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

J. Cecil, Ph.D.
Center for Cyber-Physical Systems
Dept. of Computer Science
Oklahoma State University
Stillwater, USA
j.cecil@okstate.edu

Mary Sweet-Darter, Ph.D.
Director,
Anselm Center,
Edmond, Oklahoma, USA
msweetdarter@me.com

Avinash Gupta
Center for Cyber-Physical Systems
Dept. of Computer Science
Oklahoma State University
Stillwater, USA
avinash.gupta@okstate.edu

Abstract—**This paper discusses the design of Virtual Learning Environments (VLEs) in helping students with autism learn Science and Engineering concepts. The VLEs were created for middle and high school students; subsequently assessment activities were conducted to gain a better understanding of the impact of such VLEs. The learning environments were created using various interfaces and immersion levels; these included haptic based interfaces and fully immersive 3D environments. These VLEs introduced students to concepts in Robotics and Manufacturing. Initial assessment findings have demonstrated the positive impact of such cyber learning techniques and environments.**

Keywords— Autism, Virtual Learning Environment, Cyber learning, Haptic, Immersive technologies.

I. INTRODUCTION

In this paper, the focus is on the design of Virtual Learning Environments (VLEs) and its potential to teach science and engineering concepts to autistic students. Virtual Learning Environments (VLE) are special types of Virtual Environments [28, 29] which are computer graphics intensive and use Virtual Reality (VR)/Augmented Reality technology.

Virtual Reality (AR) can be considered as one of the emerging technologies which can support learning in autistic children [24-26]. VR based learning and training environments have been used in surgical training and education [6, 7, 8, 9]. VR based engineering approaches have been the focus of numerous research efforts including manufacturing and other domains [30]. VR based simulation environments have played a key role in design of advanced cyber-physical frameworks for manufacturing as well as for process analysis [8]. Other researchers have noted the potential of VR based learning environments to help autistic individuals lead productive and meaningful lives [17, 18, 27, 28]. For example, in a preliminary study, researchers have highlighted the potential of VR based environments to help autistic children on how to safely cross a street [27,28]. In a NRC study [31], it was noted that computer graphics based simulation and VR based environments hold potential for teachers to engage students while improving understanding of scientific principles in domains ranging from environmental science to physics [32-97] including treating disorders and phobias [98-112].

Autism Spectrum Disorders (ASD) refers to a wide range of mental disorders of the neurodevelopmental type. ASD includes autism and Asperger syndrome. Autism can be characterized by difficulties in verbal/non-verbal communication, social interaction and repetitive behaviors [1]. The latest data from the Center for Disease Control and Prevention (CDC) show that about 1 in 54 children have autism [2]. The number of autistic children has been increasing over the last decade. In 2012, about 1 in 88 children were diagnosed with Autism. The causes of autism have been long linked to genetic, environmental or neural disorders. Recent studies show that autism is a complex disorder caused by several factors which often co-occur [3, 4]. Due to the difficulty in communication, a large number of autistic individuals remain unemployed [5]. Autistic children undergo mild to severe difficulties in learning under the traditional classroom atmosphere. In order to overcome this, autistic children need alternate ways of learning.

In [14], a non-immersive Augmented Reality (AR) game was designed for students with special needs. A 2D quiz game was developed in VR where players could try to answer multiple-choice questions with incrementing difficulty to learn mathematics in [18]. This game was tested simultaneously on general student population and special education students to compare the response to the quiz answers. An AR game based framework was created in [15] to group the objects as animal or fruit type to assist the learning process of children with intellectual disabilities. In [16], an experimental set up was created for training autistic students to recognize various objects using AR technology.

In [11], a study using VR in education was conducted which received positive feedback from both students and teachers. Students were excited about the interactive aspects of VR as it allowed them to independently explore and learn within a safe environment. Studies [9, 10. 12, 13] have indicated that sound, text, visual cues and 3D play a positive role in the learning process of autistic individuals. Research has also indicated that the use of avatars [22, 23] and haptic based simulation interactions [19-21] are effective in engaging non-autistic students.

II. DESIGNING THE VLEs

VLEs can also be described as 3D VR/AR based environments in which users can interact at multiple levels of immersion: non-immersion, semi-immersion, full-immersion. Immersion is the degree of interacting with the virtual environment by the user with the help of controllers, keyboard and haptic devices.

An information-centric model was created to understand the process of designing and building the VLEs. The information modeling-based design approach has been previously used in the design of VR based simulators for surgical training, manufacturing, space systems among others [6-9]. An information-centric model of this underlying process was created using the engineering Enterprise Modeling Language (eEML).

In the information-centric approach, the entire process of designing and building the VLE was subdivided into five

b. Software, physical and other resources need to complete a task (termed as Performing Agents PA)
c. Final/intermediate outcome of a given task or process (termed as decision Outcomes DO)

The information model depicting the process of creation of VLE is shown in Fig. 1.

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

Phase 1 (E1): Formulate Learning Objectives
In this phase, the project team identified the overall project objectives along with the assessment goals. The project team included an educational psychologist, virtual prototyping (3D modeling) experts, and software engineers. In this project, the overall objective was to study the design process involving the creation of the VLEs along with investigating the impact of such VLEs in helping autistic students learn science and engineering. The assessment approach (involving the format of the pre- and post-tests) were also discussed during this first phase of the process. The software tools, immersive and haptic technology mediums/platforms to be used in the creation of the VLEs were also identified. involves using pre- and post-tests to throw more light on the impact on learning and engagement.

