The Impact of Extended Reality-based Digital Approaches to Support STEM Learning for Autistic Students

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Design and Assessment of Virtual Learning Environments to Support STEM Learning for Autistic Students

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Abstract—This paper discusses the design of immersive and haptic based Virtual Learning Environments (VLEs) to help middle and high school autistic students learn science and engineering concepts. The primary focus was on studying the impact of VLEs to help autistic student learn target concepts ranging from robotics to density using Virtual Reality based immersive 3D environments as well as haptic based learning environments. The role of Applied Behavioral Analysis (ABA) based Positive Reinforcers in encouraging autistic students to interact and learn was also studied. The primary conclusion was that such 3D Virtual Reality based VLE did indeed help autistic students learn. Further, it was concluded that positive reinforcers did have a positive impact in encouraging autistic students to learn.

I. Introduction

In this paper, the overall focus is on the study of the potential of 3D based Virtual Reality based Virtual Learning Environments (VLEs) to help autistic students learn science and engineering concepts. Virtual Learning Environments (VLE) can be described as 3D based Virtual, Augmented or Mixed Reality environments; they can be viewed as a subset of Virtual Environments [28, 29] which are increasingly used in engineering, medical and other industrial contexts. Some VLEs have haptic interfaces which enable users to touch and feel objects within a 3D environment.

Autism Spectrum Disorders (ASD) can be described as mental neurodevelopmental disorders which includes autism and Asperger syndrome. Children with Autism experience difficulties in social interaction, verbal/non-verbal communication, and repetitive behaviors [1,[2]. Several studies have indicated that autism is a complex disorder caused by several co-occurring factors [3, 4, 5]. Autistic children face difficulties when learning especially in traditional classroom based learning. In this context, there is a need to explore alternative and innovative ways to help autistic children learn. In this paper, the domain of learning is science and engineering concepts..

The term Extended Reality is used to encompass 3 types of immersive mediums: Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). Virtual Reality (VR) can be described as a technology which can support 3D based immersion and interactive experiences involving participants or users; the environments are designed to mimic certain engineering, training or behavioral characteristics using simulated attributes as well as an array of interactive cues. VR based learning and training environments have been used in surgical training and education [6, 7, 8, 9]; manufacturing [8, 30]. Several researchers have highlighted the potential of such VR based environments to support learning in autistic children [24-26]. Other researchers have noted the potential of such VR based learning environments to help autistic individuals become more independent and productive [17, 18, 27, 28]. In one such study, researchers demonstrated how such VR based environments can help autistic children safely cross a street [27,28]. In a NRC study [31], Such 3D simulation and VR based environments was noted in an NRC study [31] to help students understand concepts in environmental science and physics [32-97] as well as for treating patients with disorders and phobias [98-112]. Other researchers have described game based approaches involving 2D non-immersive mediums [14, 15, 16, 18]. In related studies [9, 10. 12, 13], it was concluded that sound, text, visual cues and 3D mediums play a positive role in the learning process of autistic individuals. Other researchers have underscored that avatars [22, 23] and haptic based simulation interactions [19-21] positively impact engagement with non-autistic students.

II. The Process involving the Design and Development of VLEs

Immersion is the degree of interacting with the virtual environment by the user with the help of controllers, keyboard and haptic devices. The learning mediums involving VLEs can be at various levels of interaction and immersion: the most basic is the non-immersive medium where a 2D computer screen is used to support learning and interactive activities. For such non-immersive contexts, the mouse and keyboard are the primary means to interact and learn. The next level is semi-immersive where the user can visualize and experience 3D when looking at a screen using 3D stereo eyewear; the semi immersive also allows users to look at the physical or real world (this occurs when they look away from the projection screen where the models and interactive environments are projected). The fully immersive environment can be experienced with more expensive environments and technologies; this includes wearing a 3D headset such as in an HTC Vive or Oculus Rift platform. In such a fully immersive context, all reference to the real world is removed and the user can interact with the virtual or simulated environment in whichever direction or angle the user turns her or hir head. can also be described as 3D VR/Mixed Reality based environments in which users can interact at multiple levels of immersion: non-immersion, semi-immersion, full-immersion.

