Virtual Reality in STEM Education During COVID-19

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Abstract

The availability of virtual reality (VR) technology has opened up an avenue to bring three dimensional real-world experiences to students which may otherwise be inaccessible to them. The VR-based lessons provide opportunities for students to be engaged with complex concepts that can be visualized in three-dimensions (3D) helping them improve their understanding. A team of faculty at an HBCU has developed VR lessons in introductory Math, Biology, Physics, Aerospace Engineering and Electrical Engineering courses. However, the COVID-19 protocols impacted the implementation of these lessons in a VR environment. The lessons were therefore implemented such that students could experience them on their computer screens at any time and from anywhere. The software platform allowed interaction with the 3D environment using mouse/cursor controls. The methodology of the development of a VR lesson and links to the VR lessons are included in the paper. Attitude surveys were administered to students before and after the implementation of these interactive lessons. Results from these surveys are shared. This paper is based on an exploratory project funded by the NSF HBCU Target Infusion Projects program.

Introduction

Low self-efficacy associated with challenges in understanding the basic concepts taught in the core STEM courses is a strong contributing factor to student attrition. Strategies to improve learning experiences in STEM courses by all students at colleges and universities are therefore needed so that they persist in the STEM career pipeline. A group of STEM faculty members at a Historically Black University is committed to this important need through the far-reaching use of Virtual Reality (VR) in its STEM courses and investigating its impact on learning outcomes, engagement and persistence in STEM.

The two big questions that continue to be examined by STEM education experts are: (a) Why do students change their majors from a STEM to a non-STEM major? and, (b) Why do students struggle with STEM concepts leading them to drop out of college? Extensive research therefore is still being conducted to determine how people learn [1], [2]. The importance of engagement has been identified as key to retention, learning, and the development of self-regulated learners [3] – [9]. Interest as an affective state representing students’ experience of learning has been proposed to be the result of integration of the three dimensions of engagement which are behavioral, cognitive and affective engagement [10], [11].

The effect of engagement in meaningful academic activities on retention of first year students [5] showed statistically significant impacts on GPA and persistence. It was also noted a proportionally higher positive impact of educationally engaging activities on students from underserved groups. Cognitive engagement has been cited as an important element for learning. Cognitive engagement may be viewed as a proxy for learning [12]. The main elements of a cognitively engaging learning environment [13] are: Authenticity – relating with real life; Inquiry – collecting, analyzing, interpreting data; Collaboration – teamwork; and Technology –
active learning, authentic tasks. Active learning has also been identified as an effective pedagogical approach to improve student engagement and development of critical thinking skills that lead to metacognitive behaviors in learning [14] – [17]. The effectiveness of active learning has been examined [16] and determined to be a pedagogy that has broad support of educators. The impact of the various learning modalities on retention of concepts etc. was graphically presented as the “cone of experience” [18] showing the influence of active learning strategies.

With easy access to reasonably powerful computing resources and low-cost hardware, technology is increasingly being used to provide not only a cognitively engaging environment, but it is also impacting the behavioral and affective domains of engagement. The classical levels of technology integration in the learning process, learning about technology, learning from technology and learning with technology are now being expanded to include learning in technology which refers to virtual reality [19]. However, due to the need for large computing power, the use of virtual reality was limited to high-end applications. Finally, in 2016 virtual reality showed signs of emerging from the trough of disillusionment [20].

The biggest strengths of VR are its ability to transport the user into an environment which may not be otherwise accessible (physical danger, distance, cost, etc.), visualizing and interacting with the environment. Inexpensive hardware and software to develop and experience virtual reality is resulting in its use in applications ranging from recreation (movies, games) to procedural training (assembly/disassembly). VR is finding rapid use in developing procedural skills through immersion and interaction with the environment.

Exploiting the affordances of a VR environment to develop effective learning experiences in education is a challenge. However, it has found a steadily increasing use in K-12 education. A review of research literature on the use of virtual reality in K-12 [21] – [23] identified that virtual reality facilitated inquiry-based learning and led to increased motivation and achievement. Increased interest in STEM has also been reported [24]. Virtual reality has been used to teach not only various science concepts for example, solar system [25], chemistry [26] but also to motivate students to learn coding using drag-and-drop code blocks.