Phase 2 (E2): Design the VLEs
Before starting to design the learning environments, the scope and specific learning objectives for each of the various topics
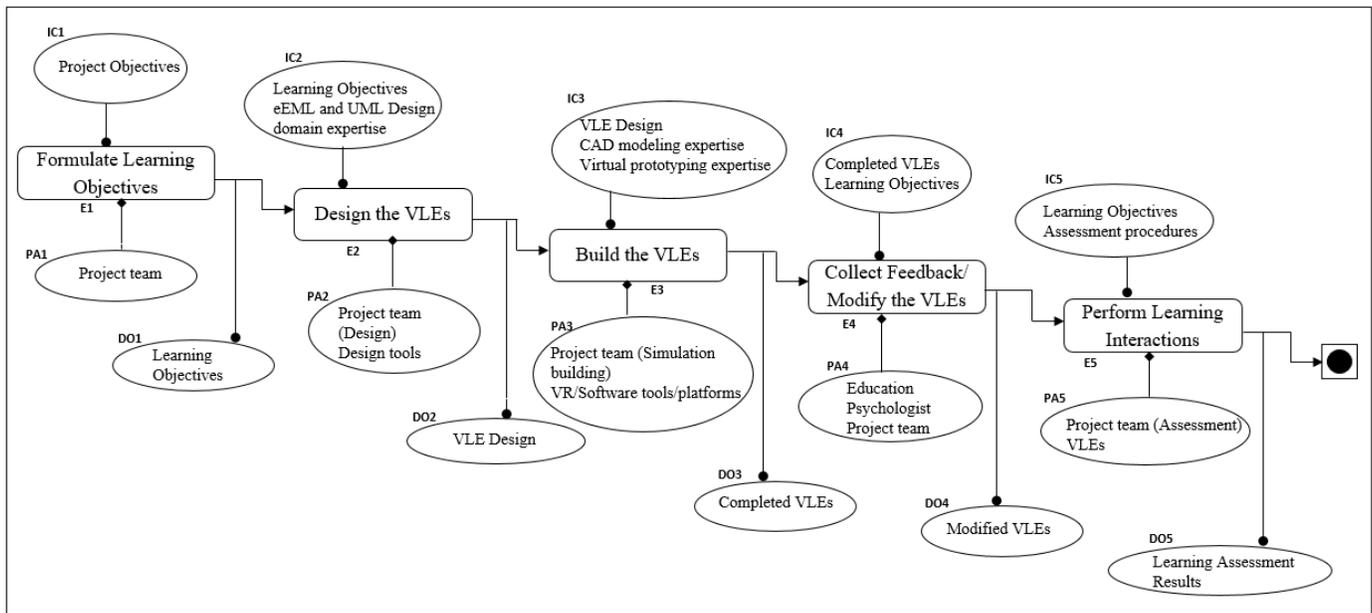

Fig.1: An eEML based information centric model to understand the process of creation of VLEs

phases (entities). The focus was on understanding and modeling various attributes of the entities and their functional and temporal relationships with each other. These attributes can be categorized as follows

a. Data or information needed to complete a task and major constraints (termed as Influencing Criteria IC)

were identified. The emphasis was on supporting an ABA based learning approach where students were rewarded for positive learning behavior including use of reinforcers (such as congratulatory messages, display of fireworks and playing computer games). The learning topics in each module (e.g.: robotics, manufacturing, etc.) were identified along with the

corresponding simulation scenarios to support the specific learning objectives. The type of immersion supported in each of the learning scenarios within each learning module was identified. These could be fully immersive (created on a platform such as the Vive™, fig 2) or support a haptic interface. The content of each module was divided into specific learning scenarios; this was identified through discussions between the educational psychologist and the software design/development team. The type of cues to be introduced (oral, text, etc.) and the sequence of learning various concepts in increasing levels of complexity were also identified in this phase of the process.

Phase 3 (E3): Build the VLEs
The VLEs were built using Unity 3D software and C# programming language. The CAD models were created using Solidworks™ CAD tool. Each module had an oral and visual introduction to the learning topics and objectives. Visual, text and voice cues were provided throughout the interactive learning sessions. For each target concept, several learning examples were provided with the emphasis on interacting with the 3D scene using either the immersive controllers (Fig. 2) or a haptic device (Fig. 4).

Phase 4 (E4): Collect feedback/Modify the VLEs
An educational psychologist interacted with each module of the VLEs and provided crucial feedback in various aspects such as learning objectives, interaction methods, use of visual and oral cues, among others. During the interactions, suggestions were provided such as adding more introductory content, re-wording the questions, adding additional segments, modifying the layout and adding more interactive components. After receiving the feedback, appropriate changes were made in the VLEs. This was a cyclic process and the psychologist interacted with the VLEs multiple times until all the appropriate modifications were completed.

Phase 5 (E5): Perform Learning Interactions
Learning assessments were conducted in which autistic students of different age groups and grades participated. They were consented and accompanied by their parents to interact with the VLEs. For both pre- and post-tests, the students could answer verbally, point to answers on the screen or write them. The students were first introduced to the concepts and performed a pre-test to assess if and how much they already know about the concepts. Subsequently, the students proceeded to interact with the VLEs. Finally, they performed a post-test to assess what they have learned from VLEs. They performed post-test multiple times until they could grasp all the concepts in each learning module.

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 and path planning.
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) [113-115] 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 [116, 117]. 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.

This research extends our earlier study involving the creation of VLEs to teach students density and fundamental assembly related concepts [9, 13]. 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 include additional density modules, several thrusts in assembly (including learning concepts 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 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 discussion of the VLEs follows.

A. Assembly Modules

The assembly modules introduced the students to the basic concepts of basic concepts of assembly, sequence and precedence. The VLEs were developed for two platforms; (i) fully-immersive platform and (ii) non-immersive platform with a haptic interface. The students interactively explored assembling various objects such as a bike, parts of a satellite

and a horse carriage using both the immersive and haptic platform. The students are also introduced to concepts such as assembly sequence and precedence conditions. Fig. 3 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.
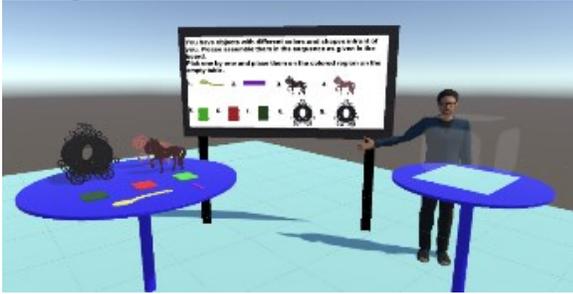

Fig. 3. A view of an assembly learning scenario for the horse carriage example

B. Density Modules

The Density VLEs extended our earlier learning scope [9, 13] to include additional relationships and properties related to floatation, and comparisons of density properties of various materials (such as wood, metals, plastic). The VLEs support both types of interfaces -- fully immersive and haptic platforms. Students explored picking up and dropping block of different materials such as wood, plastic, aluminum and steel into different liquid mediums (oil, water, etc.) and observe resulting behavior (do they float or sink.). In the advanced level, they were exposed to calculating density as a ratio of mass to volume. In the assessment activities, students were asked to calculate, comment, explore and compare the density of different materials they interacted with.

