as carried out on the fieldcourse, but suggested that it could be used as a preparation and revision tool. At Purdue University, Dib and Adamo-Villani (2011; 2013) have developed an online virtual learning environment for teaching and learning the surveying concepts of chaining and differential leveling. A pilot study with a group of undergraduate students showed that subjects found the application effective for learning surveying concepts and practices and for getting feedback on their understanding of the subject.

2.1.3. Theoretical Frameworks for Virtual Learning Environments

As education incorporates newer technologies, new pedagogies and theoretical frameworks are being explored to support the integration of technology with novel approaches for learning.

The theoretical framework supporting the development of virtual learning environments is guided by the tenets of constructivist learning theories, experiential learning theory (Kolb, 1984) and domain-specific knowledge construction paradigm.

Constructivist theories posit that learning occurs in contexts and that knowledge is grounded in authentic situations, i.e., learning and understanding derive from experiences. There are many constructivist theories, e.g., social constructivism, cognitive constructivism and situated constructivism, however, they share a perspective that learning is active and self-directed; involves “meaning making” and “requires the personal interpretation of phenomenon such as the construction of a mental model representing a complex phenomenon” (Woo & Reeves, 2007). As stated by Shiratud-din & Hajnal (2011), technology, including virtual environments, offers the opportunity to implement constructivist approaches to teaching and learning in various education settings. For example, interactive virtual environments are very user-centered and engaging (Gros, 2007) and have the potential to transform learners from passive participants to active participants in the learning process. Virtual learning environments often incorporate problem-solving activities, thus enhancing real life knowledge application.

Savery and Duffy (2001) identified seven constructivist principles of instructional approaches that promote active learning and real-life application of content knowledge:

1. Learning activities should be anchored to a larger task or problem. The purpose of learning activities must be to enable learners to function more effectively in a real world.
2. The instructional tool should support learners in developing ownership of the overall problem or task—that is, engage learners in meaningful dialogue.
3. Instruction must be authentic—that is, learners should be engaged in activities that apply knowledge to real life problem solving.
4. Tasks and learning environment should reflect the complexity of the real life environment that learners are expected to function in at the end of learning.
5. Tasks and learning environment should encourage testing ideas against alternative views and alternative contexts.
6. The design of the learning environment should support and challenge the learner’s thinking.
7. Tasks and learning environment should provide opportunity for and support reflection on both the content learned and the learning process.
Many of these principles are often implemented in effective virtual learning environments.

*Experiential learning theory* posits that learning is an active process where “knowledge is created through the transformation of experience” (Kolb, 1984, p.38). Kolb further posits that people learn best by doing, and that effective learning makes connections between what is learned (i.e., acquired knowledge) and its practical application (de Freitas, 2006). Unlike traditional instructional approaches where learning occurs in “one-way information-dispensing methods,” experiential learning approaches (e.g., virtual environments) foster active learning; address cognitive (i.e., content knowledge) and affective learning issues; enhance collaboration and peer learning and offer opportunities for more complex and diverse approaches to learning processes and outcomes (Ruben, 1999). In particular, Kolb’s experiential learning theory emphasizes the combined role of experience, perception, cognition and behavior in learning and that “concepts are derived from and continuously modified by experience” (Herz & Merz, 1998, p. 240). Kolb’s experiential learning cycle consists of four models: concrete learning, reflective observation, abstract conceptualization (i.e., forming a theory based experience) and active experimentation. As observed by Herz and Merz (1998, p.240), these four modes fit the organizational structure of interactive virtual environments: “virtual environments can potentially provide the opportunity to move through the complete cycle of experiential learning, with varying degrees of involvement from the role as actor (active experimentation) to the role as observer (reflective observation) and from specific involvement (concrete learning) to general analytic detachment (abstract conceptualization).”

*Domain-specific knowledge construction paradigm* views learning as a process of domain-specific knowledge construction and is grounded in research on human cognition and cognitive development (Brown 1990; Carey & Spelke 1994; Gelman, & Brenneman 2004). Domain-specific approaches assume that learning in conceptual domains such as science and mathematics is characterized by the development of distinct domain-specific conceptual structures and processes. One implication of the domain specific view of conceptual development is that instruction should focus on helping students acquire the core ideas and ways of thinking that are central to a particular domain of knowledge.

