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Innovative Next-Generation Virtual Reality-based ImmersiveApproaches for Learning Engineering Concepts

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Innovative Next Generation Immersive Learning Approaches involving Virtual Reality based Virtual Learning Environments (VLEs)

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Abstract

This paper discusses an innovative approach to teach engineering concepts using Virtual Reality based Learning Environments (VLEs). These VLEs were used to teach various topics to university engineering and computer science students including assembly planning using genetic algorithms and factory automation concepts. These VLE were created using the fully immersive Vive platform. Students' learning was compared between the traditional lectures versus learning using these immersive VLEs. The assessment activities focused on the impact of VR based VLEs on student learning and engagement. The primary conclusion was that learning with VLEs impacted the student learning and engagement in a positive manner.

I. Introduction

With the onset of the Fourth Industrial Revolution (which is information centric and IT related), there has been a substantial interest in adopting 3D digital approaches in different engineering and computing problem solving in industry. While this digital technology has been changing the way we live work and play, there has been far less impact on the way engineering students learn basic and advanced concepts at the university level [28]

This paper discusses the design and impact of next generation Virtual Learning Environments in teaching engineering concepts to university students (both undergraduate and graduate students). The term Extended Reality (XR) refers to 3 types of virtual environments: Virtual Reality (VR) Environments, Augmented Reality and Mixed Reality (MR) environments. In this paper, the impact of adopting VR and MR based learning environments to teach engineering concepts is discussed. In general, such Virtual Learning Environments (VLEs) have the potential to be used to teach engineering topics and concepts ranging from robotics assembly to more complex space systems design. Virtual Learning Environments (VLEs) can be viewed as subset of virtual environments which are created and used for educational and learning contexts at university and K-12 levels. In this paper, the impact of adopting such cyber learning approaches involving these VLEs to teach engineering concepts at Oklahoma State University to both undergraduate and graduate students is discussed.

Virtual Reality (VR), 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). In a fully immersive environment, the user or student is interacting with a target learning scene using 3D eyewear and controllers to interact, navigate and perform other tasks as part of the learning experience [22]. 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 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].

VLEs involve the creation of 3D based graphics rich environments that can also interface with Virtual Reality and Mixed Reality technology (such capabilities are crucial to supporting both 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 ability to interact and learn with such VLEs from remote locations is expected to rapidly transform the way our students learn. There are many benefits to adopting such immersive learning environments; apart from the power of learning in a more intuitive manner, such an approach also allows students to access these learning modules on a 'on demand' basis (24/7). The challenges to such remote interactions included latency which can delay the exchange of user selections, object movements inside a 3D learning scene, among others.

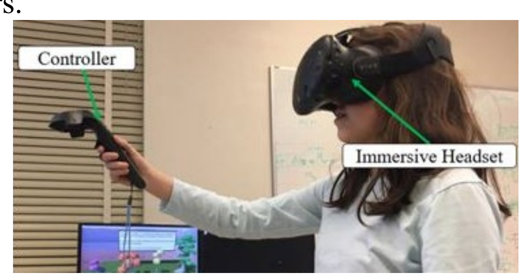

Fig 1: An immersive VR based VLE (the student is wearing a 3D headset and interacting with the target environment using a controller)

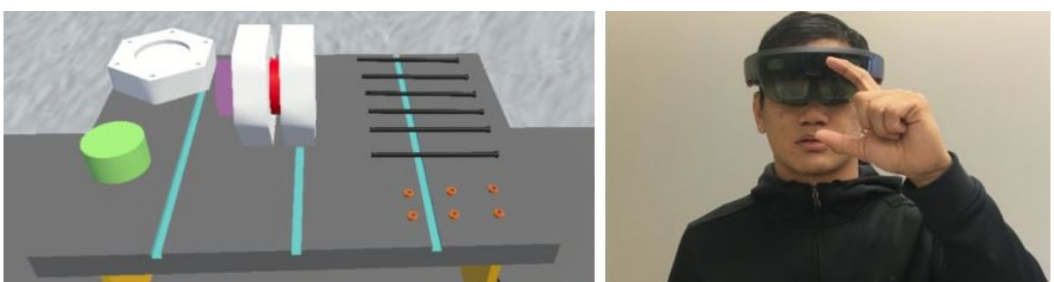

Fig 1 b: A Mixed Reality based VLE; a student can be seen interacting with the virtual scene using gestures; not show is the target physical assembly environment (which is in the real or physical world).

