Role of Affordance, Visual Density and Other HCC Criteria in Designing Virtual Learning Environments to Support STEM Learning for Autistic Students

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***Abstract*—This paper discusses the design of Virtual Learning Environments (VLEs) in helping students with Autism learn Science and Engineering concepts. The design of the environments was based on information centric principles. Further, human centered computing principles (HCC) were explored during the development of the VLEs. HCC principles such as affordance, visual density and cognitive load were taken into consideration during the design process. The VLEs were created for middle and high school students. An information-centric model was created to understand the process of designing and building the VLEs. Such information models based on engineering Enterprise Modeling Language (eEML) provided a structural foundation for the design and development of the VLEs. The learning environments were created using various interfaces and immersion levels; these included haptic based interfaces, fully immersive 3D environments and Augmented Reality (AR) based environments. These VLEs introduced students to concepts in assembly in the medical context and path-planning and navigation in the context of NASA's moon mission. Assessment activities were conducted to gain a better understanding of the impact of such VLEs on the learning of science and engineering concepts to students with Autism. The preliminary results of the assessment activities demonstrated the positive impact of such cyberlearning techniques and environments on the learning of students with Autism.**

***Keywords*— *Human Centered Computing, Autism, Virtual Learning Environment, Cyber learning, Haptic, Immersive technologies*.**

I. Introduction

This paper focused on the design of Virtual Learning environments (VLEs) based on Human Centered Computing (HCC) principles. The VLEs were developed to teach science and engineering concepts to the students with Autism. Such VLEs are 3D graphics intensive and leverage the Augmented Reality (VR) and Virtual Reality (VR) based technologies. VR and AR technologies have been used in a number of domains ranging from manufacturing, surgical training to design and analysis of space systems [1-10].

Children with Autism have difficulties in verbal and non-verbal communication, social interaction, and repetitive behaviors [11]. About 1 in 54 children have Autism, according to the Center for Disease Control and Prevention (CDC) [12]. For a long time, genetic, environmental or neural disorders were considered as causes of Autism. However, recent studies show that the cause can be attributed to several factors which co-occur, making Autism a complex disorder [13, 14]. Many students with Autism end up remaining unemployed due to difficulty in communication [15]. Such students also face difficulty in learning in a traditional classroom setting.

VR and AR based learning environments hold the potential to help autistic students learn various concepts [16-21]. A few researchers have focused on understanding the potential of VR in helping autistic students lead productive lives [21-25]. A study conducted by NRC [26] which showed that VR can be used to engage students and support learning in a number of domains such as physics, environment studies, among others [27-33].

In this paper, the focus is on creating VLEs to teach Science and Engineering concepts to the students with Autism. The developed VLEs can be categorized into two thrusts. The focus of the first thrust was to teach basic concepts in science and engineering such as density, assembly and robotics. The second thrust involved understanding more complex concepts such as navigation and path planning pertaining to the NASA's Artemis 2024 moon mission. In order to create the VLEs for the second thrusts, the VR/AR based environments created for the a