### 3. DEVELOPING WEB 3D VES: TECHNOLOGIES, CHALLENGES AND SOLUTIONS

Three open standards can be used to develop Web3D VEs: VRML (Virtual Reality Modeling Language), an open ISO standard (VRML, 1997) which was created in 1995, X3D, eXtensible 3D Graphics (X3D, 2004), proposed as a successor of VRML, and WebGL (WebGL, 2010), released very recently and still under development. In addition to open standards, other commonly used web 3D technologies include Java3D (Java3D, 2010), Unity (Unity, 2013), Flash 3D (Adobe Flash 3D graphics, 2012), Quest 3D (Quest3D, 2012), and more.

*VRML* (Carey and Bell 1997), is a language that “integrates 3D graphics, 2D graphics, text, and multimedia into a coherent model, and combines them with scripting languages and network capabilities " (Chittaro et al., 2007). VRML supports common primitives used in 3D applications, such as light sources, cameras, geometry, animation, material shaders, and texture mapping. 3D objects are described using a hierarchical scene graph structure in which entities are represented as nodes whose properties are stored in fields. This structure facilitates the creation of complex 3D worlds starting from simple objects; in addition, it is possible for the VE programmer to define new nodes, i.e. extend the language. VEs created with VRML can be immersive or non-immersive. In other words, they can be experienced using special hardware such as head-mounted displays and specialized input devices (i.e. wands or data gloves); or can be used with standard input/
output devices such as CRT/LCD monitors and mouse and keyboard.

The Extensible 3D Graphics (X3D) for defining interactive Web-based 3D content “...was recently released as the successor of VRML, and was approved in 2004 as an ISO standard (X3D, 2004). X3D inherits most of the design choices and technical features of VRML and, as a result, it is largely backward-compatible ...”(Chittaro et al., 2007). X3D presents three main improvements over VRML: it supports several of the latest advancements in 3D computer graphics such as programmable shaders and multi-texturing; it enables better data compression and hence, faster downloads; and lastly “… it divides the language into functional areas called components, which can be combined to form different profiles (i.e., subsets of the entire language) that are suited to specific classes of applications or devices, e.g., one could create a specific profile to take into account the limited capabilities of mobile devices.”(Chittaro et al, 2007).

WebGL is a cross-platform, royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0, exposed through the HTML5 Canvas element as Document Object Model interfaces. It is managed by the non-profit technology consortium Khronos Group, and its working group includes Apple, Google, Mozilla, and Opera. WebGL, still under development, brings plug-in-free 3D to the web, and is implemented in the development release of most major browsers including Mozilla Firefox, Google Chrome, Safari. The WebGL is intended to provide a common design for developing high quality immersive virtual experiences on the web.

Java 3D is another technology that can be used to develop web based virtual environments. Java 3D is a scene graph-based 3D application programming interface (API) for the Java platform that runs on top of either OpenGL or Direct3D. The Java 3D classes extend the Java language functionality to support geometry construction, manipulation, surface appearance definition, and animation. In addition to supporting standard I/O devices such as mouse, keyboard and monitor, it also provides a number of classes and interfaces to support specialized input devices. Java 3D has been used to develop many web based VEs including applications for architectural design and civil engineering project management.

Unity, Flash 3D, Quest 3D represent a sample of commercial virtual environment development tools that support web delivery in addition to standalone. Unity has been adopted by companies such as EA, Cartoon Networks, Disney, Warner Bros, and LEGO to develop and deliver their online content. It supports some of the latest real-time computer graphics advancements ranging from geometry batching to occlusion culling which can be used to speed up the downloading process and improve real-time performance. Flash3D extends the capabilities of the Adobe Flash multimedia platform ad allows for creation and display of simulated 3D environments using 2D graphics. Quest 3D is an integrated development environment (IDE) that allows to create web3D VEs using Visual Programming, hence it is an ideal development platform for artists and users with limited programming expertise; its main drawback is that it is not truly cross-platform as it does not support MacOS and iOs.

Although many options are currently available for development of web 3D environments and web 3D technology has improved significantly in the past few years, creating complex, graphically-rich web 3D environments is still a challenging task. Due to diversity of network connections and computer performance, efficient representation of virtual objects is a fundamental factor for web presentations (Zara 2004). Virtual scenes are always a simplification of reality and this is particularly true for 3D web-based VEs, which have to balance between visual quality and rendering/data download speed. In order to overcome the quality/performance trade-off problem, the 3D models need to be carefully prepared for efficient web delivery using a variety of techniques including optimization methods for converting 3D models to web based format, and Level of Detail (LOD). LOD allows for describing a complex 3D model using
different representations, from very detailed to extremely simple ones. A presentation system switches among these representations based on the distance between the virtual camera and the rendered object.

