Role of Immersive Simulation and Cyber Technology based Approaches in Supporting Learning and Curriculum Innovation

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Abstract—This paper focuses on the emergence of cyber technologies and immersive simulation-based approaches in supporting curriculum innovation and learning. A discussion of three thrusts involving immersive simulation and cyber technologies is presented. The first thrust focuses on innovative learning activities involving space systems concepts that revolved around the creation of 3D VR based immersive simulation environments for NASA’s Deep Space Mission process contexts. The second thrust involves the need to expose and encourage students towards entrepreneurial activities involving information-centric and cyber manufacturing principles. The third thrust involves the creation of 3D Virtual Learning Environments (VLEs) to support autistic students to learn science and engineering concepts interactively using both immersive and haptic interfaces.

I. INTRODUCTION

There is a need for the next generation computer scientists and engineering students to have exposure to the fundamentals of creating Virtual Reality (VR)/Augmented Reality (AR) based environments along with knowledge on the underlying principles that lead to the design and implementation of these environments. With the recent emergence of low-cost VR/AR platforms [1-7], there has been a phenomenal increase in such immersive VR/AR-based industrial applications. This continues to underscore the importance of engineering and computer science students having skills in related principles and technologies. Three related educational thrusts are discussed in this paper: the first thrust focuses on providing knowledge and skills to undergraduate and graduate students in the design of VR/AR-based approaches and environments using NASA related Deep Space Mission contexts [20]. The second thrust focuses on encouraging engineering and computer science students to be exposed to the fundamentals of cyber manufacturing and entrepreneurship. The third thrust discusses the role of such VR/haptic based learning environments to help students with autism learn science and engineering.

II. DESIGN OF AR-BASED ENVIRONMENTS FOR NASA’S X-HAB CHALLENGE

In previous publications [8, 9], the focus was on the creation of VR based environments to study and analyze transportation and habitat alternatives for the moon mission. In this first thrust, a discussion of experiential learning activities emphasizing team-based learning involved in the design of next generation user interfaces to support accomplishment of various tasks (such as laptop service, payload movement) on the Gateway as part of the Moon Mission activities. This educational project was part of NASA’s xPloration Systems and Habitation (X-Hab) design competition [19]. These activities were introduced in an interdisciplinary cyber-physical systems course for seniors and graduate students which emphasized system engineering concepts and design of VR/AR/MR digital mockups using Moon Mission context. The course included students from electrical, mechanical, industrial engineering and computer science NASA’s Gateway [22] seeks to establish an autonomous platform to support short- and long-duration deep space exploration capabilities through the 2020s (including landing on the Moon in 2024 [21]).

The students worked in teams to design and build 3D AR-based mockups to support astronauts in (training and) accomplishing two tasks on the Gateway. The first AR-based mockup (or environment) supported astronauts in repairing...
and replacing RAM (memory) components on a laptop aboard the Gateway; the second design focused on creating an AR environment to support astronauts in storing/moving payloads from one location to another inside the Gateway. A conceptual view of such a design mockup created to help an astronaut complete a target set of activities is shown in Fig. 1 (this is a view of a 3D simulation highlighting the main steps in such a RAM removal process).

In the first part of the design activity, the students modeled the software design aspects of the modules supporting the simulation activities using UML diagrams including sequence, communication, activity and class diagrams. Subsequently, after completing the System Design Review (SDR), Preliminary Design Review (PDR) and Critical Design Review (CDR) activities (which included finalizing the requirements, work breakdown structure, concept of operations, project schedule, testing plan and initial prototyping of the modules), the students began building the AR-based designs using C#, JavaScript and the Unity game engine for the Windows platform. The associated AR environments were created using the HTC Vive Pro™ VR platform [10] and the Microsoft HoloLens™ platform. Solidworks™ was used to build the CAD models for the simulation environments; some of the robot models were obtained from the official NASA 3D resources website [11].

Vive Pro is a fully immersive VR platform providing users a 110˚ field of view with controller-based interfaces [10]. Vive Pro is capable of supporting Augmented Reality through the use of two front-facing cameras. It has two wireless handheld controllers which can be used to freely explore and interact with the virtual environment. The handheld controllers suited the application due to the ease with which interactive objects (such as tools) can be manipulated by users. Steam VR tool kit and Vive SR toolkit were used for the development of these immersive designs and environments.

HoloLens is a portable mixed reality (MR) based device, which allows users to interact with the virtual world without losing the sense of the real world [12]. Astronauts regularly perform repair and replacement activities on space habitat such as ISS. Such repair and replacement tasks become more critical on the proposed Gateway citing its distance from the earth compared to the ISS. One of the AR-based designs supports astronauts in completing repair and replacement of the laptop parts (such as the RAM). When the astronaut wears the AR headset (such as the HoloLens), the help module can provide an automated simulation of the entire laptop repair and replacement process. Subsequently, the astronaut can perform the physical steps on a physical laptop with guidance from avatars and other text/voice-based instructions. An elided sequence diagram for this service process is shown in Fig. 2. Views from within the AR environment as seen by the astronaut during the laptop repair and replacement activity and the payload storage activity are shown in Fig. 3 and Fig. 4.