C. Robotics Modules

The robotics modules introduced the students to various types of robots and assembly concepts. In the introductory modules, they were introduced to two types of robots: (i) Cartesian robot and (ii) Axial robot. The different directions of movement or axis were introduced using simple pick and place tasks; the movement of the robot arms could be controlled using an immersive interface. For the Cartesian robot, an assembly work cell was created; basic concepts such as the functions of joints, grippers were highlighted using interactive examples with the help of a teaching avatar for both robot configurations. The interactive sessions involved students using a controller and perform various tasks such as controlling the movement of the gantry robot to perform various tasks including using the gripper to pick up and place a target part in a required destination while navigating along a specific axis and avoiding obstacles to reach the destination or to complete a specific assembly task. The learning modules had a user-friendly interface which enabled controlling the robot to move along x, y and z axes using menu options to move left, right, up, down, forward and backward. The instructions were color-coordinated to control the movement of the various robotic joints on the gantry frame.

Text and voice cues were provided in this module for the student to interact with the gantry and for part movement. An oral and text-based introduction was provided to explain the functioning of the robot and its various components at the beginning of the learning session.

D. Manufacturing Modules

In this set of modules, the students were introduced to concepts of manufacturing such as drilling. Drilling is a process of removing materials in a target solid or part. The VLEs were developed for two platforms; (i) fully-immersive platform with a haptic interface (fig 5) and (ii) non-immersive platform with a haptic interface (fig 4). The students interacted with a virtual drill in the VLE using either of the two platforms. As drilling is a process where a user needs to exert a certain force to drill a hole, the force-based feedback from the haptic device (fig 4) can provide an added realism by provide a limited amount of force feedback to students using the haptic device. The interactive learning activities involved introducing the basic process of drilling (material removal) and other tasks involving creating specific shapes and patterns using a virtual drilling tool. The students were provided instructions in the form of text-based cues and a 3D *avatar*. In Fig. 4, a view of a student interacting using a haptic device and drilling a virtual hole (as part of the interactive sessions) is shown. In Fig. 5, a view of the 3D layout is shown where a student is interacting using a haptic interface while wearing the 3D headset (Vive platform) to create a circular pattern (the target pattern to replicate is on the left; only the computer screen can be seen without the student and the haptic device).
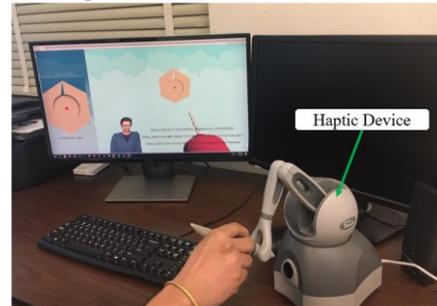

Fig. 4. A student interacting with the non-immersive haptic based VLE for drilling
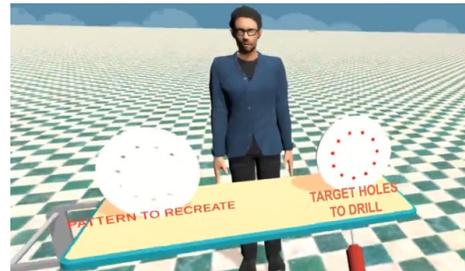

Fig. 5. A view of the fully-immersive haptic based VLE for creating a circular pattern

E. Medical Assembly Modules

In this module, the students were introduced to concepts of assembly using a medical surgical context. The medical surgery context assembling plates using bolts (which were to be used for surgical applications). The emphasis was on assembling objects with a higher level of complexity with the help of both voice and text cues (fig 6).
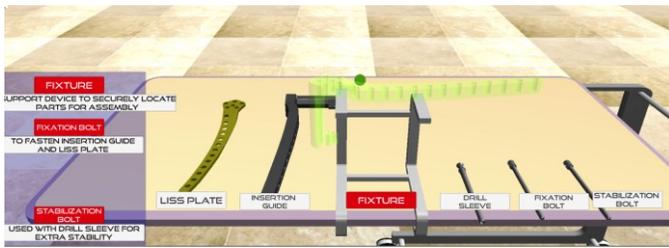
Fig. 6. A view of the assembly learning scenario for a medical context

F. NASA Moon Mission related modules focusing on Path Planning and Laptop Assembly:

In these modules, the students were introduced to the concepts of path planning and assembly using NASA's Deep Space Mission contexts (pertaining to the Artemis 2024 mission to land on the Moon). VR and AR modules created as part of a 2020 NASA X-Hab Challenge project [119] for university students were scaled down in complexity and content and used for these learning activities. Students were first introduced to NASA's Gateway (which is a large habitation/control structure that will be flying around the Moon during the mission); subsequently, the interior of the Gateway was used as a context to introduce the students to path planning and assembly/service tasks. In the path planning module, the students were exposed to the general notion of avoiding obstacles using a sparsely populated room for several scenarios of varying numbers of objects and obstacles. They subsequently were introduced to various parts of the Gateway's interior and introduced to path planning with a goal of developing multi-segment straight line paths around obstacles and reaching a specific destination (Fig. 7). They also interactively transported payloads within the Gateway using the Vive platform's interfaces (controller and headset). In a second module, the students were introduced to assembly/disassembly and service concepts using a laptop; in the first part of this session, an avatar performed the various steps (Fig. 9) while describing the various components and steps to be completed using various tools (such as a screwdriver); subsequently, guided by an avatar, the students disassembled parts of a laptop (as part of a service task to replace a defective memory board), replaced a memory board and then re-assembled the laptop; assistance from a teaching avatar was provided during the learning interactions along with text cues. After the interactions, interactive assessment tasks were conducted focusing on learning of concepts as well as being able to complete assembly and path planning tasks. Fig. 7 and 8 shows views of some of the interactive path planning and conceptual assessment scenes.
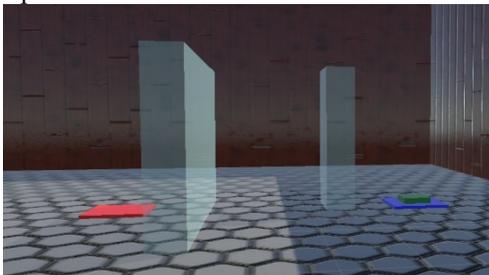