In addition to problems of download and rendering speed, a barrier is posed by the fact that VR content cannot be viewed with just a standard browser; a special viewer - either a special-purpose browser or a plug-in – is often needed. Since a universal viewer that can display all VR web content does not exist yet, it is often necessary to download a different plug-in for each different web VEs. Plug-ins can be large and their installation may require a certain degree of technical expertise, thus making web VR content inaccessible to people who have very little computer knowledge. Although WebGL promises to bring plug-in free 3D to the web, the technology is not mature yet.

Another current limitation of web-based VEs is the lack of a standard user interface for navigating 3D worlds and for interacting with 3D objects. Users are often accustomed to Graphical User Interfaces (GUIs) that use point-and-click as the major interaction technique. Moreover, web pages with hyperlinks are also based on the same click-and-go interaction method. On the contrary, a large number of different navigation/interaction paradigms have been suggested and/or implemented by researchers in VEs. According to Bowman et al. (1997) most of these techniques fall into four categories: natural travel metaphors, that is techniques that use physical locomotion or some real/pseudo world metaphor for travel; steering metaphors that involve continuous specification of direction of motion (i.e., gaze-directed, pointing, and physical device techniques); target-based metaphors which require a discrete specification of goal; and manipulation metaphors which involve manual manipulation of viewpoint (i.e., for instance, ‘camera in hand’). A user interface for travel and object selection/manipulation in web-based virtual environments is not yet standardized. Even VRML browsers complying with ISO standards differ in a number of control elements and in their arrangement on the screen. This fact can increase difficulties, and therefore skepticism, in web users with limited computer knowledge. In order to overcome the problem of absence of a standard web 3D interface, the User Interface (UI) can be designed as an integral part of the 3D scene. For instance the UI could consist of a HUD (Heads-Up Display) that remains in the same position on the screen while the user navigates through the virtual world (Adamo-Villani et al., 2009).

From the discussion above it is clear that developing graphically-rich web 3D VEs is a challenging, costly and time-consuming process that requires a team of professionals with expertise in many different fields (i.e. programming, 3D graphics, UI design). To overcome the development barrier, companies such as Linden Lab (2010) have developed online virtual world platforms (i.e. Second Life) that include a set of authoring/modeling tools to allow non-expert users to easily create web 3D interactive environments within an existing virtual world. Forterra’s OLIVE (Forterra Systems, 2010), The Croquet Consortium (2010), Sun Microsystem’s Project Wonderland (2009), ProtonMedia’s Protosphere (2010), and Linden Lab’s Second Life are all examples of such virtual world platforms. While these platforms do not support sophisticated 3D graphics, they offer an easy way to build interactive VEs for a variety of applications, including education and training.

Second Life (SL), one of the best known of these virtual world platforms, consists of a flat-earth simulation of roughly 1.8 billion square meters. First launched in 2003, SL is an example of an immersive, three-dimensional (3D) environment that supports a high level of social networking and interaction with information. Visitors can access the virtual world through a free, client program called the SL viewer. They enter the SL virtual world, which residents refer to as “the grid”, as an avatar (SL “users” are referred to as “residents”). Once there, they can explore environments, meet and socialize with other residents (using voice and text chat), participate in group and individual
activities, and learn from designed experiences. Built into the software is a three-dimensional modeling tool, based around simple geometric shapes, that allows non-expert users to build virtual objects. These objects can be used, in combination with a scripting language, to add functionality.

4. A REVIEW OF TWO PROJECTS

In this section we discuss two web-based virtual environments that were recently developed by the authors: the *Interactive 3D Tour of MSHHD* and the *VELS: Virtual Environment for Learning Surveying*. Both projects are examples of graphically-rich, single-user web VEs; the interactive MSHHD was developed using Quest 3D and VELS was developed using Unity 3D.