Fully immersive environments (fig 2) are environments where your reference to the real world is completely eliminated (or the immersion is 360 degrees). Users can wear Helmet Mounted Displays (HMDs, sometimes referred to as headsets) 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. There are several commercial platforms which support such VR and MR based interactions. VR platforms include the Oculus Rift and HTC Vive; MR platforms include HoloLens 2, Varjo and Apple's Vision Pro.

The term 'Virtual Prototype' (VP) [7, 20-21] has many descriptions; in this paper, we follow the following description which has been modified based on the original description in [7]; a VP can be described as a three Dimensional (3D) computer model which seeks to 'mimic' a target (or 'real world') object, system or environment and enables users to interact with it using Virtual Reality. Augmented Reality or Mixed Reality interfaces and 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 have highlighted 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 3D VLE and simulations oriented approaches to facilitate STEM learning. Other researchers such as Sourin [16] have reported 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 research (discussed in this paper) 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 that a majority of the literature reviewed deal with non-immersive simulation environments [1-10]. In a non-immersive VLE, a user interacts with a learning module or environment which is running on a computer screen; there is no actual 3D scene and the users do not wear any 3D eyewear (which shows depth) nor do they have any specific controllers to navigate and interact during their learning experiences. While there is a growing literature of studies involving simulations to enhance student learning [19], very few studies have attempted to demonstrate objectively that learning can be enhanced when students have access to VR/AR/MR learning environments.

As indicated earlier, the main emphasis in this paper is on how VLEs are used in teaching engineering concepts at the university level and theie impact on student learning. Results from our research study involving the use of VLEs in teaching engineering students is discussed in detail.

II. DEVELOPING THE VIRTUAL LEARNING ENVIRONMENTS

Virtual Prototypes have been used by authors and other researchers to design collaborative and concurrent engineering based approaches in both product and process development. The authors have introduced 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. In recent years, the term 3D digital twins have become more widespread. In general, they mean the same. The adoption of such VR based models as part of simulation based design approaches are not new. However, with the emergence of low cost immersive platforms such as the Vive and Oculus Rift, there has been a substantial increase in the adoption of such approaches in engineering, healthcare, space systems and education,

The main phases in creating such VLEs have been discussed in literature [29]:

1) Identify the Learning Objectives involving Target Students
2) Design the Virtual Learning Environment (VLE)
3) Build the VLEs
4) Collect Feedback and Modify VLEs(Test and Validate the VLE content)
5) Perform Learning Interactions and Assess Learning outcomes.

