An Experiential Approach to Support Learning of Cyber Physical Systems Concepts involving Mixed Reality Platforms

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***Abstract* — The potential of adopting cyber learning approaches to improve student learning and engagement is an important area of educational research. The advent of Virtual Reality (VR) based learning environments or Virtual Learning Environments (VLEs) has ushered in the cyber-based educational era which involves smart technologies supporting experiential learning and other approaches to enrich the learning experiences in Science, Technology, Engineering, and Mathematics + Computing (STEM+C) topics. In this paper, the discussion of such experiential activities to teach advanced concepts in cyber-physical systems using process contexts from NASA's Moon Mission is discussed. There are two thrusts: (1) studying the potential of experiential activities where engineering and computer science students are taught to design and build such cyber-physical environments using Mixed Reality (MR) involving astronaut training scenarios (2) assessing the impact of immersive VLEs using low-cost platforms such as the Vive in learning science and engineering concepts. The results of such learning experiences in terms of engagement and learning on students are discussed. The overall conclusion is that such experiential activities involving VR/MR technologies have the potential to impact student learning in a positive manner.**

I. Introduction

The emergence of next-generation practices such as Cyber-Physical Systems is becoming increasingly the focus of engineering, healthcare, transportation, and other organizations worldwide [1-3]. Other smart technologies such as Virtual/Mixed Reality is becoming more widely used in various industries, including healthcare, manufacturing, and space systems [4-10]. As the demand of a highly skilled workforce increases, the current generation of university students, especially in the science and engineering fields, need to be exposed to such emerging practices and technology. Experiential learning approaches hold the potential to help students learn identified concepts effectively at a higher level of engagement [11]. Experiential learning can be defined as the process in which the students learn through experience and take a more active part in learning activities. In the experiential learning approach, the students gain analytical, decision making, and problem-solving skills by continuously gaining experience in a project-based or hands-on learning scenario. Smart technology (Virtual Reality, Mixed Reality, Internet/Networking) can be viewed as next generation technology that holds significant potential in supporting experiential learning approaches for computer science and engineering topics. A related area of educational innovation is the exploration of such VR/MR based cyber learning approaches, which also hold the potential to engage students effectively while helping them grasp complex concepts through 3D immersive experiences [12, 13]. In recent years, with the emergence of low-cost VR/MR platforms, the adoption of such experiential and cyber learning approaches is less expensive compared to previous decades. This increases the ability of low cost approaches to advanced cyber learning approaches that can engage our students, who live in a cyber intensive world of apps and smart tools.

The findings and discussions in this paper build upon our previous work in this educational area involving studying the design, implementation and impact of VLEs for science and engineering learning [14-17]. Other efforts (including our own) have focused on investigating the impact of experiential learning approach through practical projects in manufacturing and space systems [2, 3, 12, 13].

II. Experiential Learning Invoving NASA Moon Mission Related Astronaut Training Activities

Experiential learning is an engaged learning process whereby students "learn by doing" and by reflecting on the experience [18]. The experiential learning process (ELP) includes the following activities:

1. Phase 1: Selection of target topics for EL and design of the EL activities
    - Instructor carefully selects and designs the experiential learning activities; the various target topics are identified (eg: the creation of Virtual Reality based models, learning a specific algorithm, etc.); subsequently, details of the learning experiences are proposed and expanded. In this course, the emphasis was on Virtual Learning experiences including Virtual Reality, software and Mixed Reality environments.

- These experiences provide opportunities for students to obtain a deeper understanding of target concepts through software based 'hands on' activities, learning by proposing new solutions in 3D environments, comparing alternatives, choosing best alternative, learning from mistakes and successes).