Fig. 7. A view of the fully-immersive path planning module showing start, endpoint and obstacles
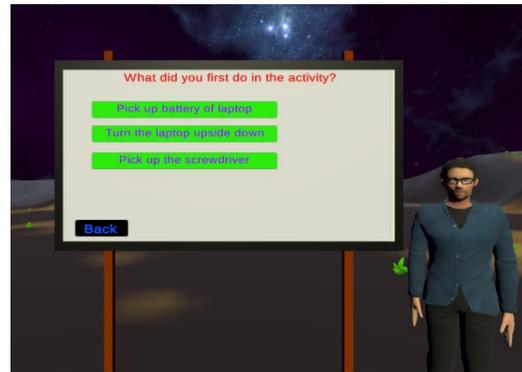

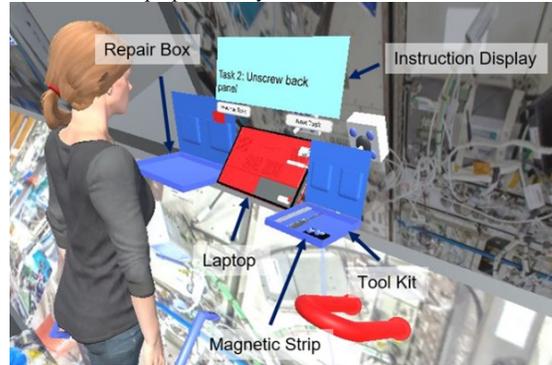Fig. 8. A view of the laptop assembly assessment module

Fig 9: View of a learning scenario inside the VLE where a teaching avatar (left) explains concepts of disassembly and service using a laptop (inside the Gateway structure)

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 learning was through pre- and post-test questions (this included providing answers within the VR based environments as well as through paper responses). A total of eight autistic students were involved in this study; four from middle school (grades 6, 7 and 8) and four from high school (grades 9 to 12). A pre-test was conducted before the start of each learning session (for each of the learning modules) with all participants. Subsequently, after each of the participants had completed their learning sessions with the VLEs, a post-test was conducted (using the same set of questions as the pre-test). A breakdown of the assessment activities is provided below for each of the learning thrusts (a total of 15 VLE modules were created).

Assembly VLEs:
Eight students interacted with the Assembly VLEs (4 middle school students, 4 high school students). Among the middle school students, 3 autistic participants were able to understand the target assembly concepts in the first round of learning interactions; a fourth participant needed an additional round of learning interactions for learning the same concepts. Among the high school students, three students were able to demonstrate an understanding of all concepts after one round of interactive sessions with the VLEs; the fourth students needed two rounds of learning interactions.

Density VLEs:
Six students interacted with the Density VLEs (2 middle school students and 4 high school students). Among the middle school students, only one student was able to understand all the concepts in the first round of learning interaction. The second middle school participant and all the high school participants needed two rounds of interactions with the VLEs to understand the targeted concepts. One of the participants was not able to grasp the concept of density as a ratio of mass to volume. Feedback obtained indicated that additional interactive sessions may have to be created to highlight the variations in properties of materials as well as for calculating density in terms of mass and volume.

Drilling and medical assembly VLEs:
Two high school students interacted with the manufacturing module, which introduced them to the fundamentals of drilling (e.g.: what is the drilling process, what are the essential tools used, what shape features can be produced by these tools, etc.). In the medical assembly module, the students were introduced to more advanced assembly concepts and processes involving a surgical plate assembly (used in orthopedic surgery). Both the students demonstrated learning of related concepts and were able to complete interactive assessment tasks in the first round of learning interactions.

NASA Moon Mission related modules focusing on Path Planning and Assembly Service:
Two middle school and two high school students participated in these learning interactions. All the participants were able to grasp the target concepts in the first round of learning interactions for both the modules.

An ABA based approach was used to support and encourage the learning interactions. For the majority of the participants, interacting with a 3D computer based learning environment acted 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). One of the high school participants elected (as a reinforce) to create computer based art twice during the learning interactions (other reinforce options included completing a VR based assembly of a robot, playing VR games, surfing the web using a tablet). Two middle school participants chose to play VR based computer games (wearing headset and controller). One of these middle school participants played one computer game before coming back to completed his last set of learning interactions successfully, A second middle school participant was able to complete the learning interactions after playing two different computer games. Additional data involving a larger number of autistic students needs to be collected to study the impact of such reinforcers.

V. CONCLUSION

This paper discussed an innovative approach involving the design of Virtual Learning Environments (VLEs) in teaching science and engineering concepts to autistic students. Information-centric engineering principles were adopted to design and build the VLEs. Several VLEs were created to support science and engineering learning among school students including introducing them to density, robotics, assembly, path planning, manufacturing and space systems. The project team included an educational psychologist, virtual prototyping experts and software engineers. Assessment studies were conducted including pre and post-tests for the various learning modules; these included multiple choice questions posed inside the VR environments as well as interactive tasks each student had to complete related to each module's target learning concepts.

The primary outcomes of this research indicated that the VLEs can help autistic students learn science and engineering concepts. However, some autistic students may require multiple interactions with the learning environments. The role of positive reinforcers needs to be studied more comprehensively. The initial results indicate the possibility that the VR based learning environments itself may act as reinforcers. However, for some of the autistic students, additional reinforcers may be helpful in encouraging them to continue their learning interactions, In the future, we plan to conduct more comprehensive studies including a larger group of participants.

REFERENCES

[1] Landa, R. J. (2008). Diagnosis of autism spectrum disorders in the first 3 years of life. Nature Clinical Practice Neurology, 4(3), 138-147.

[2] https://www.cdc.gov/ncbddd/autism/data.html

[3] https://www.nimh.nih.gov/health/topics/autism-spectrum-disorders-asd/index.shtml

[4] American Psychiatric Association. (2013). Autism spectrum disorder. Diagnostic and statistical manual of mental disorders, 50-59.

[5] Ohl, A., Grice Sheff, M., Small, S., Nguyen, J., Paskor, K., & Zanjirian, A. (2017). Predictors of employment status among adults with Autism Spectrum Disorder. Work, 56(2), 345-355.

[6] Cecil, J., Gupta, A., & Pirela-Cruz, M. (2018). An advanced simulator for orthopedic surgical training. International journal of computer assisted radiology and surgery, 13(2), 305-319.