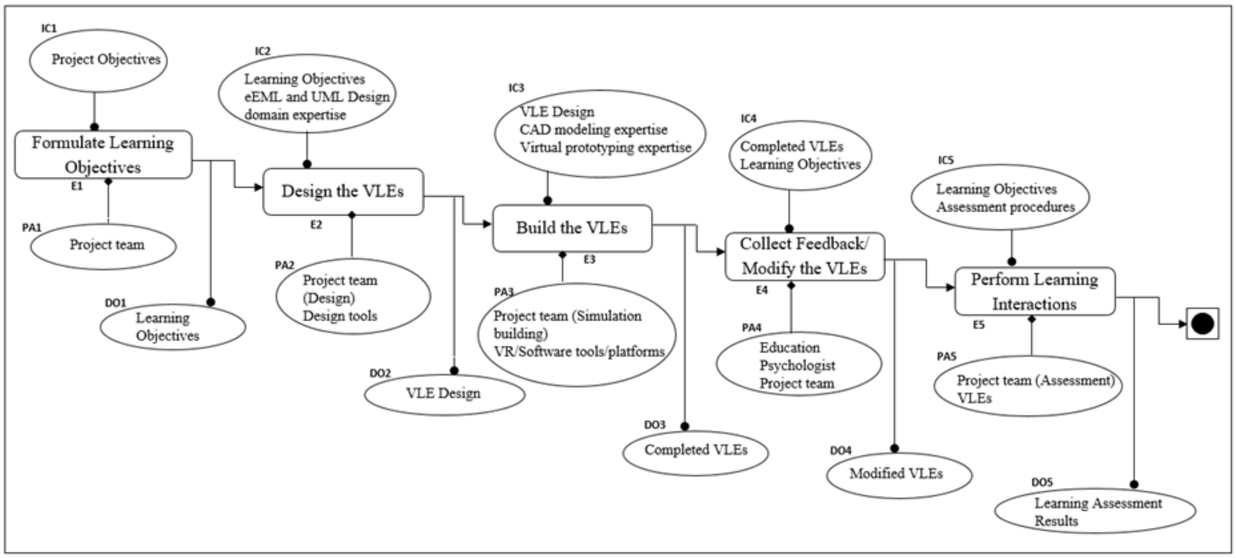

Figure 1 c: The main phases in the creation of the VLEs and the assessment tasks (from [29]).

The project team includes the instructor (or knowledge source), the software engineering team (who designs and builds the VLEs) and an educational assessment expert. 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. As such, the instructor (or professor) provide their knowledge and expertise 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). The content/knowledge expert works closely with the software team and the educational assessment experts. 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. The next phase involves validation and testing where feedback is obtained after interacting with the developed VLEs; here the instructor and others who are familiar with the subject or topics interact with the VLE to ensure the following: is the content correct and complete for the identified learning scope? Do the interfaces of the VLE perform satisfactorily? (response of menu buttons, other controller commands, display of the 3D scenes, etc.). Modifications may be undertaken based on the outcomes of this phase. Subsequently, after the VLE is validated, the learning interactions and assessment is conducted involving the students.

III. VLE BASED LEARNING

Several VLEs have been created and used as part of engineering courses targeting senior and graduate students from computer science, industrial, mechanical and aerospace engineering programs. These VLEs have been used in a graduate level course (which is also a senior level elective) titled Introduction to Cyber Physical Systems course at Oklahoma State University (OSU). 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 this paper, we discuss the learning process and the assessment outcomes related to the functioning of the GA operators (cross over, mutation and inversion).

In this course (IEM 4353/5343), one of the learning modules created using VLEs related to Genetic Operators including cross over, mutation and inversion. Specifically, one of the identified sub-topics involved formation of new child assembly sequences from parent 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; specifically, how to generate new child sequences given a parent sequence or two parent sequences. A second learning focus was on understanding the design elements underlying the creation of an automated micro assembly work cell; this was a cyber-physical work cell which had an array of cyber resources (for gripper selection, path planning, assembly sequence generation) and physical resources (a robotic work cell, assembly plate, micro positions for controlling movement of the gripper and assembly plate, cameras and controllers).

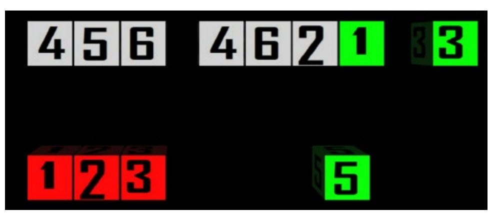

Figure 3: A view of an intermediary step in the generation of a new parent sequence using the crossover operator (the 3D image has been converted to 2 D for inclusion in this paper).

An immersive VLE was created using the Vive platform where students were able to learn interactively using the 3D headsets and controllers. The students were first given an overview of the learning topic and how the simulation based VLE would be used by them. 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. A teaching avatar described the steps as they were simulated step by step. 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). In terms of background information, the learning interactions focused on how to generate new child sequences; a sequence would be a string of genes and would form a chromosome. In a GA, these chromosomes would follow specific steps in the algorithm where a fitness function would be used to generate a near optimal value.

Subsequently after their learning sessions, each student could then interact with an assessment module; the students were given a maximum score of 100 points: there were 3 assessment questions:

Question 1: Generate a new parent sequence based on the cross over operator; they could move the individual genes (shown as numbers) from each of the parents. This was 50 point.

Question 2: generate a new parent sequence based on inversion operator (50 p)

Question 3: generate a new parent sequence based on the mutation operator. These studies were conducted for two different class cohorts. The results discussed are the assessment conducted for graduate students only. In cohort 1, 15 students (group C1-Trad) were taught using the traditional whiteboard lecture approach. The instructor explained the basics of the genetic algorithm and used slides to highlight the functioning of the three operators. For each operator, the instructor worked out 3 examples (meaning 3 problems for identifying new parent sequences using crossover, 3 problems for identifying parent sequences using mutation and another 3 problems for using inversion operator).