2. Phase 2: Implementation of the EL activities involving students
   - Throughout the experiential learning process, the student learner was actively engaged in designing new environments, experimenting virtually with design alternatives, solving design/software and engineering problems, being creative and curious, and is challenged to take initiative, making decisions and being accountable for results.
   - Relationships are developed and nurtured during the ELP: student learner to self, learner to others (other learners, experts, instructor), and learner to the world at large (the NASA mission to the Moon, the relationship of the learner to the future of specific concepts that is changing or will change their world view etc.).
3. Phase 3: Reflection on learning by Students
   - During and after ELP, students reflected on their learning; this included analysis, critical thinking and synthesis (similar to related concepts outlined in [19, 20]; such reflection involves identifying relationship of key factors coming into play during the problem solving activity during the EP, identifying what factors lead to any early mistakes, what modifications were need to overcome design/engineering obstacles, etc.
   - During this ELP, the students learners were engaged intellectually, socially (working in teams, interacting with outside NASA engineers, faculty), and/or physically/virtually (with VR, software and MR environments).

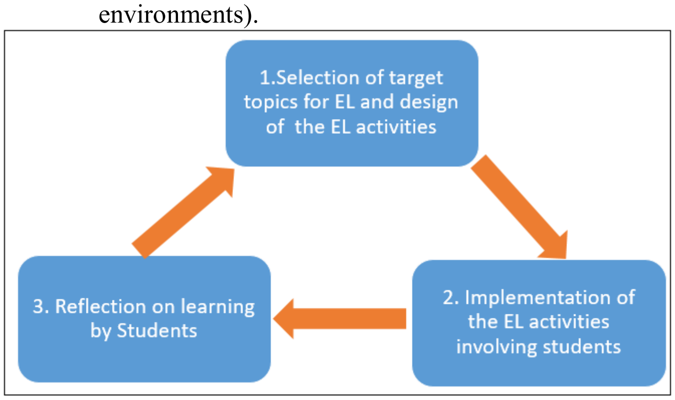

Fig. 1. Phases in Experiential Learning

This paper discusses the experiential learning activities to teach concepts related to design of cyber physical systems as part of a senior level interdisciplinary course titled 'Introduction to Cyber Physical Systems' at Oklahoma State University. Table 1 shows the topics and concepts that the students learnt during the course and the experiential learning activities used to teach such topics and concepts.

Topic	Experiential Learning Activity
1.How to design and create non-immersive VR models	1. Exposed to the fundamentals of creating models using NASA Moon Mission contexts 2. Introduced to process of creating non-immersive VR models of the following a. inside layout of habitat b. layout of airlock c. lunar surface for navigation d. tools for science sampling activities
1.How to design and create immersive MR environments	1. Foundational understanding of how to design MR environments 2. MR environments were identified; these included a. operation of airlock b. display of astronaut's vitals c. navigation approach d. science sampling activities 3. Students modeled cyber-physical interactions and created information centric models 4. Based on design, they created cyber-physical environments using MR tools and technologies such as HoloLens 2, Vive Pro, Solidworks, Unity, C#
3. Understanding of system engineering approach	1. Obtaining understanding of system engineering approach through the creation of IDEF-0 models 2. IDEF-0 models helped in understanding the functional relationships between various design activities
4.Understanding of agile software development methods	Exposed to agile software development methods through the design of a. activity diagram: helped understand the workflow of the activities to be performed by the astronauts b. sequence diagram: helped understand the cyber-physical interactions for the tasks performed by the astronauts using the UI

Table 1. Topics Learnt as part of the experiential learning approach

As part of the experiential learning approach, the students were exposed to the following topics through the experiential learning activities performed during the duration of the course.

1. Design of non-immersive VR models:

For this topic, the students were exposed to fundamentals of creating 3D models for the NASA moon mission contexts. The students focused on learning non immersive VR models for various requirements for the NASA SUITS project. The students learnt to create VR models such as layout of the lunar habitat and airlock, lunar surface consisiting of rocks and cretors and various tools and equipments used for science sampling and other activities to be performed by the astronaut during the lunar mission. The foundational VR environments for the UI were created using the Unity 3D engine, C# (which was used to program scripts to support various simulation and visualization tasks) and SolidWorks (to create the various CAD models to represent the habitat's interior, the lunar surface and astronaut avatar models).