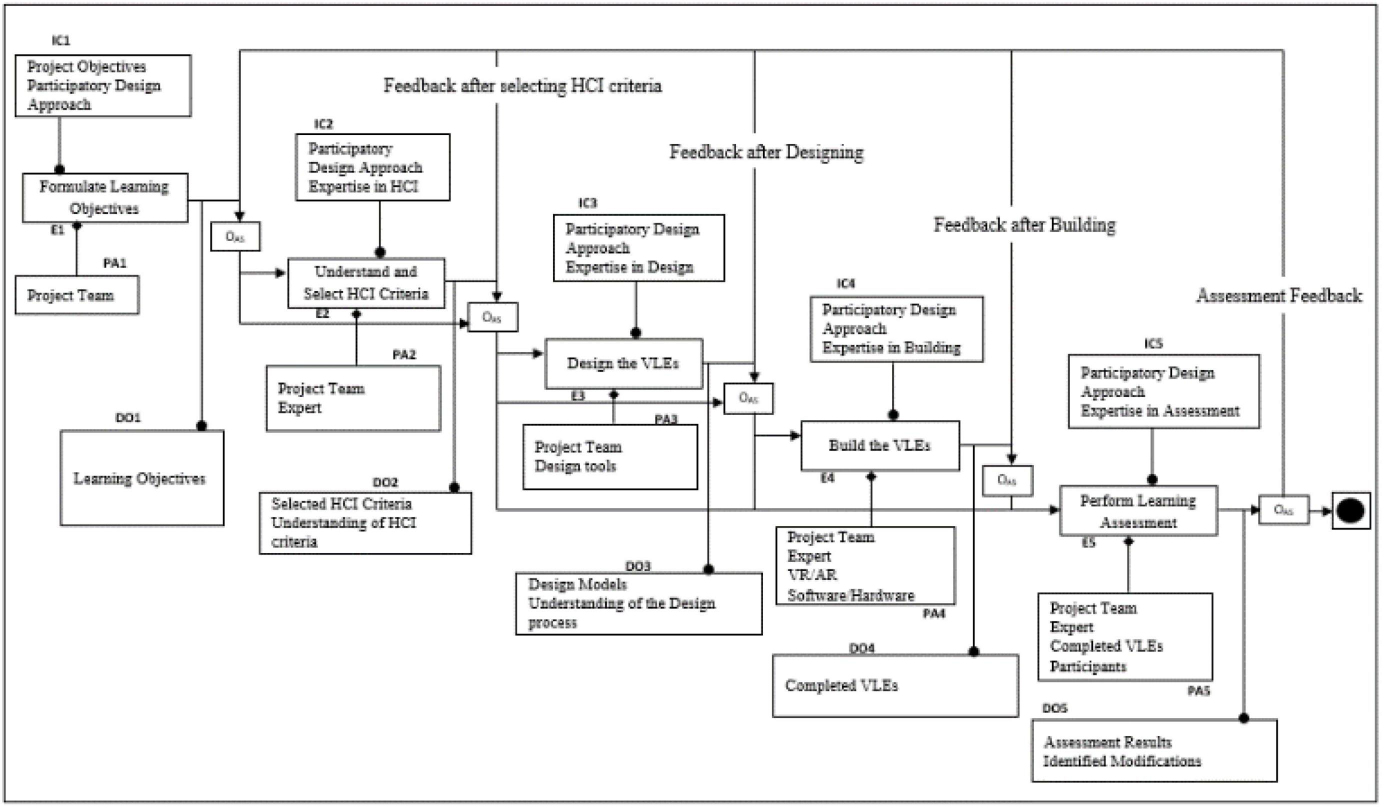


Fig.1: An eEML based information centric model to understand the process of creation of VLEs

NASA university project were scaled down in content and complexity. In the NASA university project, multiple universities competed to create AR based UIs to support the astronaut during the moon mission.

The rest of the paper is categorized in the following sections. In section II, the design of the VLEs based on information centric principles has been discussed. An elaboration of the VLEs created for science and engineering learning is provided in section III. In section IV, the results of the assessment studies conducted to understand the impact of VLEs in science and engineering learning on the students of Autism.

II. Designing the VLEs

The participatory design approach was used in the design of VLEs for training and education for students with Autism. Participatory design approach is an approach in which the end-user of the VR-based training would provide input on the design and usage of the VR environment. Participatory Design is a method to involve the people who are going to be affected to have their input during the design process [34, 35]. The participatory design method was first used in Scandinavia [36]. Participatory design has been utilized by several researchers in the field of VR [37-41]. This is useful because the experts and professionals in the field have a greater understanding of standard and non-standard working environments, and as such would understand which of those environments would be the most familiar and efficient in training. Communication occurred biweekly to receive feedback on the project and consider possible changes and improvements to the environment. Throughout the project, several corrections were made to the layout and design of the environments in response to feedback received.

In order to understand the design and building process of the VLEs, information centric models were created. Such information centric models have been used previously to design AR and VR environments for various domains such as manufacturing, surgical training, space systems, among others [42-47]. engineering Enterprise Modeling Language (eEML) was used to created such information models.

