Virtual Learning Environments in Engineering and STEM Education

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ABSTRACT—This paper discusses an innovative approach to teach engineering concepts using Virtual Reality based Learning Environments (VLEs). New learning modules have been created using Virtual Reality technology and introduced in interdisciplinary senior level and graduate level courses targeting mechanical, industrial and electrical engineering students. These Virtual Reality based learning environments have been used to teach micro systems related topics as part of overall efforts to enhance the learning experiences of students. The learning outcomes including student performance are discussed. The process undertaken to design and develop these VLEs are elaborated along with the technologies used to develop such environments. A brief discussion of next generation Internet technologies which hold the potential to impact engineering and K-12 education is also provided.

I. INTRODUCTION

This paper discusses the potential of Virtual Environments which use Virtual Reality (VR) technology for education and learning activities. In general, such Virtual Environments (VE) are widely used in various engineering domains from robotics assembly to more complex space systems design. Virtual Learning Environments (VLEs) are a subset of virtual environments which are created and used for educational and learning contexts at university and K-12 levels. In this paper, we discuss the design and introduction of these VLEs to teach engineering concepts at Oklahoma State University to both undergraduate and graduate students.

Virtual Reality [1-22] and Cyber computing techniques [23] are among the more recent technologies adopted for educational purposes. The potential of using such technology to teach simple and complex Science, Math and Engineering (STEM) concepts is significant [22, 23, 24]. Our students live in a cyber enhanced digital world where use of digital technologies is commonplace. Educational trends need to explore adoption of such technologies. As noted in [23], computer or software based learning tools refer to a larger set of tools and environments which enable students to learn using some type of a computer technology (which may be web based or running on a PC). Virtual Learning Environments (VLE) are a smaller subset of such computer based learning environments [23, 24].

II. VIRTUAL LEARNING ENVIRONMENTS (VLE)

VLEs involve the creation of 3D based graphics rich environments that can also interface with Virtual Reality technology (such capabilities are crucial to supporting both immersive and non-immersive interactions by users or students. With recent advances in Internet technology (such as Internet2 and the more advanced GENI type frameworks, see [23]), the impact of such VLEs is expected to rapidly transform the way our students learn.

Virtual Reality, in general, can be described as a technology that enables the creation of a 3 dimensional (3D) simulation environments; users can interact with such environments using 3D eyewear and trackers (figure 2). The 3 levels of immersion are non, semi and full immersion [22].

Non immersive environments [22, 23] do not provide active stereo views of the target simulation; here the environment looks similar to a typical 2D computer screen (figure 1); this is the most basic of VLEs. At the next level are Semi immersive environments; these can provide active 3D stereo views of target environments and users can interact using trackers, sensors and 3D eyewear (or stereo eyewear, see figure 2). The screen of interaction can be a computer screen or a much larger wall sized screen. These environments are referred to as ‘semi immersive’ [23, 24] as the user can interact with the 3D environment when they want to but also can look...
away at the real world around him or her (meaning they are partially immersed).

![Fig 1: A non immersive VLE](image1.png) ![Fig 2: A semi immersive VLE](image2.png)

Fully immersive environments are environments where your reference to the real world is completed eliminated (or the immersion is 360 degrees). Users can wear Helmet Mounted Displays (HMDs) on which the target environments are projected. Other types of such environments are also called CAVEs (CAVE Automated Virtual Environments) where multiple projectors are mounted in various configurations.

The term ‘Virtual Prototype’ [7, 20-21] has many descriptions; in this paper, we use the description as in [7], where it is described as a three Dimensional (3D) computer model which seeks to ‘mimic’ a target (or ‘real world’) object, system or environment using Virtual Reality technology. This model can be a representation of a target environment, a simple object or a system of ‘objects’ at various levels of abstraction.

Several reports highlight the potential of computer simulations in engaging and motivating students especially in Science Technology Engineering and Mathematics [STEM]. However, as noted in [11], there is a need for additional research to study the impact of such simulations oriented learning to improve science achievement.

Other researchers such as Sourin [16] report a 14% improvement when students utilized a virtual world during their learning of computer science concepts. Other less extensive studies involving student surveys report that students indicated that virtual reality environments helped them learn [17, 18].

Research papers have also attempted to address what the students experience when interacting with such VLEs. In [12, 13], the authors outline a phenomenon referred to as flow where individuals enter a state of completely focused motivation which facilitates learning; when students experience such a state of ‘flow’, they report that they became focused only on the task and become less aware of extraneous factors [14, 15].

In the context of engineering education, it is important to note that other than our own pilot project (discussed in section 4) involving use of Virtual Reality to support learning, there have been very few reports on the impact of using VLEs and related technologies in engineering at the university level [11]. In the context of technology, it should be noted a majority of the literature reviewed deal with non-immersive simulation environments [1-10]. While there is a growing literature of studies utilizing virtual reality and simulations for student learning [19], very few studies have attempted to demonstrate objectively that learning can be enhanced when students have access to virtual reality learning environments.