While VR is increasingly being used in K-12, its incorporation in higher education is rather slow. There are multiple reasons for the slow incorporation of this modality as an effective learning environment. The major challenge in using VR in higher education is the development of learning materials that fully utilize the affordances of VR to learn abstract concepts. Design elements of a VR environment for higher education have been identified and investigated [27], [28]. These design elements include realism of surroundings, passive observation, teleportation, manipulation and interaction with objects, assembly of objects, interaction with other users, role management, screen sharing, instructions, knowledge tests, immediate feedback, making meaningful choices, virtual rewards. However, not utilizing all the advantages of VR in a learning environment, or not incorporating all the design elements, and studying the efficacy of such a suboptimal approach can yield useful insights into the directions needed to develop VR technology-appropriate pedagogies. For example, A 3D VR environment was used [29] as a meeting area to conduct 2D presentations. “Google Earth” was implemented in geography courses [30]. VR was also used [31] to teach concepts of geomorphology. The impact of use of gestures was studied [32] in a lesson on vector comprehension in electric fields which again was
extending a 2D lesson into an immersive VR environment. Obvious candidates for VR-based learning though are concepts involving spatial visualization skills such as understanding DNA [33]. Some evidence of enhanced learning outcomes has also been reported [34].

The foregoing review of literature indicates that considerable amount of work needs to be done to develop, validate and implement effective pedagogical paradigms of VR learning environments.

This paper provides results of exploratory work in developing and implementing VR learning environments. The constraining protocols of COVID-19 forced the move from immersive VR for which the learning material were developed to a computer monitor based implementation. The objectives of the study are to:
(a) Identify the challenges in fully exploiting characteristics of presence and interaction of VR in developing learning materials in STEM for higher education
(b) Determine the impact of VR lessons on student engagement

Method

Fifteen VR lessons were prepared by five faculty from different STEM areas which include Aerospace Engineering, Biology, Electrical Engineering, Mathematics, and Physics. Undergraduate students from each major assisted faculty in the development of the VR lessons. One undergraduate research assistant from each of the five STEM areas assisted the faculty in developing and testing the lessons. The research assistants gained experience in the lesson development process starting from establishing learning objectives, and then storyboarding and prototyping.

The implementation of these lessons was in the following courses 1) Introduction to Aerospace Engineering, 2) Aerodynamics-I, 3) Molecular Cell and Genetic Biology, 4) Molecular Cell and Genetic Biology Laboratory, 5) Signals and Systems, 6) Microprocessors, 7) Pre-Calculus and Algebra, 8) Calculus I, 9) Differential Equation, 10) Physics I, and 11) Physics I Lab. The study was approved by the Institutional Review Board and the participating students provided their consent informed consent forms. The responses of the participants to the various surveys were collected online using Qualtrics.

Participations

The participants of the research were undergraduate students enrolled in the various STEM courses at an HBCU. All the participants self-identified as African American.

Materials

Hardware/software: The lessons were designed to be implemented using the ClassVR headsets. The lessons were developed using the web based CoSpaces software platform. The software allows import of 3D models, audio/video files. CoSpaces includes a physics engine which can be used to attach various physics attributes to objects. Objects and scenes can be manipulated in the software either using drag-drop blocks (CoBlocks) or a scripting language (TypeScript). The VR lessons created in CoSpaces can be uploaded to the ClassVR headsets. However, because of COVID the VR lessons could not be implemented in an immersive VR environment with the
ClassVR headsets. These lessons were instead experienced by the participant students on computers as the lessons can also be viewed and interacted with on a computer screen. The instructors demonstrated the lessons during the remote teaching and students were provided the link to interact with the lesson on their computers in their own time.

Learning materials
Three VR lessons were developed in each of the five areas (Aerospace Engineering, Biology, Electrical Engineering, Mathematics, and Physics). These lessons were implemented during the Fall 2020 semester. Table I illustrates the three VR lessons for each of the five areas. A corresponding link to each published lesson is included in the table.