The information modeling approach supported the categorization of the entire process of the design and building of VLEs into five phases. The information modeling helped in understanding and modeling of various attributes of the phases and the functional and temporal relationship between the various phases. For each phase, the attributes were classified as following.

a. Influencing Criteria (IC): Information needed to complete the phase and the major constraints
b. Performing Agents (PA): The resources required to complete the phase (software and hardware)
c. Decision Outcomes (DO): Outcome of a given phase

The five phases in the design and development of these learning environments were modeled from an information-centric perspective using eEML (Fig. 1).

Role of Human Centered Computing (HCC) Principles in designing User Interfaces

Based on information centric models, the design of the overall interfaces was accomplished. We followed a hierarchical menu design, beginning from the top level activities and progressing to lower level tasks focusing on different aspects to provide assistance or control interfaces. Each of the interactive screens under various user options are designed based on HCC principles. The menu layout, the interactive screens, the types and position of the MR avatar and other aspects are designed based on HCC factors: Affordance, Visual density and Cognitive load.

Dynamic Affordance: Affordance is 'what the environment offers to the individual'. It can be viewed as action possibilities that can be perceivable readily by an actor in an environment or as the properties of the world which are defined with respect to how people interact with them [48-50]. In this project, we propose ***dynamic affordance (DA)*** which can be defined as function of comprehension of a scene by a user inside a virtual 3D environment moving along a specific path P (within that target 3D environment) over a fixed period of time (T). **DA** seeks to throw light on the comprehension and understanding of a target 3D VR environment from various positions and perspectives as a user navigates or traverses along certain paths within that environment; this includes understanding relationships of objects of interest (OOI), which is key to comprehension of interface menus, controls and cues; such OOI can be entities on the lunar surface, the lander, various tools to be used in collecting science samples, menu buttons, vital sign monitors (of astronauts), training avatars, etc.); such an understanding of target simulated scenes will vary based on various elements and factors such as density of objects in a given scene (visual density), audio interruptions/distractions (from heart monitors, etc.), presence of cues, introduction of avatars, etc. (which can be included or removed, varied or modified).

The **visual density** in a target 3D VR scenario is a measure of the number of objects/ cubic unit in a given layout. A user's understanding can be affected by the visual density and appearance/characteristics of the OOIs (color/contrast/lighting and textures).

Human-in-the-Loop (HITL) HCC assessment: We studied the impact of alternative menu and interaction layouts with varying levels of detail, number of actors/OOI, color/contrast features, (among others) on users' comprehension and understanding (measuring affordance and studying impact of visual density on affordance and cognitive load).

Cognitive Load: During these user/participant interactions at OSU, we also measured the ***Cognitive Load*** **(CL)** to gain an understanding as to which of the design options requires less cognitive load for accomplishing various tasks [51]. For this project, **CL** is the working memory load burdened on a user using a UI. There is a fundamental relationship between comprehension and cognitive functioning of a human. The working memory, in general, may vary across users; our plan is to design the UIs for such varying user capabilities. If the complexity of a certain task is greater than a user's CL, it negatively affects the learning outcomes resulting in cognitive overload [52, 53].

III. THE CREATION OF THE VIRTUAL LEARNING ENVIRONMENTS

Several VLE based modules were developed (built) for autistic students to teach concepts in assembly, robotics, density, manufacturing. This research extends our earlier study involving the creation of VLEs to teach students density and fundamental assembly related concepts [22, 25]. Based on feedback and assessment from that study, modifications to content and mode of interactions were implemented. In this paper, the focus of interest is the design of additional VLEs with the scope of learning extended to space systems (introduction to NASA's Moon Mission and related concepts in path planning and navigation) and assembly training in the medical context. A discussion of the process involving the design and creation of VLEs is also provided in this paper. A summary of the assessment activities including the role of positive reinforcers have also been discussed.

A view of a student interacting with a VLE using the Vive immersive headset and controller is shown in Fig. 2 (this medium is referred to as fully immersive as the student's reference to the real world is completely removed).