[7] Cecil, J., Albuhamood, S., Cecil-Xavier, A., Ramanathan, P., An Advanced Cyber Physical Framework for Micro Devices Assembly, Special Issue on "Advanced CPS for Industry 4.0 - Enabling Technologies, Real-world Implementations, and Impact Assessments", IEEE Transactions on Systems, Man, and Cybernetics: Systems, August 2017, Issue 99, pp. 1-15

[8] Cecil, J., Krishnamurthy, R., and Gupta, A., Exploring Immersive Simulation based Design Frameworks in Support of the Moon Mission, Proceedings of the 13th Annual IEEE International Systems Conference, Orlando, Florida, April 8-11, 2019.

[9] Cecil, J.,Sweet-Darter, M., Cecil-Xavier, A., Exploring the use of Virtual Learning Environments to support science learning in autistic students, Proceedings of the 2017 Frontiers in Engineering FIE / IEEE conference, Indianapolis, Oct 18 – 20, 2017

[10] L. Bozgeyikli, A. Raij, S. Katkoori and R. Alqasemi, "A Survey on Virtual Reality for Individuals with Autism Spectrum Disorder: Design Considerations," in IEEE Transactions on Learning Technologies, vol. 11, no. 2, pp. 133-151, 1 April-June 2018.

[11] N. A. A. Aziz, K. A. Aziz, A. Paul, A. M. Yusof and N. S. Mohamed Noor, "Providing augmented reality based education for students with attention deficit hyperactive disorder via cloud computing: Its advantages," 2012 14th International Conference on Advanced Communication Technology (ICACT), PyeongChang, 2012, pp. 577-581.

[12] E. Ferrari, B. Robins and K. Dautenhahn, "Therapeutic and educational objectives in robot assisted play for children with autism," RO-MAN 2009 - The 18th IEEE International Symposium on Robot and Human Interactive Communication, Toyama, 2009, pp. 108-114.

[13] Cecil, J., Krishnamurthy, R., Sweet-Darter, M., and Gupta, A Role of Immersive Simulation and Cyber Technology based Approaches in Supporting Learning and Curriculum Innovation, Proceedings of the 14th Annual IEEE International Systems Conference, Montreal, Canada, April 20-23, 2020.

[14] E Richard, et al., "Augmented Reality for Rehabilitation of Cognitive Disable Children: A preliminary Study," in Virtual Rehabilitation 2007, 2007, pp. 102-108.

[15] R. Colpani and M. R. P. Homem, "An innovative augmented reality educational framework with gamification to assist the learning process of children with intellectual disabilities," 2015 6th International Conference on Information, Intelligence, Systems and Applications (IISA), Corfu, 2015, pp. 1-6.

[16] N. S. Lakshmiprabha, A. Santos, D. Mladenov and O. Beltramello, "[Poster] An augmented and virtual reality system for training autistic children," 2014 IEEE International Symposium on Mixed and Augmented Reality (ISMAR), Munich, 2014, pp. 277-278.

[17] A. Kurniawati, A. Kusumaningsih and I. Hasan, "Class VR: Learning Class Environment for Special Educational Needs using Virtual Reality Games," 2019 International Conference on Computer Engineering, Network, and Intelligent Multimedia (CENIM), Surabaya, Indonesia, 2019, pp. 1-5.

[18] R. G. Mangowal, U. L. Yuhana, E. M. Yuniarno and M. H. Purnomo, "MathBharata: A serious game for motivating disabled students to study mathematics," 2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH), Perth, WA, 2017, pp. 1-6.

[19] Ham, Insook, FEEL, IMAGINE AND LEARN! - Haptic Augmented Simulation and Embodied Instruction in Physics Learning, Columbia university, Doctoral Dissertation, Doctor of Education in Teachers College, Columbia University, 2010.

[20] Williams, R. L., II, Chen, M.-Y., & Seaton, J. M. (2003). Hapticsaugmented simple machine educational tools. Journal of Science Education and Technology, 12(1),1-12.

[21] Jones, M. G., Minogue, J., Tretter, T. R., Negishi, A., & Taylor, R. (2006). Haptic augmentation of science instruction: Does touch matter? Science Education,90(1), 111-123.

[22] Falloon, G., Using avatars and virtual environments in learning: What do they have to offer?, British Journal of Educational Technology Vol 41 No 1 2010 108–122.

[23] Deuchar, S. & Nodder, C. (2003). The impact of avatars and 3D virtual world creation on learning. In the proceedings of the 16th Annual NACCQ Conference. Palmerston North

[24] Parsons S, Mitchell P (2002). The potential of virtual reality in social skills training for people with autistic spectrum disorders. Journal of Intellectual Disability Research, 46, 430-43.

[25] Parsons S, Mitchell P, Leonard A (2004). The use and understanding of virtual environments by adolescents with autistic spectrum disorders. Journal of Autism and Developmental Disorders, 34, 449466.

[26] Parsons S, Mitchell P, Leonard A (2005). Do adolescents with autistic spectrum disorders adhere to social conventions in virtual environments? Autism 9, 95-117.

[27] Strickland, D., Lee, M., Mesibov, G. and Hogan, K, Brief Report: Two Case Studies Using Virtual Reality as a Learning Tool for Autistic Children, Journal of Autism and Developmental Disorders, Vol. 26, No. 6, 1996.

[28] [28].Strickland, D ,Virtual Reality for the Treatment of Autism, Virtual Reality in Neuro-Psycho-Physiology, 1997, 1998 © Ios Press: Amsterdam, Netherlands (editor: G. Riva), http://utenti.multimania.it/dualband/pdf/strickl.pdf

[29] Cecil, J., Ramanathan, P, et al., Collaborative Virtual Environments for Orthopedic Surgery, Proceedings of the 9th annual IEEE International Conference on Automation Science and Engineering (IEEE CASE 2013), August 17 to 21, 2013, Madison, WI.

[30] Cecil, J., Gunda, R., Calyam, P., Seetharam, S., A Next Generation Collaborative Framework for Advanced Manufacturing, Proceedings of the 9th annual IEEE International Conference on Automation Science and Engineering (IEEE CASE 2013), August 17 to 21, 2013, Madison, WI.

[31] Cecil, J., Kanchanapiboon, A., Kanda, P., Muthaiyan, A., 'A Virtual Prototyping Test bed for Electronics Assembly, Proceedings of the 27th Annual IEEE International Electronics Manufacturing Technology (IEMT) symposium, San Jose, July 17-18, 2002, pp.130-136.