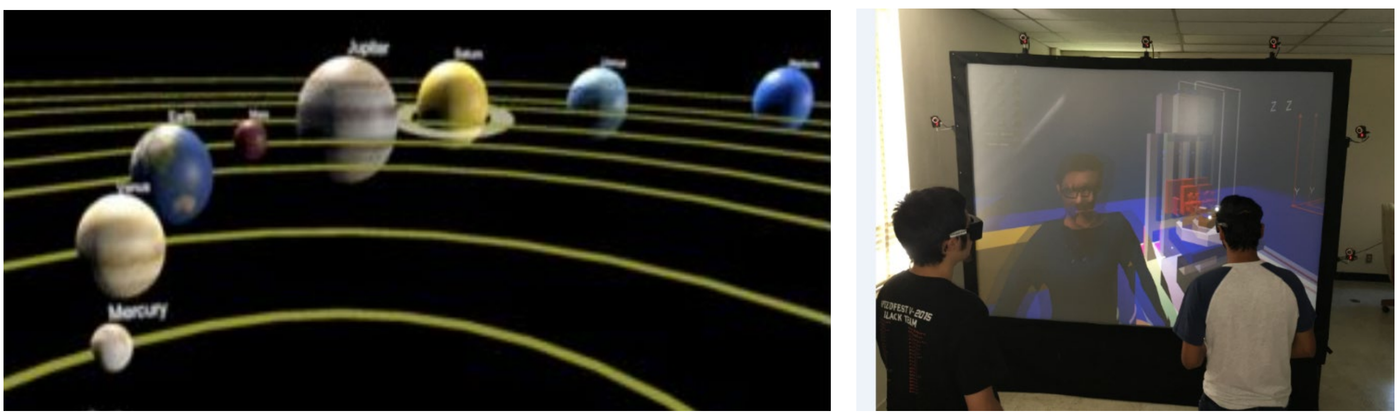

Fig 1 (a, left): View of a non-immersive VLE to learn concepts relating to our solar system (b, right): A view of a semi-immersive VLE (students are wearing 3D eye-wear which removes the blurriness seen); note that they can turn away from the screen to see the real world (such a dual immersive and physical view is the reason it is referred to as semi-immersive medium)

The creation of such VLEs is a complex process; very few research literature has focused on the process of creating and building such VLEs. Previous work by the authors have emphasized the notion of an information-centric model, which can serve as the foundational basis to design and build such VLEs [9, 36]. Such an information modeling-based design approach has been previously used to design VR based simulators for surgical training, manufacturing, and space systems among others [6-9]. Such an information centric model captures the information inputs, controlling factors or constraints, the decision outcomes and the performing agents or mechanisms. The primary information attributes are based on the categories of attributes reflected in the IDEF-0 functional model. The engineering Enterprise Modeling Language (eEML) which was used to build this information model has its roots in the IDEF-0 modeling language; however, it is capable of also representing temporal precedence relationships among activities; it also has a more detailed way of modeling task outcomes which can be divided into physical and information outcomes; information outcomes can be further divided into feedback or new information, among others. One of the earlier approaches to the role of information modeling involves the design of an automated fixture design systems to prismatic parts. In this approach [37], a functional model was created as a foundation to understand the complex engineering tasks involved in the activity of fixture design; this was used as a basis to design and build an automated software system which served as a link between CAD models and Computer Aided Manufacturing (CAM) activities [38, 39]. Such an approach also is a pre-cursor to adoption of software engineering approaches which are now adopted to design, build and test software systems.