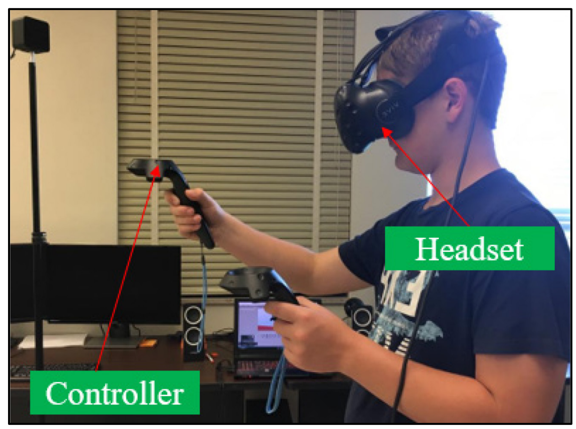


Fig. 2. A student interacting with the VLE using the Vive immersive headset and controller

Medical and educational specialists agree that children with Autism and teens learn best using Applied Behavior Analysis (ABA) [54-56] which follows a single subject experimental analysis of behavior design. The long term interest is to throw more light and assess patterns and technology preferences that influence learning behavior. Research has consistently shown that positive reinforcement, as opposed to negative reinforces (or penalties) punishment, is the most effective method to teach an individual a desired behavior [57, 58]. Positive reinforcement provides opportunities for reward when participants perform desired learning behaviors. For example, when teaching a child to match the correct computer action to a computer-based request, every correct application earns the student reinforcement. Some children may need an extrinsic reinforcer (such as a token or playing a computer game the student likes); others may gain reinforcement by a computer

display of fireworks or some other visual experience they receive after successfully completing a learning task. Other children may be intrinsically motivated solely by the computer learning experience itself and feel reinforced by successful completion of the computer learning task itself.
A discussion of the VLEs follows.

A. Augmented/Virtual Reality based Environment for Path Planning and Navigation for Moon mission

These learning modules focused on the creation of augmented reality-based VR/AR environments focusing on NASA's Artemis 2024 mission to land on the moon. These modules were used to introduce the concepts of path planning using NASA's space mission contexts. Several AR and VR-based environments were created as a part of a NASA university project. University students in the computer science and engineering department created such VR and AR environments focusing on operating the airlock, navigating on the lunar surface, and performing science sampling tasks such as interacting with and collecting lunar rocks. The environments were scaled down in complexity and content so that they can be used by middle and high school students.
The environments were developed using Unity game engine and C# programming language. The CAD models for the environments such as the lunar lander, the airlock, lunar terrain, among others were created using Solidworks CAD modeling software. The fully immersive HTC Vive platform was used to create the VR-based environments. The autistic students could interact with the fully immersive environments using the wireless controller (as shown in Fig. 2). The AR based environments were created using the Microsoft HoloLens 2 platform. The users interacted with the AR environment using the HoloLens through hand based gestures as shown in Fig. 3.

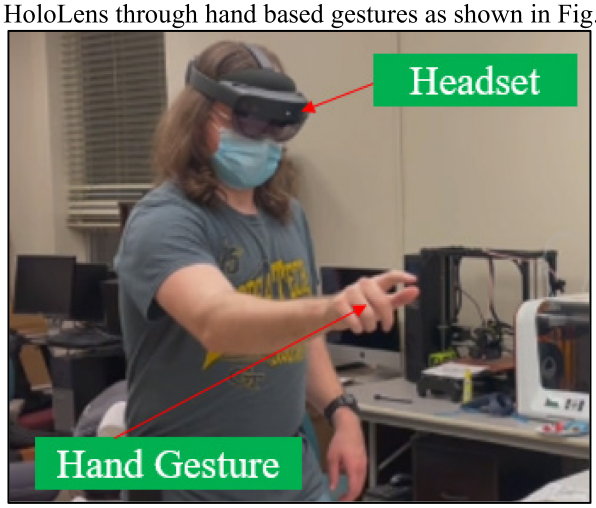
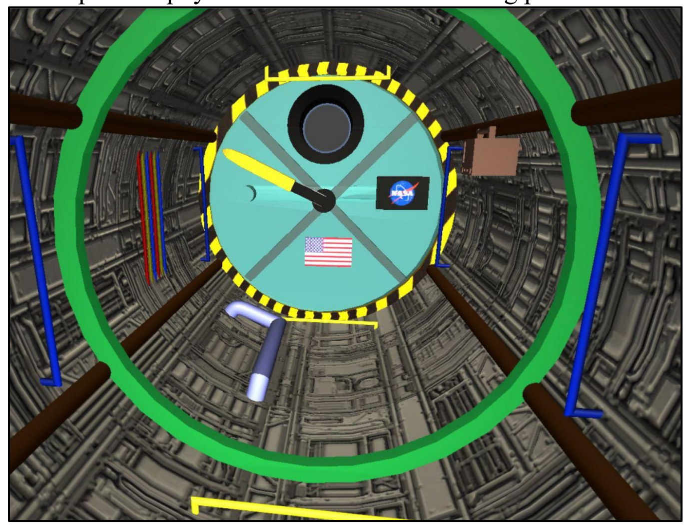