[32] National Research Council. (2011). Learning science through computer games and simulations. Committee on science learning: Computer games, simulations and education. In M. Honey & M. Hilton (Eds.), Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

[33] Baenninger, M., & Newcombe, N. (1989). The role of experience in spatial test performance: A meta-analysis. Sex Roles, 20, 327-344.

[34] Barab, S.A., Hay, K.E., Barnett, M.G., & Keating, T. (2000). Virtual solar system project: Building understanding through model building. Journal of Research in Science Teaching, 37, 719-756.

[35] Barab, S. & Squire, K. (2004). Design-Based research: Putting a stake in the ground. The Journal of the Learning Sciences, 13, 1-14.

[36] Cecil, J. (2011). Report, NSF International Workshop on Information Centric Engineering (ICE) in Emerging Process Domains (held jointly with EI2N 2011 workshop). Oct 19 – 21, Hersonissos, Greece

[37] Cecil, J. (2012). Virtual Learning Environments for Engineering Education, In W. Aung et al. (Eds.), "Innovations 2012": World Innovations in Engineering Education and Research. International Network for Engineering Education & Research.

[38] Choi, B. & Baek, Y. (2011). Exploring factors of media characteristic influencing flow in learning through virtual worlds. Computers & Education, 57, 2382–2394.

[39] Clark, D., Nelson, B., Sengupta, P. & D'Angelo, C. (2009). Rethinking science learning through digital games and simulations: Genres, examples, and evidence. Invited Topic Paper in the Proceedings of The National Academies Board on Science Education Workshop on Learning Science: Computer Games, Simulations, and Education. Washington, D.C. http://www7.nationalacademies.org/bose/Clark_Gaming_Commissioned Paper.pdf. [accessed 3 January 2012].

[40] Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. The Journal of the Learning Sciences, 13, 15-42.

[41] Cooper, T. (2007). Nutrition game. In D. Livingstone & J. Kemp (Eds), Proceedings of the Second Life Education Workshop 2007 (pp. 47–50). Chicago, IL. Retrieved on September 9, 2008, from www.simteach.com/slccedu07proceedings.pdf.

[42] Csikszentmihalyi, M. (1997). Finding flow: The psychology of engagement with everyday life. New York: Basic Books.

[43] de Jong, T. (2009). Learning with computer simulations: Evidence and future directions. Presentation to the National Research Council Workshop on Gaming and Simulations, October 6-7, Washington, DC.

[44] Dickey, M. D. (2005). Three-dimensional virtual worlds and distance learning: Two case studies of active worlds as a medium for distance education. British Journal of Educational Technology, 36, 439–451.

[45] Guttiérez, A. (1996). Visualization in 3-dimensional geometry: in search of a framework. In L. Puig, & A. Guttiérez (Eds.), Proceedings of the 20th conference of the international group for the psychology of mathematics education (pp. 3–19). Valencia: Universidad de Valencia.

[46] Hauptman, H., & Cohen, A. (2011). The synergetic effect of learning styles on the interaction between virtual environments and the enhancement of spatial thinking. Computers & Education, 57, 2106–2117.

[47] Huang, H-M., Rauch, U., Liaw, S-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. Computers & Education, 55, 1171–1182.

[48] Ketelhut, D.J., Dede, C., Clarke, J, Nelson, B., and Bowman, C., (2007). Studying situated learning in a multi-user virtual environment. In E. Baker, J. Dickieson, W. Wulfeckm and H.F. O'Neil (Eds), Assessment of problem solving using simulations. New York: Lawrence Erlbaum.

[49] Klopfer, E., Yoon, S., and Rivas, L. (2004). Comparative analysis of palm and wearable computers for participatory simulations. Journal of Computer Assisted Learning, 20, 347-359.

[50] Klopfer, E., Yoon, S., and Um, T. (2005). Teaching complex dynamic systems to young students with StarLogo. Journal of Computers in Mathematics and Science Teaching, 24(2), 157-178.

[51] Klopfer, E., Scheintaub, H., Hunag, W., Wendal, D., & Roque, R. (2009). The simulation cycle: Combining games, simulations, engineering and science using StarLogo TNG. E-Learning, 6, 71-96.

[52] Ligorio, M. B. & van Veen, K. (2006). Constructing a successful cross-national virtual learning environment in primary and secondary education. AACE Journal, 14, 103–128.

[53] Ma, J., & Nickerson, J.V. (2006). Hands-on, simulated and remote laboratories: A comparative literature review. ACM Computing Surveys, 38, 1-24.

[54] Meir, E., Perry, J., Stal, D., Maruca, S., and Klopfer, E. (2005). How effective are simulated molecular 1 level experiments for teaching diffusion and osmosis? Cell Biology Education, 4, 235-248.

[55] National Academy of Sciences. (2007). Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, National Academy of Sciences, National Academy of Engineering, Institute of Medicine. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.

[56] National Center for Education. (2008). 21st Century Skills, Education & Competitiveness: A resource and policy guide. Partnership for 21st Century Skills.

[57] Omale, N., Hung, W. C., Luketkehans, L., & Cook-Plagwiz, J. (2009). Learning in 3-D multiuser virtual environment: Exploring the use of unique 3-D attributes for online problem-based learning. British Journal of Educational Technology, 40, 480–495.

[58] Quellmalz, E.S., DeBarger, A.H., Haertel, G., Schank, P., Buckley, B., Gobert, J., Horwitz, P., and Ayala, C. (2008). Exploring the role of technology-based simulations in science assessment: The Calipers Project. Presented at American Educational Research Association (AERA) 2007, Chicago, IL. In Science assessment: Research and practical approaches. Arlington, VA: NSTA.

[59] Quellmalz, E.S., Timms, M.J., and Schneider, S.A. (2009). Assessment of student learning in science simulations and games. Paper commissioned for the National Research Council Workshop on Gaming and Simulations, October 6-7, Washington, DC., 2005

[60] Shen, J., & Eder, L. B. (2009). Intentions to use virtual worlds for education. Journal of Information System Education, 20, 225–233.

[61] Sourin, A., Sourina, O. & Prasolova-Førland, E. (2006). Cyber-learning in cyberworlds. Journal of Cases on Information Technology, 8, 55–70.