In cohort 1, 15 other students (group C1-VR) were exposed to the same concepts using the VR based VLEs. In cohort 2, a similar group breakdown was followed: 10 students in group C2- Trad and 10 students in group C2-VR.

IV. ASSESSMENT

Following the learning activities for both groups, as part of the assessment, each student had to solve the following: 1 problem for mutation (25 p), 1 problem for inversion (25 p) and 2 problems for crossover (2 x 25 = 50 p). The maximum score was 100 points.

One of the benefits of using such a VLE based approach is that it allowed students to learn by exploring various solution options in an interactive manner following a cycle of proposal, comparison and final decision making. Students could pause the simulation when a certain step in the sequence was not clear and/or backup or repeat a step if necessary. They were given an opportunity to practice with 3 problems in each operator category as the students in group C1-Trad. A t-test was conducted to assess the impact of adopting the VR based learning approach.

The Null Hypothesis for the t-test was the following:
The VR-based learning method does not lead to improved understanding of the target concepts compared to traditional learning methods.

Cohort 1		
	Group C1- Trad	**Group C1-VR**
Mean	67.5	85.83333333
Standard Deviation	14.01529776	13.25123534
Variance	196.4285714	175.5952381
N	15	15
Significance	0.05	
| T |	3.68	
Critical Value	2.048	

Table 1: T-test summary

The findings of the assessments for the two groups are shown in Table 1. The derived 't' statistic's absolute value (3.68) is higher than the essential threshold value (2.048) after a t-test was performed to assess the efficacy of VR-based learning. Therefore, the null hypothesis can be rejected at the 0.05 significance level, proving that there is a substantial difference between the results of VR-based learning and traditional learning approaches. The alternative hypothesis is accepted with the conclusion that VR-based learning has a better impact on student learning than the traditional lecture based approaches.

A similar t-test was conducted for a different cohort C2 comprising only of undergraduate students as well. For brevity, this data is not being included. The t-test indicated that the VR based learning indeed impacted their learning as well in a positive manner. The experiences of the group of students were also studied through surveys. Feedback from the group which was exposed to learning using the VLEs indicated that a majority (90%) preferred VLE based learning over traditional classroom lectures and discussions. A more detailed survey based on the NASA TLX was also conducted regarding the user interactive experience involving the VR based VLE..

The NASA task load index (NASA TLX) [27] is a tool for measuring and conducting a subjective mental workload (MWL) assessment. It allows you to determine the MWL of a user while they are performing a task. In this research, it was used to throw light on the MWL of the user when interacting with the VR based VLEs. It rates performance across various factors listed below:

1. Mental demand: how much thinking, deciding, or calculating was required to perform the task.
2. Physical demand: the amount and intensity of physical activity required to complete the task.
3. Temporal demand: the amount of time pressure involved in completing the task.
4. Effort : how hard does the participant have to work to maintain their level of performance?
5. Performance: the level of success in completing the task.
6. Frustration level: how frustrated or content the participant felt during the interactions.

The original TLX ratings were adapted to suit this VR based learning context. In general, in the original TLX ratings, users are asked to rate their score on an interval scale ranging from low (1) to high (20). In our adopted approach, we have modified the interval scale to range from 1 to 10. Table 2 provides the survey outcomes averaged for the 15 participants in Group C1-VLE.

Criteria (rating between 1-10)	**Rating**
User friendliness of avatar during VLE interactions	8
Ease of interacting with the VLE content wearing the 3D headset	8.6
Ease of navigating using the controllers	8.9
For below responses: 1: Low 10:High	
Effort: how hard did you have to focus in order to complete the interactions?	3.7
Mental Demand: How demanding was the learning experience?	2.9
Physical Demand: how physically demanding were the interactions>	2.7
Temporal Demand: how hurried were you in completing the learing and assessment?	1.9

Table 2: Survey results of the modified NASA TLX

The primary conclusion from the modified NASA TLX is that the physical, mental, temporal and effort demands were on the lower end of the scale. The other feedback elements of the VR based interactive experience were positive in general (ranging from 8 to 8.9 on a scale of 10).

V. CONCLUSION

The results from this study underscores the potential of such VR based VLEs in helping students learn engineering concepts. Other research objectives are also continuing including studying the role of avatars and their impact on student learning experiences. It is important to note that this is a pilot study and is the first of its kind targeting engineering students. In this 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.

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