2. Design of immersive MR environments:

For this topic, the emphasis was on obtaining a foundational understanding of the process of designing MR based environments. Based on the requirements of the NASA SUITS project, the students, first, identified the MR environments to be built. Subsequenlty, the students modeled the cyber and physical entities necessary for the CPS based interactions. Finally, the students created the cyber physical environments using MR based tools and technologies. The immersive MR platform was the HoloLens 2, which allows users to interact with the virtual world and the real world simultaneously [21]. A view of main UI showing the possible interactions is shown in Fig. 2. In Fig. 3, a student can be seen interacting with the MR based UI using HoloLens 2's hand based gestures. In Fig. 4., view of a student interacting with the cyber physical environment created as part of the expereintial activitites. Fig. 5. Shows a view of a student performing the science sampling activities using various physical tools such as hammer and rake by following the instructions provided through the HoloLens 2 UI.

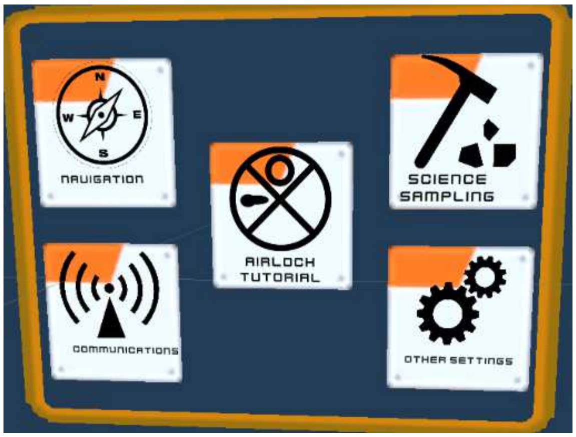

Fig. 2. The view of the MR based UI showing various types of interactions

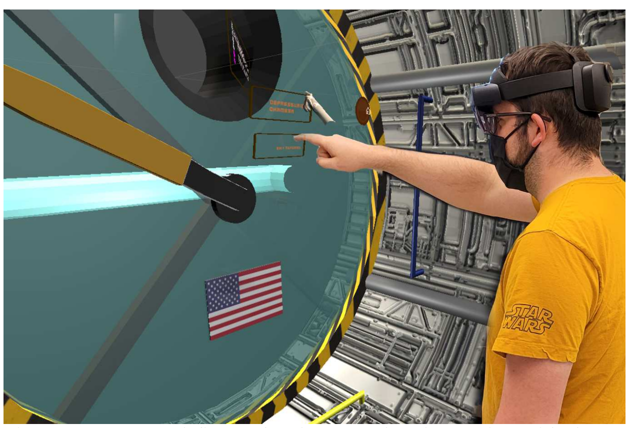

Fig. 3. A conceptual figure showing a student interacting with the UI from within the Spacecraft using HoloLens 2

Fig. 4. A view of a student interacting with the cyber physical environment created as part of the experiential activities.

Fig. 5. A view of a student performing the science sampling task as part of the NASA SUITS project

3. Understanding of system engineering approach

The students obtained the understanding of the system engineering approach which helped them in modeling the functional relationship between various design activites for the NASA SUITS project. For this topic, the students created information centric models using Integrated Definition (IDEF-0) modeling language. The IDEF-0 model provided four ICOM (inputs, controls, outputs and mechanisms) catagories of attributes to support various target activities (information/physical inputs, controlling factors or constraints, outputs from each modeled task and performig resources or mechanisms for each identified activity).