As indicated earlier, the main emphasis in this paper is on how VLEs are used in teaching engineering concepts at the college level and the impact on student learning. Results from a pilot study involving use of VLEs in teaching engineering students will be discussed.

### III. DEVELOPING THE VIRTUAL LEARNING ENVIRONMENTS

Since 2004, VLEs have been used by J. Cecil’s group (while he was at New Mexico State) to introduce students to complex engineering concepts in various manufacturing domains including computer aided manufacturing, electronics assembly as well as emerging domains such as micro and nano assembly. In recent years, the process of creating virtual prototypes in general has also been studied for various engineering domains including micro assembly [25].

The main phases in creating such VLEs include:

1) Identify the Learning Objectives and Target Student body
2) Understanding of the engineering process of interest
3) Design the Virtual Learning Environment (VLE)
4) Build the VLE

In the first phase, the instructor identifies the learning objectives specific to the students in the course. Subsequently, a collaborative team of experts, VLE designers, and education assessment specialists design and develop the VLE under the supervision of the instructor in phases 2, 3 and 4. In the second phase, the understanding of the target engineering process takes place. As such, the experts bring in their content and skills to engage in understanding the process that goes on in the development of the VLE. The third phase is the software design of VLE.
Designing the VLE is one of the most important phases in the creation of a Virtual Learning Environment (VLE). This complex phase involves developing a detailed architecture of the VLE (including identifying and specifying the various modules in the software environment); formal techniques such as creating collaboration, sequence and class diagrams are useful as they provide a structured way to design the VLE. The fourth phase is the building of the VLE using software tools and VR technology. A key part of this activity include developing (or ‘coding’) the various components or modules of the VLE.

IV. IMPLEMENTATION OF VLE IN CLASSROOM

Several VLEs have been created and used as part of engineering courses targeting senior and graduate students from industrial, mechanical and aerospace engineering programs. These VLEs have been used in a course titled Introduction to Micro Devices Assembly course at Oklahoma State University (OSU). These VLEs were developed as part of a pilot initiative funded as part of an NSF DUE project. Two of the VLE based modules introduced students to the design of micro assembly work cells as well as assembly planning techniques using Genetic Algorithm (GA) based concepts.

In the Micro Assembly course (IEM 4353/5343), one of the topics where the students did not perform well related to Genetic Operators including cross over, mutation and inversion. Specifically, one of the identified issues was problems involving forming new child sequences when various GA operators (such as cross over, mutation, etc.) were used; subsequently, these operators were adopted as part of a more complex assembly planning approach. The creation of the VLEs focused on improving student understanding of these operators as well as helping students develop robust work cell designs involving assembly of micron sized parts using a given set of physical design elements (such as micro positioners, grippers, cameras, etc).

A semi-immersive VLE was created where students were able to run a number of simulations using various sets of parent links for assembly sequence generation tasks. When a user wanted to continue their learning for different problems or questions, the VLE randomly changed the sequences of the parents to provide a diverse variety of examples (there was no limit to this number of examples); students could pause during the simulation as well as navigate or zoom in to get a better view of the problem question as well as the answers in the examples. Students could learn at their own pace and could learn interactively by selecting different candidate links. For example, in figure 3, the use of the cross over operator is shown (within the VLE).

One of the benefits of using such a VLE based approach is that it allowed students to learn by exploring various options and by executing a limitless supply of examples. Students could pause the simulation when a certain step in the sequence was not clear and repeat a step if necessary.

The design of micro assembly work cells was also taught using the VLEs (see figure 4). In this activity, the students were introduced to the major design components involved in automating robotic micro assembly tasks which included using cameras, micro positioners, advanced grippers and control components. They were then evaluated on their understanding of the functionality of these devices; subsequently, they had to develop their own design of their work cell based on these design elements.

The results showed that after introducing semi immersive based VLE based teaching techniques, there was an improvement in the overall performance of the students in understanding concepts in the 2 topics in which they were introduced. Assessment data was collected based on performance in homework and exam questions.

Figure 3: Closeup view of a VLE for teaching GA operators

The most significant outcome was in the improvement in the student performance in understanding concepts in the modules in which the VLEs were introduced. Assessment data was collected for 60 students based on performance in quizzes, homework and exam questions. The performance of the students with and without the VLEs was studied. Thirty students were taught these concepts using the traditional lecture and discussion approach. Another thirty students were taught the same concepts using the VLEs. The initial assessment results indicated the following:
(i) Student performance in quizzes increased by 22%;
(ii) Student performance in homework and exams increased by 30% (for the modules in the 2 topics: work cell design and genetic algorithms (GA) operators).

The experiences of the group of students were also studied through surveys. A majority of these students (86%) preferred VLE based learning over traditional classroom lectures and discussions. There were ten undergraduates and twenty graduate students who learnt the micro assembly concepts using VLEs.

A more detailed discussion of the outcomes can be found in [4]. Our assessment and analysis work is continuing in this and other engineering courses. This study is one of the first that has focused on the design and impact of such VLEs in engineering education. As discussed in [7], the use of VLEs holds significant potential in impacting learning in engineering education.