The students were also introduced to System Engineering principles, which was the foundation of completing various project activities.

Student Learning was assessed through homework assignments and the team-based project activities. The impact of adopting such experiential approaches was studied especially the creation of VR based immersive environments where students created design solutions based on their understanding of a target process and design principles.
Fig. 2. An elided sequence diagram showing the steps involved in replacing the RAM using the AR headset.

Fig. 3. A view from within the AR environment as seen by the astronaut (the background scenes are from images inside the International Space Station ISS).

Fig. 4. Two views of the AR environment as seen by an astronaut during the payload storage activity. Instructions to pick up the payload is shown (left) and to open the storage is shown (right).

The primary assessment outcomes, from the first semester of the year-long project, involving 18 students (subdivided into three teams) were compared to 30 students who were exposed to learning these concepts using a traditional lecture-based approach.

1. The class average for homework assignments improved by 20% when the experiential learning approach was implemented.
2. The class average for the final project improved by 25% when the experiential learning approach was implemented.

The majority of students (80%) indicated that the software-based design activities involving the creation of 3D virtual reality-based digital mockups enabled them to acquire a better grasp of the fundamentals of the designing/building such 3D mockups, led to a better understanding of the complexities of NASA’s Gateway module layout and structure while improving their understanding of systems engineering and software engineering methods.

III. INNOVATIVE CURRICULUM IN ENTREPRENEURSHIP FOR CYBER MANUFACTURING TOPICS

The emergence of cyber-physical systems, Internet-of_Things (IoT) and cyber manufacturing frameworks herald a new informatics centric era. This fourth industrial revolution holds significant potential for global manufacturing practices which can harness the power of cyber technology and other ‘smart’ technologies. In this context, there is a need to develop an innovative curriculum which not only exposes students to cyber manufacturing-related principles and technologies but also encourages them to become entrepreneurs in this information-centric age. In this context, new curriculum content has been developed with new course modules introducing engineering and computer science students to the principles of entrepreneurship with a view towards encouraging them to consider developing ideas for new cyber-based products in manufacturing and engineering. These modules have been introduced as part of a senior-level /graduate student elective course to engineering and computer science students. The first set of modules introduced students to the challenges faced by entrepreneurs and the process involved in creating a business plan to establish a new enterprise (‘startup’). Subsequently, the students worked as part of project teams to identify new cyber or physical products in the area of cyber manufacturing (or smart manufacturing) for commercialization. For example, products of interest were both cyber and physical ranging from ‘apps’ (short for application programs) to 3D printed parts for various applications. As part of this innovative project-based learning activity, some of the students at Oklahoma State University (OSU) interacted with students in China (at the Huazhong University of Science and Technology HUST, Wuhan) to identify new cyber and physical products. They collaborated using skype and discussed ideas for cyber and physical products.

Other OSU student teams worked among themselves to propose new product ideas and created business plans for commercialization. One of these ideas was to design a new
smart refrigerator. The initial design was completed along with a proof of concept product involving IoT interfaces to a physical refrigerator. A brief description of the IoT Based Smart Refrigeration System (SRS) follows.

An IoT based Smart Refrigeration System (SRS)
The emergence of IoT has been noticed in various domains ranging from manufacturing, healthcare, agriculture among others. IoT based applications are also being developed for household activities. Various cyber-physical systems are available for home security, power management, etc. In this project, the OSU team proposed an IoT based SRS which was linked to the user through a mobile app. The major function of the system was to monitor the food content of the refrigerator and to alert the user when the food content needed attention. Real-time feedback was provided to the user through a set of monitoring cameras and sensors placed inside the refrigerator. The users were also able to receive notifications when the quantity of a certain food content went low. Another feature of this IoT based system was that it provided a database of recipes based on the food content available in the refrigerator. The database could be constantly updated by the user. A touchscreen window was attached to the front of the refrigerator so the user could gain access to the required information about the food content and recipes. Fig. 5 shows the architecture of the SRS. Further, an android based app was also developed which provided required and necessary information related to the SRS to the users.

Other student teams focused was on identifying potential tools/technologies that would benefit the space systems industry.

Student feedback indicated a need for more technology exposure and tools. Subsequently, new course modules were created to introduce students to new emerging Virtual Reality based platforms such as the Hololens and Vive. There was a great deal of interest in understanding these tools and then using them to develop new cyber apps and interfaces. Overall, the student learning in these course modules improved significantly through the introduction of these team-based entrepreneurial activities. Apart from improved performance in exams and homework activities, class surveys also indicated an increase in student engagement in learning activities.