Fig. 3. Hand gesture based interactions using the HoloLens 2 headset

Students were introduced first to the lunar lander which was connected to the airlock (shown in Fig. 4). In the VR environment, the students used the controller to open the airlock and in the AR environment, they operated a physical airlock after following the instructions through the AR interface. After opening the airlock, the students were able to put their feet on the virtual lunar surface. The goal of the path planning module was to show them an obstacle-free path to the science sampling location where they would interact with virtual lunar rocks (Fig. 5). In the AR environments, the users interacted with the mockup of the physical lunar lock created using plaster.


Fig, 4. View of the virtual airlock used to access the lunar surface

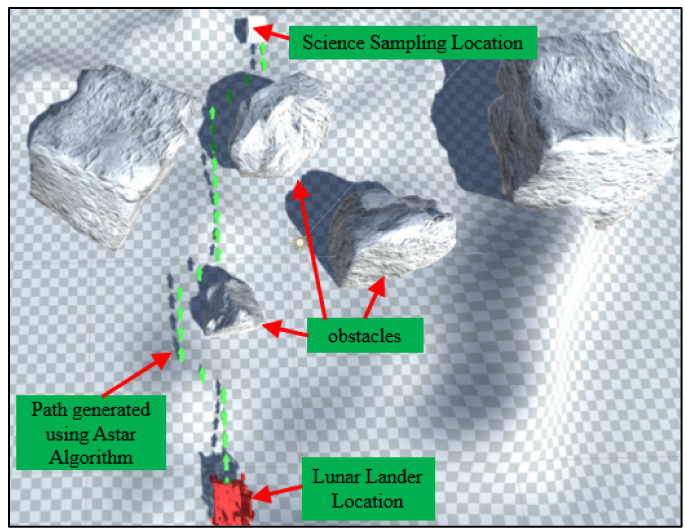


Fig. 5. A view of path planning module showing start point (lunar lander), end point (science sampling location), and obstacles

B. Assembly modules based on medical training context

The students learned about the concept of assembly using a medical training context in this module. A medical training simulator was scaled down in complexity and content to develop the learning module. In this module, the students assembled surgical plates used for orthopedic surgery using bolts and guides. Both voice and text cues were provided to the students during the assembly process. Before assembling the plates using the controllers, the students observed the automated assembly procedure with guidance provided by a 3D avatar. After the interaction with the module, the students answered questions regarding the assembly. Fig. 6. shows the view of the assembly module.