4.1. The Interactive 3D Tour of Muscatatuck State Hospital Historic District (MSHHD)

Virtual MSHHD is a web-based digital heritage application that uses VR as a tool to document and preserve historic sites, and educate the public about them (Adamo-Villani et al., 2010). MSHHD (Columbus, IN), founded in 1920 as the Indiana Farm Colony for Feeble-Minded Youth, includes buildings of historic value built in Deco, Moderne, Industrial, and Twentieth-Century Functional architectural style. The site is currently being transformed into an urban training facility for homeland security and natural disaster training and the plans for converting the area include major modifications to the district and its buildings. In 2006, The Indiana Army National Guard (INARNG) agreed to several mitigation stipulations for the adverse effect it will have on MSHHD. One stipulation was the creation of a photorealistic web-based interactive virtual tour to document and virtually preserve the historic area.

A team of Purdue University students and faculty was charged with the task of developing the tour. The team selected 3D animation and Virtual Reality (VR) as the technologies of choice. VR-based cultural heritage applications have gained popularity in recent years and some examples have been reported in the literature (Hirose 2006; Roussou et al., 1999). Researchers argue that VR application for cultural heritage offer several benefits including an effective way of communicating the scientific results of historical investigations through photorealistic reconstructions of places and people that no longer exist, may not be easily experienced, or are threatened; intuitive visual representation of abstract concepts, systems and theories that would be difficult to communicate with diagrams, textual descriptions and static images; and enhanced viewer’s engagement and motivation through high level of interactivity and “immersion”. Immersion is defined as “the illusion of being in the projected world….. surrounded by images and sound in a way which makes the participants believe that they are really there” (Roussou 2001).

These reported strengths have motivated the choice of VR and 3D animation as the base technologies for the interactive application. The tour is deliverable on CD-ROM for distribution to schools, and on the web for the general public. In addition, it is designed for display in portable immersive devices for museum exhibits.

4.1.1. 3D Content

Sixty-four (64) buildings and six (6) historic features were identified at MUTC. The buildings date between 1924 and circa 1980. Of the 64 buildings, 34 are over 50 years of age and are considered contributing buildings within the MSHHD. In addition, all 6 features (4 tunnels and 2 drainage ditches) and the unique “butterfly” pattern of roads, not seen in any other Indiana mental health facility, are considered contributing elements to the historic district. The virtual tour includes 3D reconstructions of all thirty-four buildings, two tunnels, the road layout, vegetation, and bodies of water. Figure 1 shows an aerial view of the historic site and a photograph of one of the buildings of interest.

To get geometrical information about real 3D objects various techniques and devices could
be utilized. Fully automated methods are not available yet and while most automated techniques involve limited user input, they require a substantial amount of interactive work to covert the resulting data into renderable structures (Zara 2004). Therefore, due to the lack of directly applicable automatic reconstruction techniques, the team made the decision to build all 3D models using commercial modeling software (i.e., Autodesk Maya and 3D Studio MAX). To provide accuracy and realism, the 3D objects were developed from maps, architectural blueprints, photographs, drawings, and layout information, and were textured using procedural maps, digitally captured images, light maps, and ambient occlusion maps. Figure 2 shows the 3D reconstruction of the hospital building.

The models were then exported from Autodesk Maya and 3DS MAX to different formats for display on the various delivery platforms, including the WWW. To achieve good visual quality, as well as high speed of response in a real-time web-based environment, the models were optimized in different ways to limit the poly-count. In addition, Level of Detail (LOD) techniques were used extensively in order to lower the client’s hardware requirements. The application detects the client’s hardware configuration and the amount of detail displayed on models and textures changes dynamically depending on the user’s computer system. The terrain was created using a 2D height map. The resolution of this height map changes according to the LOD system. Cube maps were used to generate the sky and atmosphere as well as allow for reflections of 3D geometry on certain surfaces. How often and at what resolution the reflection cube map is rendered changes according to the LOD system.

### 4.1.2. Application Development

Quest 3D (2010) is the integrated development environment (IDE) that was chosen to develop the web-based interactive VE. The selection of this third party game engine was motivated by
several considerations. Quest 3D allows for a relatively short development time, as all of the coding is done using Visual Programming. Because it is a DirectX 9 game engine, it is supported by all DirectX 9 compliant graphics cards and operating systems. Lastly, Quest 3D supports a large number of delivery formats including web, executable, installer and windows screensaver. Although the user is required to download and install a plug-in in order to view the content, the size of the plug-in is relatively small and its installation is straight-forward.