As outlined in [36], there are multiple phases in this process to design and build VLEs; they include: Identify Target Learning Objectives, Design the software elements of the VR based learning environment, Build the VLE (using software tools and immersive equipment), Validate/Modify the VLE through pilot student interactions. Feedback can be obtained to improve the user friendliness as well as resolve any other issues with content scope and correctness. Finally after validating it, students can interact and learn using the VLE (this phase can include pre- and post- tests, collecting data on their experiences, as well as assess the potential of the VLE to support learning and engagement)

III. THE VIRTUAL LEARNING ENVIRONMENTS CREATED

Several VLE based modules were created for autistic students to teach concepts in assembly, robotics, density, manufacturing and path planning. Students interacted wearing a 3D HMD or headset and controllers for navigating and picking up objects, etc. In figure 2, a student can be seen interacting with such a medium using a Vive platform.

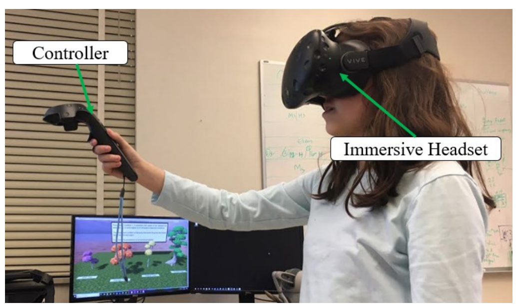

Fig. 2. A student seen wearing a 3D Vive headset interacts with an immersive VLE.

Researchers have reported that children with autism learn best using Applied Behavior Analysis (ABA) [33, 34]. In this learning approach, positive reinforcement, is considered the most effective method to teach an individual a desired behavior [35, 36When participants perform desired learning behaviors, they are rewarded. When a child performs a desired action, it is rewarded which is the positive reinforcement. This reward can be earning points or tokens to play a computer game, or do computer art or may be rewarded by giving a cookie (if that is their preference. Some children may be intrinsically motivated by the computer environment where the interaction with a computer can be the positive reinforcer.

This research outlined in this paper extends some of our preliminary work involving VLE based learning approaches to help autistic students learn [9, 13, 36]. Additional modules were created related to advanced concepts such as sequence and precedence constraints), advanced robotics, introduction to manufacturing and space systems (introduction to NASA's Moon Mission and related concepts in path planning and assembly).

A summary of the content of the VLEs is provided in this section.

Density Modules

The Density VLEs included study of more advanced concepts related to additional relationships between mass and volume as well as extended modules to introduced students to density properties of various materials (such as wood, metals, plastic). Using both haptic and immersive interfaces, students explored floatation concepts using different objects made of wood, plastic, aluminum and steel into different liquid mediums (oil, water, etc.) and observed resulting behavior (do they float or sink, etc.). The more advanced modules exposed students to calculating density as a ratio of mass to volume. Assessment involved asking students to comment and compare the density of different materials they interacted with along with calculating density values for various materials.

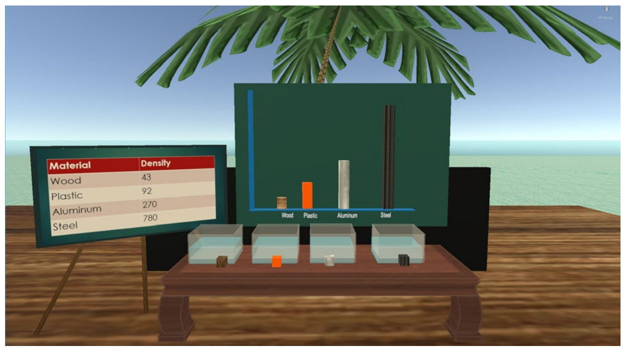

Fig 3 a: View of the density learning modules (the virtual beakers and objects can be seen)

Assembly Modules

Students were introduced to basic concepts of assembly, sequence and precedence constraints/relationships. With the help of avatars (see fig 3b), they interactively explored assembling various objects such as a bike, parts of a satellite and a horse carriage using both the immersive and haptic interfaces. The students were also introduced to concepts such as assembly sequence and precedence conditions. Fig. 3b shows a view of a learning scenarios where a teaching avatar guides a student to explore assembly concepts using a toy horse carriage as an example.