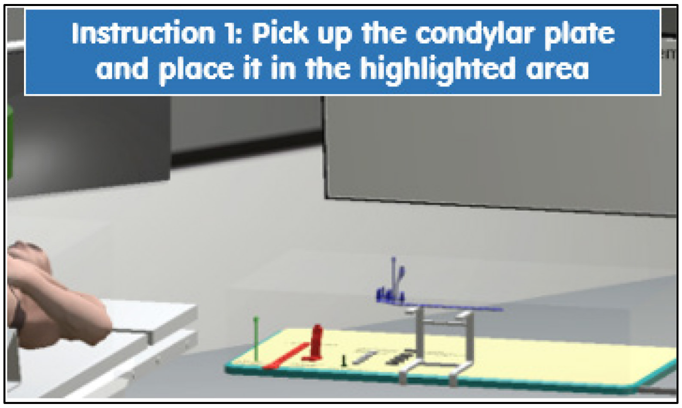


Fig. 6. A view of the assembly learning module based on medical context

C. VR based environments for social interactions

One of the areas where autistic studenrs lag behind is the social interactions. In these learning modules, the focus is on improving the social interaction skills by immersing them in virtual scenarios which might happen in real life. One of such scenarios is. The goal of the module is to prepare students in case of a weather emergency such as a tornado and taking assistance of an officer to navigate to a tornado shelter. First, the students become familiar with the procedure of a tornado drill in a training scenario, and then they are tested in a challenge scenario. In the beginning of the challenge scenario, the students are interacting with a VLE focusing on assembly learning using satellite parts. At a point of time during interaction, a tornado siren goes off. Students are asked to immediately stop what they are doing and call for help so that an adult figure (an officer) can guide them to the closest shelter (Fig. 7.). When the student calls for help, an avatar of a police officer enters the room and guides the student to the tornado shelter located downstairs. In the challenge scenario, a similar set up is displayed. However, when the tornado siren goes off students does not receive any guidance to go to the shelter.

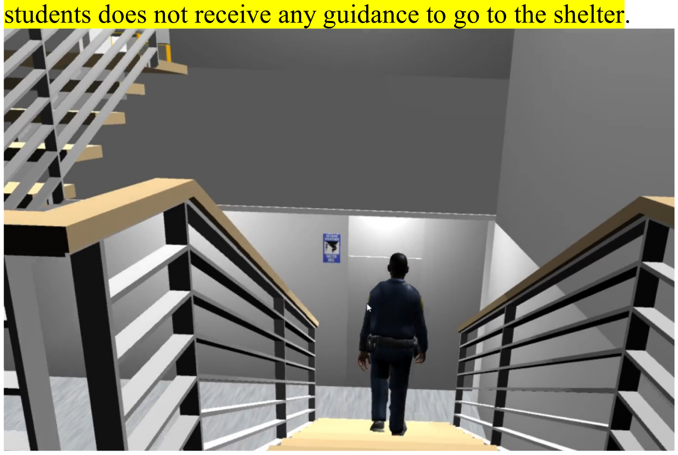


Fig. 7. A view of the VLE (from the user's perspective) in which an officer guiding the user to the tornado shelter

IV. Discussion and Outcomes

The assessment activities had 2 thrusts: (a) assess learning impact (viz. did the autistic students learn the concepts they were exposed to? How many repetitions did they need with the learning environments?) (b) what was the impact of the Applied Behavior Analysis (ABA) based positive reinforcers on the learning activities? During all learning interactions, positive learning behavior was emphasized through congratulatory messages and rewarded through positive reinforcers. For these interactions, the participants were allowed to select their preferred learning reinforcement from a menu of reinforcers (the successful completion of a learning activity resulted in their obtaining this reinforcement or reward). Examples included tokens that when collected earned the student a choice of activities ((such as giving them an opportunity to play a computer game, try to assemble a robot, or create computer based art).

Assessment of affordance

TEST 1: 2 groups of 10 students (5 middle and 5 high school students) participated. One group interacted with scenes with lower visual density; other with scenes of high visual density
Affordance was measured based on understanding of scene tasks and target concepts learned through interactions.
Null Hypothesis: Visual Density does not influence Affordance and Learning. Based on t-test, the null hypotheisis was rejected.
TEST 2: Introduce interruptions and disturbances to study impact on student learning; ambulance siren, someone talking in the back of the room (in scene); 2 groups of three middle school students were involved: one group interacted without interruptions and distractions; the second group interacted with interruption and distractions
Assessment focused on how such interruptions and distractions affected understanding and grasp of the target learning concepts for autistic students.
Null Hypothesis: Interruptions and distractions does not influence Affordance and Learning. Based on t-test, the null hypotheisis was rejected.
Finding #1: students who interacted with low visual density environments demonstrated high affordance, measured by understanding of target concepts compared to those who did not receive any reinforcers
Finding #2: students who interacted with VLEs without disturbances scored higher on the post tests of knowledge regarding assembly and path planning