The online virtual tour is a single-user VE and exists within a website that presents historical information about the area. The 3D tour is rendered inside the browser window using a web player plug-in specific to the graphics engine used for development (i.e. Quest 3D). Users are required to download the plug-in and install it on their computer the first time they visit the web 3D tour. The 3D tour loads automatically on subsequent visits to the website. A standard mouse and keyboard setup is used as the default control option; however users may also use a gamepad. The web 3D tour was tested on a variety of computers with different hardware/software configurations. In particular, low-end computers without dedicated graphics cards were used to test real-time performance and the dynamic LOD system. The VE was iteratively developed with continuous feedback from a group of experts in VR, Archaeology, and Instructional Design. In addition, several formative evaluations with users were conducted in order to assess and improve the usability and functionality of the application.

4.1.3. The User’s Experience

Before starting the tour the participant has the option to choose between a “Quick Tour” and a “Detailed Tour”. Each tour presents a different level of information about the facility and its history. The “Quick Tour” is a narrated story (with closed captions) aimed at 4th-5th grade students; the “Detailed Tour” presents in-depth information with references, and gives the user access to digital copies of original text documents and images.

Viewers begin the virtual tour of MSHHD by selecting one of two possible start locations. While all 34 buildings can be explored from the outside, only 6 are ‘active’, i.e. they can be entered. Upon approaching or entering a building, information about its history, functions and previous inhabitants can be displayed in a variety of media formats such a text, images and narration. Users navigate the environment with mouse, keyboard, and/or gamepad and have the option to ‘walk’ through the environment or ‘fly’ to any location. If the ‘walk’ option is chosen, a terrain following constraint limits the subjects to only a specific plane. In other words, users can only ‘walk’ on the paths instead of being able to ‘fly’ freely through the virtual site. While the user is in ‘walk’ mode, there are three main actions: move, look, and interact. Moving ‘pushes’ the camera around the environment, while looking ‘rotates’ the camera. While in ‘fly’ mode, the user does not have direct control over the view, but rather controls the camera in order to take certain actions. While in this mode there is only one main action: interact. The user can click on a building and the camera automatically frames the building and displays appropriate information. The user can then take a step back, or interact with a door on the building and the camera will take appropriate actions to show the interior.

The main objective of the interactive VE is to allow the public to explore and experience the historic site as it was before the recent transformations, and learn through text, images and narrated stories, what life was about for the patients and employees of MSHHD. Figure 3 shows 4 screenshots of the web-based interactive tour.

In the following section we describe our second project, a collaborative web-3D multi-user virtual environment developed in Second Life. The purpose of the application was to explore the potential of using a virtual world platform for medical education.
4.2. The VELS: Virtual Environment for Learning Surveying

The VELS is an interactive, web-deliverable virtual environment for learning surveying concepts and practices. It is designed for undergraduate students enrolled in surveying courses and includes realistic virtual terrains and surveying instruments that look, operate, and produce results comparable to the physical ones. It includes four educational modules: basic surveying math, chaining, differential leveling, and triangulations and coordinate calculations. In this paper we describe two modules: chaining and triangulations and coordinate calculations.

4.2.1. Chaining Module

Chaining (or taping) is the measurement of the horizontal distance between two points. It requires the use of several instruments (e.g. steel tape, chaining pins, plumb bobs, hand level, tension handles, clamp handles, and lining rods) and is usually performed in six steps: lining in, applying tension, plumbing, marking tape lengths, reading tape, and recording the distance. The VELS guides the students through these six steps and helps them understand how to measure the distance between two given points on a horizontal plane, steep slope and rough terrain using the proper techniques and instruments. Figure 4 shows screenshots of the sequence of steps performed by the students in the virtual environment. The VELS has been programmed to allow for 1/16\textsuperscript{th} of an inch variation, that is, if the student sets up perfectly at the point of interest two times in a row, the plumb bob is within 1/16\textsuperscript{th} of an inch from the previous location (this replicates real life settings where the plumb bob will be swinging and will always be at a very small distance from the point). If all the criteria are followed correctly, two consecutive measurements will vary within a 1/8\textsuperscript{th} of an inch. Hence, in the VELS, precision is reached if the same measurement or measurements within 1/8\textsuperscript{th} of an inch or 1/100\textsuperscript{th} of a foot are achieved multiple times. Accuracy is achieved by repeating multiple measurements, and therefore compensating for the random 1/8\textsuperscript{th} of inch variation generated by the virtual environment.
The chaining module of the VELS includes an evaluation engine that tracks the student’s interactions with the program and outputs performance reports. Specifically, the evaluation engine tracks activities such as: (a) the student ability to select the correct tools; (b) the student ability to set up at the correct point of interest; (c) the student ability to hold the tape horizontally, therefore the level has to be perfectly plumb; (d) the student ability to exert the correct amount of tension on the tape, so that the tape can read the horizontal distance;