IV. DESIGN OF VLEs TO TEACH SCIENCE AND ENGINEERING TO STUDENTS WITH AUTISM

Virtual Learning Environments (VLEs) are a special category of VR based environments created to support the learning of specific concepts at K-12 and/or University levels [13, 14, 15]. A Virtual Reality (VR) environment can be described as a 3-Dimensional environment in which users can interact immersively using trackers, sensors and other interactive devices. VLEs are such VR based cyber technology environments that can enrich the learning experience for students in various topics and domains. VLEs have been the focus of various educational and research efforts aimed at introducing STEM concepts to K-12 and university students [16, 17, 18]. In this section of this paper, a summary of an innovative initiative to help students with autism learn science and engineering concepts is discussed. Autism and Autism Spectrum Disorders (ASD) are general terms for a group of complex disorders of brain development.

The learning modules were created for autistic students at elementary (grades 1-5), middle school (grades 6 to 8) and high school (grades 9 to 12) levels. A discussion of the learning modules created for high school students follows. The topic modules introduced autistic school students to concepts in assembly, robotics, and manufacturing. For purposes of brevity, the discussion is limited to the VLE modules dealing with assembly and manufacturing concepts.

A. VLEs for learning Assembly concepts

The assembly learning modules focus on introducing basic concepts in assembly. Using the VLEs, the students learn interactively concepts using simulation environments where they are exposed to assembly processes (using examples of simple and complex assembly). Further, they also learn about concepts related to assembly such as sequence and the notion of precedence constraints. There are two types of interactive environments: the first is an immersive 3D learning platform (implemented using the Vive platform); the second is a haptic interface based learning platform.

Fig. 6. A view of a VLE module where students are exposed to concepts of precedence
As part of the learning process, the interactions are facilitated by avatar-based interactions (Fig. 7) as well as text (Fig. 6) and visual cues. Specific learning scenarios in 3D (Fig. 6) introduce and highlight concepts of sequence and precedence using different examples; the initial phase involves being able to understand basic terms (such as assembly, what is precedence, etc); subsequently, the students can interact with avatars and complete several assembly tasks where basic concepts are emphasized to help them in assembling the objects correctly. After these interactions, the key points from each specific scenario is reiterated and emphasized. Fig. 6. shows an image from one of these VLE scenarios where the students are first exposed to the notion of precedence. In this scenario, the role of precedence constraints is highlighted; subsequently, they are given several scenarios where each student has to show a sequence (using a haptic device) that satisfies a given precedence condition.

Some of the assembly process examples include assembling a bicycle, a small satellite and a carriage using both the immersive 3D and haptic interface (implemented respectively the Vive and Haptic platforms). Fig. 7 shows a view of the module in which the user needs to assemble the horse carriage based on a sequence displayed.

The assessment of learning is through conducting pre and post-tests to the participating students. During the learning activities, students can go back to repeat a learning activity or assembly example. If a student is not able to grasp a specific concept, they are encouraged to interact with any relevant VLE module as often as they feel is necessary; they can subsequently come back and attempt to answer those questions related to those associated concepts.

B. VLEs for learning Density

The density learning module introduces autistic students to the concepts and principles related to density. The students are first introduced to density through the concept of floatation through interactive examples involving objects of different materials (wood, metal, foam, etc). Subsequently, they explore more advanced concepts including the relationship between density, mass, and volume. Examples include performing virtual experiments where a small-sized part which is metallic may sink while a larger sized part (that is made up of foam) floats (Fig. 8). As with the modules for assembly, these VLEs were created using the fully immersive Vive platform and the Geomagic Touch (which provides a haptic interface). The haptic interface allows students to actually feel the weight when they pick up the various objects during the interaction. Voice and text cues are also provided along with a teaching avatar which assists in the interactive learning process.

In the assessment activities, students are asked to compare the density of different materials (such as metal or wood). In addition, the students are also assessed on their understanding of the relationship of volume and mass of an object to its density.

Two high school and two middle school autistic students participated in these learning activities.

For the density concepts, two students were able to answer the questions correctly on the first attempt after interacting with the VLE. The other two students were able to answer 80% of the questions correctly after one interaction with the VLE. They were able to answer the remaining questions correctly after interacting with the VLE for the second time.

For the assembly concepts, three students were able to answer the questions correctly after interacting with the VLE for the first time. The fourth student was only able to answer 40% of the questions after the first interaction with the VLE. However, the student was able to answer the remaining questions correctly after the second interaction with the VLE.

The primary assessment outcomes indicated that such VLEs have the potential to help autistic students learn science and engineering.

V. CONCLUSION

This paper focused on the emergence of cyber technologies and immersive simulation-based approaches in supporting engineering curriculum innovation and learning. The first thrust focused on innovative learning activities involving space systems concepts that revolved around the creation of 3D VR based immersive simulation environments for NASA’s Deep Space Mission process contexts. The second thrust involved the need to expose and encourage students towards
entrepreneurial activities involving information-centric and cyber manufacturing principles and practices. With the recognition of the importance of cyber manufacturing and Industry 4.0 principles, there is a need to encourage engineering students towards becoming entrepreneurs to support such smart manufacturing and IoT based practices. The third thrust involves the creation of 3D Virtual Learning Environments (VLEs) to support autistic students to learn science and engineering concepts interactively using both immersive and haptic interfaces.

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