Other assessment and evaluation activities are continuing on studying the impact of using VLEs to teach engineering concepts. It is important to note that this is a pilot study and is the first of its kind targeting engineering students. In this pilot study, there was no assessment of the learning patterns of the students or their backgrounds. Data was not collected about the performance of students based on gender, race and economic background. Additional comprehensive studies are needed to throw more light on the learning patterns of a diverse body of students. Future studies also need to address the impact of team based learning when using VLEs.

V. OTHER EMERGING CYBER TECHNOLOGIES

One of the more recent developments is the adoption of cyber technologies and tools to support educational activities. The adoption of cloud technologies as well as other next generation Internet tools is expected to revolutionize the way students access, share and learn using distributed resources from different locations.

As part of a pilot initiative, one of the VLEs modules related to teaching micro assembly work cell design was made accessible through a cloud. Students were able to access this learning module through their ‘smart’ phones.

Two other important initiatives in Next Generation Internet and Computing are underway which hold significant potential in impacting engineering and STEM education in a significant manner. The GENI (www.geni.net) initiative involves the design and deployment of the next generation of Internets (which is being funded by the US National Science Foundation NSF). These advanced networks and approaches (being explored in these initiatives) have several innovative aspects including software defined networking and adoption of cloud technologies; these networks will enable students and teachers in distributed locations to access and share resources especially involving high bandwidth data; using such networking approaches and technologies will enable sharing of VLE based environments (involving rich 3D virtual reality data), as well as enable students to interact with distributed manufacturing equipment in educational labs (where camera monitoring of remote manufacturing and engineering activities enables better learning).

The US Ignite initiative (http://us-ignite.org/) is another initiative whose outcomes will profoundly impact engineering and education (among other areas). It seeks to foster next-generation Internet applications that provide transformative public benefit using ultrafast high gigabit networks. The six national priority areas are Education & Workforce, Advanced Manufacturing, Health, Public Safety, Energy, and Transportation. Both the GENI and US Ignite initiatives underscore the impact of next generation computing frameworks on engineering and educational practices.

In a pilot demonstration of the potential of next generation Internet frameworks, educational activities involving sharing of resources and learning modules among K-12 and engineering students was conducted in spring 2013 involving Oklahoma State University and University of Wisconsin Madison.

Apart from demonstrating the use of such technology for school students, an important objective was to demonstrate the feasibility of this
next generation technology on helping children with autism learn using VLEs that were equipped with haptic interfaces (figure 5). One of these demonstrations involved children with autism interacting with their teacher at another location using haptic device (which enabled them to “feel” the objects they touched virtually inside a computer); the next generation collaborative framework was used to teach science and math concepts to autistic students in grades 1 and 1 from a local school (Sangre Ridge Elementary) in Stillwater; this pilot demonstration was part of a project aimed at supporting learning activities for children with autism; some of these activities have been recorded and posted on youtube.com at https://www.youtube.com/watch?v=BAfd2ax6tk4. Another recording of interactions among middle school students (from Stillwater Middle School) can be found at http://youtu.be/EIlNqpCAIu4 [25]. In these demonstrations, students at different locations could interact with each other and explore a micro robotics simulation environment using next generation Internet networks.

These collective pilot demonstrations highlight the potential of the next generation Internet frameworks for supporting educational activities; while the current Internet has had a phenomenal impact on education, the next generation of Internets holds the potential to further revolutionize educational activities especially for engineering and STEM learning contexts. It will enable (a) teachers and students to interact with each other from different locations, (b) facilitate special education students to learn using immersive and haptic interfaces as well as (c) enable accessing resources from geographically distributed location using cloud and other related technologies.

VLEs (with or without networking capabilities) can also be used to supporting teaching Science Technology Engineering and Mathematics (STEM) concepts for K-12 students including children with autism. One of the VLEs created was a virtual solar system for elementary school students (figure 6). Other VLEs developed for middle school students introduce them to physics concepts including properties of matter including mass-volume-density relationships.

VI. CONCLUSION

In this paper, we have provided an overview of Virtual Learning Environments (VLEs) and their use in engineering education. A brief discussion of the process of creating such VLEs was also provided. The impact on student learning as part of an engineering course at Oklahoma State University (OSU) was also discussed.

One of the main challenges in the development of VLEs is that it is a time consuming process; the creation of a VLE can range from six months to more than a year (depending on the scope and level of complexity of the targeted engineering concepts). The faculty and engineers involved need to also be familiar with Virtual Reality technology and design of VLEs [22-24]. As the outcomes of this study for engineering students (reported in this paper) indicate, (once the VLE is developed), the impact on student learning and performance can become the basis to justify the investment in cost and time.

The paper also briefly discussed the emergence of next generation computer networking technologies and related initiatives including GENI and US Ignite. Pilot demonstrations conducted highlight the potential of these emerging technologies to support engineering and STEM education.

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