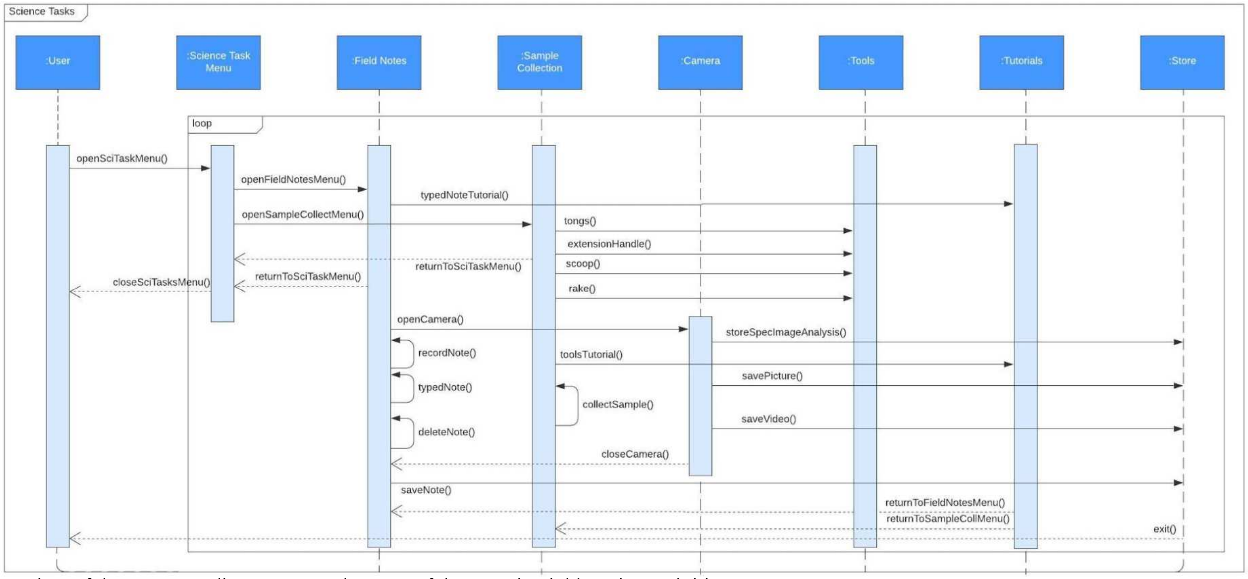

Fig. 6. A view of the sequence diagram created as part of the experiential learning activities

4. Understanding of agile software development methods: For this topic, the students were exposed to agile software development methods. As part of the NASA SUITS project, the students created Unified Modeling Language (UML) based models of the design of the MR based UIs. The students created UML activity and sequence diagrams. Activitiy diagrams depict the behavior of any system showing the workflow of the activities being executed. Sequence diagrams show object interactions arranged in time sequence. Activity diagrams helped understand the workflow of the activities to be performed by the astronauts and the sequence diagrams helped understand the cyber-physical interactions for the tasks performed by the astronauts using the UI. A view of the sequence diagram created as a part of the experiential learning activities is shown in Fig. 6.

III. Discussion

A comparison of the impact on student learning and engagement between (a) adopting a traditional software lab based approach (Learning Experience A, LEA) and (b) an experiential learning approach (Learning Experience B, LEB). This comparison involved teaching the same course (Introduction to Cyber Physical Systems) in two different years to the same target population: this was a senior level elective for undergraduate students in computer science, mechanical / electrical and computer engineering. The approach in LEA focused on software related assignments where students designed and built 3D simulation environments using a 3D engine (Unity). In LEB, the emphasis was on providing experiential learning activities.
(there were 20 students in LEA and 21 students in LEB and the students worked in teams of 4 or 5).. There were 4 homework assignments that was used as the basis for comparison: In both activities (LEA and LEB), the students worked in teams of 4 or 5. Both experiences involved mentors for each team. In LEB, these mentors were NASA engineers. Homework 1 focused on creating non immersive VR models. Homework 2 and 3 dealt with understanding of systems engineering concepts and agile software engineering principles respectively; Homework 4 involved students designing cyber-physical interactions and implementing their design through creation of simulators. In activity (a), the students were given specific software design and programming tasks after exposure to software principles and methods. In activity (b), the major difference was the exposure to practical learning contexts where the students were introduced to the same concepts as in (a) but with the added emphasis on designing and building software modules and cyber-physical environments involving the Moon Mission contexts. These contexts have been discussed in detail in previous sections.