[62] Sternberg, R.J. (1997). Styles of thinking and learning. Canadian Journal of School Psychology, 13, 15-40.

[63] Stensvold, M.S., & Wilson, J.T. (1990). The interaction of verbal ability with concept mapping in learning from a chemistry laboratory activity. Science Education, 74, 473–480.

[64] Trevino, L. K., & Webster, J. (1992). Flow in computer-mediated communication. Communication Research, 19, 539–573.

[65] Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three dimensional spatial visualisation. Perceptual and Motor Skills, 60, 343–350.

[66] Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. Psychological Bulletin, 117, 250-270.

[67] Win, J., Li, P., & Rao, S. (2008). Why they enjoy virtual game world? An empirical investigation. Journal of Electronic Commerce Research, 9, 219–230.

[68] Ye, E., Fang, Y., Liu, C., Chang, T. J. & Dinh, H. Q. (2007). Appalachian tycoon: an environmental education game in second life. In D. Livingstone & J. Kemp (Eds), Proceedings of the Second Life Education Workshop 2007 (pp. 72–76). Chicago, IL. Retrieved on January 3, 2012 from www.simteach.com/slccedu07proceedings.pdf.

[69] Chan, M. S., & Black, J. B. (2006). Direct-manipulation animation: Incorporating the haptic channel in the learning process to support middle school students in science learning and mental model acquisition. Proceedings of International Conference of the Learning Sciences. Mahwah, NJ: LEA.

[70] Reiner, M. (1999). Conceptual construction of fields through tactile interface. InteractiveLearning Environments, 7(1), 31-35.

[71] Dionisio, J., Henrich, V., Jakob, U., Rettig, A., & Ziegler, R. (1997). The virtual touch:Haptic interfaces in virtual environments. Computers & Graphics 21(4), 459-468.

[72] Edys S. Quellmalz, Michael J. Timms, & Steven A. Schneider, Assessment of Student Learning in Science Simulations and Games, commissioned paper, Committee on Science Learning: Computer Games, Simulations, and Education, National Research Council. " Learning Science Through Computer Games and Simulations. Washington, DC: The National Academies Press, 2011. (http://www7.nationalacademies.org/bose/Schneider_Gaming_Commissi onedPaper.pdf)

[73] Wilensky, U. (1999a). NetLogo. http://ccl.northwestern.edu/netlogo. Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University.

[74] Barnett, M., Squire, K., Higginbotham, T., and Grant, J. (2004). Electromagnetism

[75] supercharged! In Proceedings of the 2004 International Conference of the Learning Sciences. Los Angeles: University of California Press.

[76] Sengupta, P., Uri Wilensky, Learning Electricity with NIELS: Thinking with Electrons and Thinking in Levels, Int J Comput Math Learning (2009) 14:21–50

[77] Klopfer, Eric;Yoon, Susan;Um, Tricia, Teaching Complex Dynamic Systems to Young Students with StarLogo, The Journal of Computers in Mathematics and Science Teaching; 2005; 24, 2, pg. 157

[78] StarLogo http://education.mit.edu/starlogo

[79] Forcael, E., Glagola, C., and González, V. (2012). "Incorporation of Computer Simulations into Teaching Linear Scheduling Techniques." J. Prof. Issues Eng. Educ. Pract., 138(1), 21–30

[80] Adams, W.K., Reid, S., LeMaster, R., McKagan, S.B., Perkins, K.K., Dubson, M., and Wieman. C.E. (2008a). A study of educational simulations part I—Engagement and learning. Journal of Interactive Learning Research, 19(3), 397-419.

[81] Adams, W.K., Reid, S., LeMaster, R., McKagan, S.B., Perkins, K.K., Dubson, M., and Wieman, C.E. (2008b). A study of educational simulations part II—Interface design. Journal of Interactive Learning Research, 19(4), 551-577.

[82] Baker, E.L., and Mayer, R.E. (1999). Computer-based assessment of problem solving. Computers in Human Behavior, 15, 269-282.

[83] Barab, S.A. (2009). The Quest Atlantis project: A 21st century curriculum. Paper commissioned for the National Research Council Workshop on Gaming and Simulations, October 6-7, Washington, DC. Available: http://www7.nationalacademies.org/bose/Gaming_Sims_Commissioned_ Papers.html [accessed March 16, 2010].

[84] Barab, S.A., and Dede, C. (2007). Games and immersive participatory simulations for science education: An emerging type of curricula. Journal of Science Education and Technology, 16(1), 1-3.

[85] Barnett, M., Squire, K., Higginbotham, T., and Grant, J. (2004). Electromagnetism supercharged! In Proceedings of the 2004 International Conference of the Learning Sciences. Los Angeles: University of California Press.

[86] Behrens, J.T. (2009). Response to assessment of student learning in science simulations and games. Paper prepared for the National Research Council Workshop on Gaming and Simulations. Available: http://www7.nationalacademies.org/bose/Behrens_Gaming_CommissionedPaper.pdf [accessed March 23, 2010].

[87] Bewley, W., Chung, G., Delacruz, G., and Baker, E. (2009). Assessment models and tools for virtual environment training. In D. Schmorrow, J. Cohn, and D. Nicholson (Eds.), The PSI handbook of virtual environments for training and education: Developments for the military and beyond, volume 1 (pp. 300-313). Westport, CT: Greenwood.

[88] Chang, H.-Y. (2009). Use of critique to enhance learning with an interactive molecular visualization of thermal conductivity. In M.D. Linn (Chair), Critique to learning science. Symposium conducted at the annual meeting of the National Association for Research in Science Teaching, Garden Grove, CA.

[89] Clark, D.B., and Jorde, D. (2004). Helping students revise disruptive experientially-supported ideas about thermodynamics: Computer visualizations and tactile models. Journal of Research in Science Teaching, 41(1), 1-23.

[90] Culp, K.M. (2009). Response to: Learning context: Gaming, simulations, and science learning in the classroom. Paper commissioned for the National Research Council Workshop on Gaming and Simulations, October 6-7, Washington, DC. Available: http://www7.nationalacademies.org/bose/Culp_Gaming_Presentation.pdf [accessed March 23, 2010].