An Applied Behavioral Analysis (ABA) based approach was adopted to support and encourage learning interactions. For the majority of the participants, interacting with a 3D computer-based learning environment served as positive reinforcement itself. Three of the high school participants did not want additional reinforcers and were able to complete their learning interactions without such additional reinforcers (in essence, the 3D based graphics environments acted as the positive reinforce itself). Two of the high school participants elected (as a reinforcer) to create computer-based art twice during the learning interactions (other reinforcer options included completing a VR based assembly of a robot, playing VR games, surfing the web using a tablet). Three of the middle school participants chose to play VR based computer games (wearing headset and controller); of these three, Two middle school participants played one computer game before coming back to complete his last set of learning interactions successfully, One middle school participant was able to complete the learning interactions after playing two different computer games.

Impact of Positive Reinforcers

2 groups of 6 students were involved in study related to positive reinforcers.

One group did not receive any positive reinforcers; the other group received positive reinforcers during their interactions with the VLEs.

Null Hypothesis: Positive reinforcers do not influence learning.

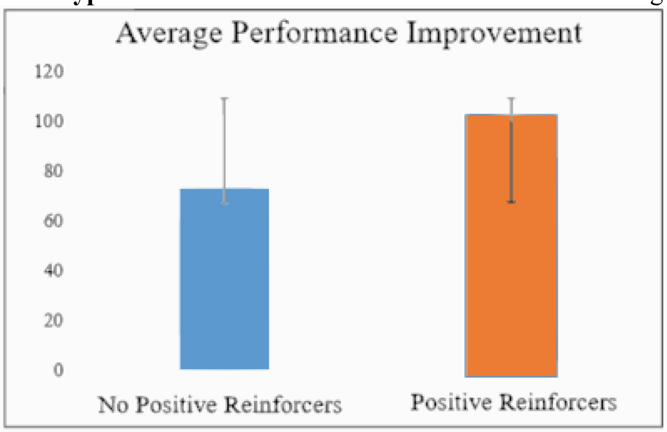


Fig. 8. Results from the study showcasing the role of positive reinforcers

Results

The results of the study are shown in Fig. 8. As seen in Fig 8., the improvements in the group who received positive reinforcers is higher compared to the group who did not receive any reinforcer. The results underscore the importance of using positive reinforcers in teaching and training using science concepts using VR based environments. A t-test was performed which showed a significant difference in the mean scores of the two groups. Hence, the null hypothesis was rejected. The alternate hypothesis which stated that positive reinforcers influence learning was accepted.

The results discussed in this paper primarily highlight the potential of designing immersive VLEs to teach STEM concepts to autistic students. It extends our previous studies involving autistic students and STEM learning [22,25] where 12 students were introduced to density, functioning of our solar system as well as basic robotics. Additional studies is needed with a larger number of participants. These activities are continuing with the involvements of schools and autistic students in Edmond, Muskogee and Oktaha school districts.

V. CONCLUSION

A discussion of the design of Virtual Learning Environments (VLEs) in helping students with Autism learn Science and Engineering concepts was provided in this paper. HCC principles such as affordance, visual density and cognitive load were explored during the design of the VLEs. Information centric models were created which served as a foundation to design, develop and assess the VLEs. Such models were created based on the participatory design based discussions with expert child physiologist. The VLEs were developed targeting the middle and high school students. Various interfaces and immersion levels including haptic based interfaces, immersive and AR based platforms were used during the development of the VLEs. These VLEs introduced students to concepts in assembly in the medical surgical context and path-planning and navigation in the context of NASA's moon mission. In order to gain better understanding of the impact of the VLEs, assessment activities were conducted; the preliminary results of the assessment activities demonstrated the positive impact of such cyberlearning techniques and environments on the learning of students with Autism.

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