A comparison of the student performance in learning was conducted on the basis of these 4 homework assignment. The class average for the two learning experiences (traditional and experiential) is shown in Fig. 7. The class average was higher for each of the four homework assignments when the students learnt using the experiential learning approach.

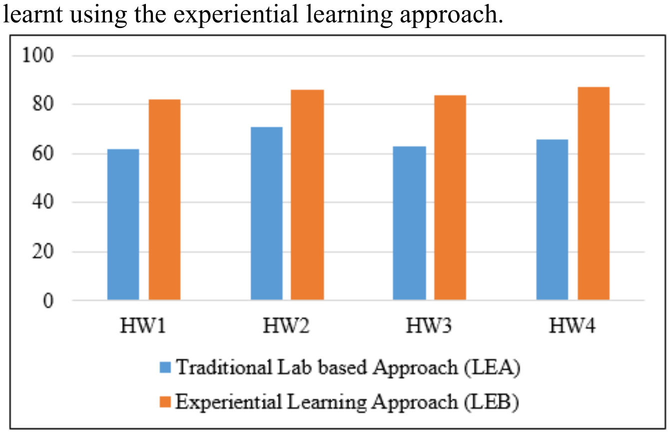

Fig. 7. Results of the study focusing on the comparsion of traditional lab based learning and experiential learning approaches

Engagement:
Student engagement was captured through surveys and feedback forms during and after completion of the team based project. The majority of students (90%) indicated creation of MR/VR based UIs and VR/MR mockups helped them understand the following:
(a) foundational concepts underlying cyber-physical system
(b) the process of designing and building such cyber-physical systems.
Majority of students (80%) indicated that the experiential activities helped in improving their understanding of systems engineering and software engineering principles and methods (these included adoption of UML based modeling methods including design of sequence and activity diagrams).

As the LEB course was taught in spring 2021 (during the pandemic), there were several challenges faced by students which are summarized below:

1. Weariness from using zoom and other web based tools for interaction with teacher, teaching assistant (TA) and team mates
2. Debugging the software modules and deliverables created by students took more time to be resolved initially as students were not comfortable using online tools; the feedback from students was split on this aspect; in a class of 21 students, 12 of them preferred working using online tools; 9 students indicated they would have preferred discussing such problems with TA face to face.
3. For some of the homework deliverables, the students had to come in person to the lab to use the Virtual Reality/Mixed Reality environment while observing physical distancing and other safety procedures. Majority of the students (90%) felt that all of the software and cyber-physical related deliverables could have been completed in a shorter time duration in a typical non-covid semester.
4. 80 % of the students indicated there was a need for universities to explore creation of remote cyber-physical labs with next generation interfaces where team members could interact from their homes with necessary MR headsets.

IV. Conclusion

This paper focused on the impact of adopting experiential learning approaches to teach a cyber-physical systems (CPS) course.. There were two educational thrusts. To support these experiential learning activities, students were introduced to target concepts and methods in cyber physical systems through hands-on cyber and cyber-physical activities using NASA's moon mission context. The assessment objective was to study the impact of introducing such experiential learning activities involving next generation technology and approaches (such as Virtual / Mixed Reality, Cyber-Physical Systems) and practical problem solving contexts (such as designing simulators for NASA's Moon Mission). The students worked closely with NASA engineers through biweekly meetings as part of these experiential learning expereinces. The assessment results indicated that adoption of experiential learning approaches has a positive impact on student learning and engagement.

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