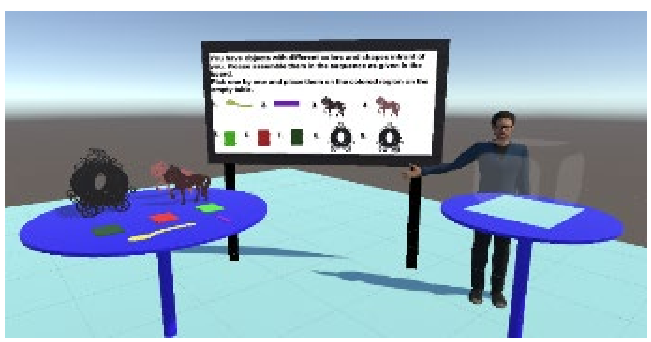

Fig. 3 b. A view of an assembly learning scenario for the horse carriage example; teaching avatars play a key role during the interactions.

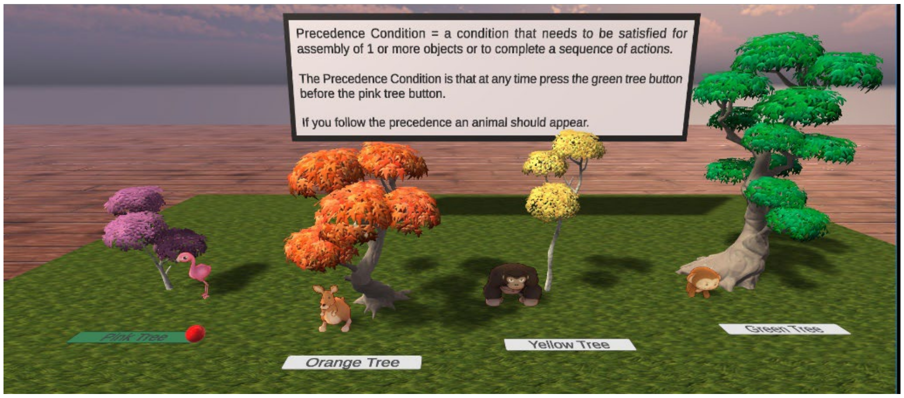

Fig. 3c. A view of a scene where students are exposed to concepts of precedence constraints in a sequence or plan.

Robotics related VLEs

In these learning modules, students were exposed to the functioning of Cartesian and Axial robots. The concept of degrees of freedom was also introduced using examples highlighting different directions of movement or axis by the arms of a robot. A virtual reality based assembly work cell was created which was used by students to virtually perform various tasks to pick up and place a target part in a required destination while avoiding obstacles to reach the destination or to complete a specific assembly task. Avatars were used to help with learning interactions using both text and voice cues.

Manufacturing Modules

Using these modules, students were introduced to basic shape creation using drilling processes using fully-immersive and non-immersive platforms with a haptic interface (fig 4 and 5); a virtual drilling tool was provided to help the students understand drilling concepts. Assessment tasks involved students given target tasks creating a circular pattern.

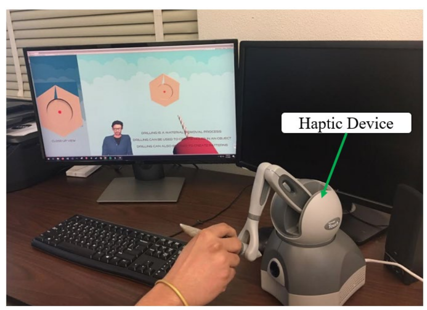

Fig. 4. A student interacting with a non-immersive haptic based VLE to learn drilling concepts.