Figure 4. Screenshots extracted from the VELS-chaining module. Point selection (frame 1); plumb bob setup (frame 2); tension meter setup (frame 3); hand level setup (frame 4); tape reading (frame 5)
(e) the reading on the tape as a record of the
students measurements; (f) the student decision
to delete or retain a specific reading (this is used
to evaluate the student interpretation of the
results); (g) the time spent on each task; (h) the
number of correct and incorrect answers. The
evaluation engine outputs two types of reports:
a summary report that provides formative feed-
back to the student and a detailed performance
report for the instructor in the form of an excel
spreadsheet. The instructor uses this report to
generate the final grade. A detailed description
of the VELS chaining module can be found in
Dib et al. (2011).

4.2.2. Triangulations and
Coordinate Calculations Module

This module was designed with the intention
to replicate the field exercise with high level of
fidelity. In the field exercise, the student
performs the following steps: (1) select the
tools needed to complete the exercise, (2)
inspect the site in order to determine the most
suitable set up location and target points, (3) set
up the instrument, (4) take measurements, (5)
record the measurements in the correct tabular
format, (6) perform the calculations. The VLE
interface requires the user to follow the same
exact sequence of activities; Figure 5 shows
four screenshots illustrating the sequence of
tasks in the VLE.

The VLE requires the student to assume
all the roles that are usually assumed by the
whole team in the field exercise. Therefore, each
student has to achieve an acceptable level of
competency in all the tasks listed above, without
relying on team members for assistance. The
VLE does not simplify the real case scenario,
as it does not provide the users with default
horizontal lines, azimuth and bearings. In the
VLE, the users have to identify or calculate the
horizontal sight, the bearings and the azimuths
by observing all the variables and parameters, as
they would be expected to do in the settings of a
real field exercise. The VLE is programmed to
provide the user with a randomized error within
a certain tolerance. It takes into consideration
the instruments limitations. Experienced users
when replicating a field measurement, assuming
that no procedural or user error has been made,
expect to get the same answer plus or minus
the instrument tolerance, usually referred to the
smallest unit of measurement. Any deviation
greater than the allowable error needs to be
investigated and eliminated, if ruled erroneous.
The VLE has been designed with all these em-
bbedded details in order to instil in the students
the best practices and procedures.

4.2.2.1. Initial Evaluation

The goal of this initial evaluation was to validate
the usability and functionality of this module
with a group of experts. The expert panel-
based evaluation aimed to assess: (1) usability
of the VLE module; (2) quality of 3D graph-
ics and animations; (3) accuracy and fidelity
of the virtual instruments; and (4) quality of
the educational content. The panel of experts
consisted of seven individuals: two experts in
VR application development, two experts in
3D modeling and animation, and three experts
in Surveying and Surveying Education. Each
expert was asked to perform an analytical
evaluation of the elements of the application
that pertained to his/her area of expertise. The
goal of the analytical evaluation was to let the
experts perform a variety of user tasks in the
VLE, identify potential problems and make
recommendations to improve the design. The
two experts in VR application development
assessed the usability of the VLE module by
determining what usability design guidelines
it violates and supports.

The usability guidelines used in the
evaluation were based on the work of Gabbard
(1998) and Gabbard et al. (1999). The experts
in 3D modeling and animation were given a
questionnaire with questions focusing on the quality of the virtual environments, characters
and animations; the experts in Surveying were
given similar questionnaires with questions on
the fidelity and accuracy of the virtual instru-
ments and quality of the surveying and math
exercises. The evaluators used a five point Likert
scale for rating the response to each question
Overall, the VELS module was found easy to use (MEAN=4.5) and all evaluators were able to complete the users’ tasks without difficulty. However, one evaluator commented that the camera controls are not intuitive, and it takes too much time to learn how to use them. The quality of the 3D terrains, characters and animations was rated very high by the experts in 3D graphics (MEAN=5) and, therefore, recommendations for improvement were not necessary.