[91] Day, S.B., and Goldstone, R.L. (2009). Analogical transfer from interaction with a simulated physical system. In Proceedings of the Thirty-First Annual Conference of the Cognitive Science Society (pp. 1,406-1,411). Amsterdam: Cognitive Science Society. Available: http://cognitrn.psych.indiana.edu/rgoldsto/pdfs/day09.pdf [accessed February 22, 2010].

[92] Dede, C. (2009a). Immersive interfaces for engagement and learning. Science, 323(5910), 66-69.

[93] Dede, C. (2009c). Learning context: Gaming, gaming simulations, and science learning in the classroom. Paper commissioned for the National Research Council Workshop on Gaming and Simulations, October 6-7, Washington, DC. Available: http://www7.nationalacademies.org/bose/Dede_Gaming_CommissionedPaper.pdf [accessed February 2011].

[94] Dede, C., and Ketelhut, D.J. (2003). Designing for motivation and usability in a museum-based multi-user virtual environment. Paper presented at the American Educational Research Association Conference, Chicago.

[95] Dede, C., Ketelhut, D.J., and Ruess, K. (2002). Motivation, usability, and learning outcomes in a prototype museum-based multi-user virtual environment. In Proceedings of the Fifth International Conference on the Learning Sciences (pp. 406-408). Mahwah, NJ: Lawrence Erlbaum.

[96] de Jong, T. (2009). Learning with computer simulations: Evidence and future directions. Presentation to the National Research Council Workshop on Gaming and Simulations, October 6-7, Washington, DC. Available: http://www7.nationalacademies.org/bose/deJong_Gaming_Presentation.pdf [accessed February 15, 2011].

[97] Dieterle, E., Dede, C., Clarke, J., Dukas, G., Garduño, E., and Ketelhut, D.J. (2008). Formative assessments integrated into a MUVE that provides real-time feedback for teachers on student learning. Paper presented at the 2008 American Educational Research Association Conference, New York, NY.

[98] Dunleavy, M., Dede, C., and Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. Journal of Science Education and Technology, 18(1 February), 7-22.

[99] Hodges, L., Anderson, P., Burdea, G., Hoffman, H., & Rothbaum, B. (2001). Treating psychological and physical disorders with VR. IEEE Computer Graphics and Applications, 21, 25–33.

[100] Botella, C., Quero, S., Banos, R. M., Perpina, C., Garcia Palacios, A., & Riva, G. (2004). Virtual reality and psychotherapy. Studies in Health Technology and Informatics, 99, 37–54.

[101] Glantz, K., & Rizzo, A. (2003). Virtual reality for psychotherapy: Current reality and future possibilities. Psychotherapy, 40, 55–67.

[102] Krijn, M., Emmelkamp, P. M., Olafsson, R. P., & Biemond, R. (2004b). Virtual reality exposure therapy of anxiety disorders: A review. Clinical Psychology Review, 24, 259–281.

[103] Pull, C. B. (Ed.). (2005). Current status of virtual reality exposure therapy in anxiety disorders: Editorial review. Current Opinion in Psychiatry, 18, 7–14.

[104] Anderson, P. L., Zimand, E., Hodges, L. F., & Rothbaum, B. O. (2005). Cognitive behavioral therapy for publicspeaking anxiety using virtual reality for exposure. Depression and Anxiety, 22, 156–158.

[105] Bouchard, S., Cote, S., St-Jacques, J., Robillard, G., & Renaud, P. (2006). Effectiveness of virtual reality exposure in the treatment of arachnophobia using 3d games. Technology and Health Care, 14, 19–27.

[106] Cote, S., & Bouchard, S. (2005). Documenting the efficacy of virtual reality exposure with psychophysiological and information processing measures. Applied Psychophysiology Biofeedback, 30, 217–232

[107] Emmelkamp, P. M., Bruynzeel, M., Drost, L., & van der Mast, C. A. (2001). Virtual reality treatment in acrophobia: A comparison with exposure in vivo. Cyberpsychology and Behavior, 4, 335–339.

[108] Emmelkamp, P. M., Krijn, M., Hulsbosch, A. M., de Vries, S., Schuemie, M. J., & van der Mast, C. A. (2002).

[109] Virtual reality treatment versus exposure in vivo: A comparative evaluation in acrophobia. Behavior Research and Therapy, 40, 509–516.

[110] Glantz, K., & Rizzo, A. (2003). Virtual reality for psychotherapy: Current reality and future possibilities. Psychotherapy, 40, 55–67.

[111] Klinger, E., Bouchard, S., Legeron, P., Roy, S., Lauer, F., Chemin, I., et al. (2005). Virtual reality therapy versus cognitive behavior therapy for social phobia: A preliminary controlled study. Cyberpsychology and Behavior, 8, 76–88.

[112] Krijn, M., Emmelkamp, P. M., Biemond, R., de Wilde de Ligny, C., Schuemie, M. J., & van der Mast, C. A. (2004a). Treatment of acrophobia

[113] Parsons, T., Rizzo, A., Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis, Journal of Behavior Therapy and Experimental Psychiatry, 39 (2008) 250–261.

[114] National Research Council. Donovan, S., and Bransford, J., (eds), How Students Learn: History, Mathematics and Science in the Classroom, National Research Council of the National Academies, 2005.

[115] National Research Council. How People Learn: Brain, Mind, Experience, and School: Expanded Edition. Washington, DC: The National Academies Press, 2000

[116] National Research Council, Educating Children with Autism, Washington, DC: The National Academies Press, 2001.

[117] Neitzel, J. (2010). Reinforcement for children and youth with autism spectrum disorders: Online training module (Chapel Hill, NC: National Professional Development Center on Autism Spectrum Disorders, FPG Child Development Institute, UNC-Chapel Hill). In Ohio Center for Autism and Low Incidence (OCALI), Autism Internet Modules, www.autisminternetmodules.org.

[118] Petit, Mary Jo, Effects of positive reinforcement on non-compliant behavior, http://www.nwmissouri.edu/library/researchpapers/2013/Pettit,%20Mary%20Jo.pdf

[119] Cecil, J., Krishnamurthy, R., Kennison, S., Gupta, A., Murakonda, N., Lopez, A., Crosby, N., Zimmer, N., Venkatramanan, K., Bhakta, M., Skinner, T., Olivero, S., Walston, H., Miftah, M., (2020). Design of Next Generation User Interfaces based on Augmented Reality technologies to train astronauts on the Gateway in support of the Moon Mission. In AIAA AVIATION 2020 FORUM (p. 3203)