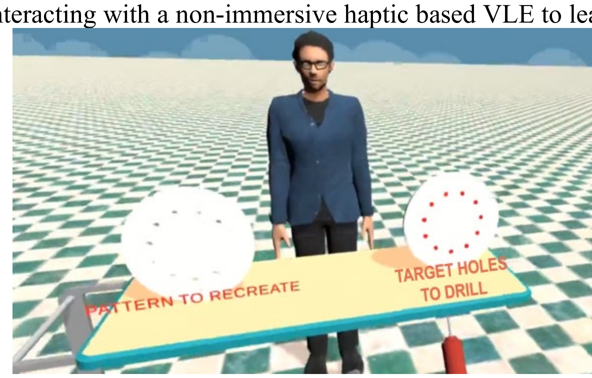

Fig. 5. A view of the fully-immersive haptic based VLE for creating a circular pattern using a virtual drilling tool

IV. Discussion and Outcomes

For two of the modules (density module and drilling module), positive reinforcers were introduced. Students were given the following options during the interactions. They could choose one of these reinforcers (a) play a video game using the VR headset (b) spend time browsing the internet using a tablet (c) create art using a sketching tool. The assessment activities focuses on assessing impact on student learning and the role of positive reinforcers to help them learn. Regarding the positive reinforcers, the students could select their preferred choice: these included tokens to play a computer game, play with a 3D modeler to create a robot, or be given an opportunity to create computer based art. Assessment of learning was through pre- and post-test questions . A total of eight students were involved in this study; four from middle school (grades 6, 7 and 8) and four from high school (grades 9 to 12).

Assembly VLEs

Ten students interacted with the Assembly VLEs (5 middle school s, 5 high school). Among the middle school participants, 3 students were able to understand the target assembly concepts in the first round of learning interactions; two of the students needed an additional round of learning interactions for learning the same concepts. Among the high school students, four students were able to demonstrate an understanding of all concepts after one round of interactive sessions with the VLEs; the fifth students needed two rounds of learning interactions to grasp the assembly concepts.

Density VLEs

Eight students interacted with the Density VLEs (4 middle school students and 4 high school students). The assessment tasks included conducting virtual experiments with varying object sizes and materials; for example, an object made of steel was compared with a larger sized object made of wood; the students were given opportunities to explore these examples before assessment; during assessment they were asked to identify which object would have the higher density, which object would float in water or oil, etc. Finally, the students had to calculate the density values when given the mass and volume values. Among the middle school students, two students were able to understand the target concepts in the first round of learning interaction. The other two middle school students were given positive reinforcers and needed two rounds of interactions with the VLEs to understand the targeted concepts; among the high school autistic students, 3 were able to understand the identified concepts after one round of learning interactions without any positive reinforcement. The fourth student chose to play a video game when offered positive reinforcement. However, this student after two rounds was not able to understand the relationship of density and volume. This module was targeted as needing to be modified with additional learning experiences along with modifying the method of virtual interactions.

Drilling VLEs

Four high school autistic students interacted with the manufacturing module, which introduced them to the fundamentals of drilling.. The assessment included these questions: what shape features can be produced using the drilling process, what are the essential tools used, and replicate target patterns similar to those shown in figure 5. Three of these students demonstrated learning of related concepts and were able to complete interactive assessment tasks in the first round of learning interactions. The fourth autistic student needed three rounds of learning interactions and practice before grasping the target concepts. Positive reinforcement was offered to this student during each round; the student chose to play a video game two times before continuing the learning activities.

Qualitative feedback was also obtained regarding the engagement of the participants. However, discussion of this is outside the scope of this paper. The initial inferences indicate that some autistic students prefer interacting with an avatar while others prefer text based cues without the presence of an avatar.

V. CONCLUSION

This paper discussed the potential of designing immersive and haptic based cyber learning environments to help autistic students learn science and engineering. Targeted topics for the creation of these VLE ranged from density to robotics. The project team was interdisciplinary and included experts in pedagogy, psychology, engineering, computer science and VR/MR modeling. Assessment studies focused on both student learning and engagement using pre and post tests.

The primary conclusion underscored the positive impact of using VR and haptic based VLEs to help autistic students learn science and engineering concepts. While learning was impacted in a positive manner, some students needed multiple interactions with the learning environments. More research is needed to throw more light on the role of positive reinforcers. One area which was identified for additional learning experiences involved introducing students to the relationship between density and volume as well as the calculation of density from provided values of mass and volume. Future activities are planned which involve more learning and assessment activities involving a larger group of participants.

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