The virtual instruments were found accurate (MEAN=4.5) and comparable to the physical ones (level of fidelity: MEAN=4). One evaluator commented that the angle, currently reported in degrees and decimals, should be reported in degrees minutes and seconds in order to be true to real surveying equipment. The quality of the surveying exercise was rated very high (MEAN=5); one faculty commented that “The VLE replicates the field exercise exactly”.

4.3. Technical Details

The platform for the VELS is based on Autodesk Maya and Unity3D. Maya software was used to model and texture instruments and characters, and to animate their functionality. Interactivity was programmed in Java using the Unity game development platform. The virtual
environment is deliverable via web or CD-ROM on standard personal computers (PCs and Macs) and is designed to run on hardware and software infrastructure that is already widely deployed in universities. Students can use the VELS on low-end personal computers (PC/MAC) anywhere anytime.

The VELS presents the students with a variety of terrains to practice on. The virtual terrains are created at run time from DEM (Digital Elevation Model) data. The DEM data is available in a file format (spatial data transfer standard .ddf) that cannot be opened by Unity 3D. In order to import the terrain data into Unity, each DEM file is first opened in the United States Geological Survey (USGS) Global Mapper software, saved as a gray-scale image, imported in Photoshop, exported as a .raw file and saved in a database (e.g. the terrain database). A script imports the .raw file into Unity and reads it as a string into a buffer. By knowing the bit order, the file can be manually parsed and the gray-scale data is used to generate the height-map (with black being the lowest depth, white being the highest); the terrain polygonal mesh is then created at run time from the height map. In order to texture the terrain mesh, each height map vertex is located individually and different textures (e.g. dirt, grass, water, sand, etc.) are assigned based on the height of the vertex. A series of vectors are used at each vertex to calculate how the textures should blend into each other based on the height of the specific vertex. Figure 6 shows a raw image and the corresponding textured terrain generated in Unity.

To date, the terrain database contains 8 raw images, thus the application provides a selection of 8 terrains on which to practice. More images can be added in the future to provide students with a larger variety of terrains.

5. SUMMARY, CONCLUSIONS AND FUTURE WORK

The paper presents an overview of web 3D virtual learning environments. It includes a general definition of Virtual Reality Technology and Virtual Learning Environments, discusses literature findings on the benefits and challenges of using web-based VEs for self-discovery learning, and presents a review of the latest technologies/platforms used to develop online VEs. In addition, the chapter includes a description of two 3D web virtual learning environments that were recently developed by the authors. The purpose of this paper is to let the reader develop a general understanding of web 3D virtual environment technologies and trends, and their prospective application in education for the promotion of effective interactive learning experiences.

The VELS, one of the two projects reported in the paper, is currently being further developed and tested. One of the goals of our research is to provide a demonstration that certain topics in engineering education, and specifically in surveying, can be taught as or more effectively using online virtual learning environments than by traditional methods. Future work will include refinement of the VLE based on the findings of the initial evaluation, and assessment of learning outcomes. Summative evaluation will be conducted once the online VLE is fully completed to: (1) assess the overall worth and effectiveness of the VLE; (2) draw out key lessons learned from the project; and (3) determine the sustainability, transferability, scalability, and relative importance of the initiative in enhancing students’ understanding of surveying concepts and practices.

The VELS, sponsored by the National Science Foundation (NSF-TUES), addresses the need to create innovative learning environments that incorporate the best of traditional pedagogy with new paradigms that reflect our times (our students live in an information age where technology is an intrinsic and ubiquitous part of how we live and learn). The project’s long-term goal is to use emerging computer graphics technologies to develop and validate innovative educational technologies that support students learning and lead to effective instructional approaches in the engineering and technology curricula.
Provided that our work is successful, expanding the online VLE approach to other surveying concepts as well as other subject domains seems to be a logical step in which to proceed. If we are able to show a correlation between the VLE and student attitudes and performance in the classes in which it is used, we expect to expand the tasks to other civil engineering/building construction management courses, as well as broadening usage in the target classes.

ACKNOWLEDGMENT

Part of the work reported in the paper is supported by NSF-TUES award # 1140514.
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