<table>
<thead>
<tr>
<th>Area</th>
<th>VR Lesson</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace Engineering</td>
<td>Control surfaces and axes of rotation of an aircraft</td>
<td><a href="https://edu.cospaces.io/HAE-BWF">https://edu.cospaces.io/HAE-BWF</a></td>
</tr>
<tr>
<td></td>
<td>Turbofan Engine</td>
<td><a href="https://edu.cospaces.io/DTB-FGM">https://edu.cospaces.io/DTB-FGM</a></td>
</tr>
<tr>
<td>Biology</td>
<td>Protein Translation</td>
<td><a href="https://edu.cospaces.io/PCE-QDR">https://edu.cospaces.io/PCE-QDR</a></td>
</tr>
<tr>
<td></td>
<td>DNA Model</td>
<td><a href="https://edu.cospaces.io/UYE-HBU">https://edu.cospaces.io/UYE-HBU</a></td>
</tr>
<tr>
<td></td>
<td>Genetic Engineering</td>
<td><a href="https://edu.cospaces.io/EXS-TRT">https://edu.cospaces.io/EXS-TRT</a></td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>Classification of Signals</td>
<td><a href="https://edu.cospaces.io/FZB-TPD">https://edu.cospaces.io/FZB-TPD</a></td>
</tr>
<tr>
<td></td>
<td>Notions of stack operation</td>
<td><a href="https://edu.cospaces.io/RFQ-UWD">https://edu.cospaces.io/RFQ-UWD</a></td>
</tr>
<tr>
<td></td>
<td>Introduction to Fourier Series</td>
<td><a href="https://edu.cospaces.io/FBH-SZU">https://edu.cospaces.io/FBH-SZU</a></td>
</tr>
<tr>
<td>Math</td>
<td>Graph Transformations</td>
<td><a href="https://edu.cospaces.io/JPV-ZWJ">https://edu.cospaces.io/JPV-ZWJ</a></td>
</tr>
<tr>
<td></td>
<td>Derivative Application - Position, Velocity, and Acceleration</td>
<td><a href="https://edu.cospaces.io/JXE-RHC">https://edu.cospaces.io/JXE-RHC</a></td>
</tr>
<tr>
<td></td>
<td>Differential Equations Application – Car Suspension</td>
<td><a href="https://edu.cospaces.io/PGY-VVU">https://edu.cospaces.io/PGY-VVU</a></td>
</tr>
<tr>
<td>Physics</td>
<td>Momentum and Collision</td>
<td><a href="https://edu.cospaces.io/AZD-UWR">https://edu.cospaces.io/AZD-UWR</a></td>
</tr>
<tr>
<td></td>
<td>Free Fall and Constant Acceleration - Introduction</td>
<td><a href="https://edu.cospaces.io/VCQ-LDA">https://edu.cospaces.io/VCQ-LDA</a></td>
</tr>
<tr>
<td></td>
<td>Newton's laws of motion</td>
<td><a href="https://edu.cospaces.io/VUQ-XYE">https://edu.cospaces.io/VUQ-XYE</a></td>
</tr>
</tbody>
</table>

Table I: Fall 2020 VR lessons

A number of these lessons were directed towards providing students better visualization of concepts taking advantage of the 3D affordance and manipulation of the 3D objects. Computer screenshots of some lessons are given below (Fig. 1).
Assessment instruments
Several surveys were given to the students enrolled in the classes in which the VR lessons were implemented. The pre-class surveys measured:
(a) Awareness and experience with VR technology using a 5-point response scale (1 = not at all, 5 = a great extent)
(b) Motivational and self-regulated learning (a subset of the MSLQ [35] using a 7-point response scale (not at all true of me, 7 = very true of me)

The post-class survey was administered within three days of students’ interaction with the VR lessons activities. The survey measured the following
(a) Usability of the VR technology, engagement in the VR lessons, and perceived outcomes associated with the VR lessons using a 5-point response scale (1 = not at all, 5 = a great extent)
(b) Course perceptions using a 5-point response scale (1 = not at all, 5 = a great extent)
(c) Motivational and self-regulated learning (a subset of the MSLQ [35])

Results and conclusions

VR Lessons Outcomes: The students responses indicated a positive impact of VR lessons. The responses to the 9-items on the survey registered averages above 3.5 on the 5-point scale (Table II). The responses to application of the concepts and understanding of the concepts had the highest averages (3.75 and 3.69 respectively). Interest in STEM-related career and desire to complete a STEM-related degree registered higher than 4 on the 5-point scale.

Table II: VR Lessons Outcomes (N = number pf respondents, SD = standard deviation)

<table>
<thead>
<tr>
<th>Extent to which the use of virtual reality (VR) for topics in this class has improved each of the following:</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your knowledge of course concepts.</td>
<td>136</td>
<td>3.56</td>
<td>1.009</td>
</tr>
<tr>
<td>Your understanding of how course concepts can be applied.</td>
<td>136</td>
<td>3.75</td>
<td>.972</td>
</tr>
<tr>
<td>Your interest in the topics in this class.</td>
<td>136</td>
<td>3.65</td>
<td>1.118</td>
</tr>
<tr>
<td>Your confidence that you will understand the major concepts in this class.</td>
<td>134</td>
<td>3.69</td>
<td>1.028</td>
</tr>
<tr>
<td>Your motivation to learn as much as you can in this class and other related classes.</td>
<td>136</td>
<td>3.66</td>
<td>1.150</td>
</tr>
<tr>
<td>Your belief that the content in this class will be useful to your future career.</td>
<td>136</td>
<td>3.83</td>
<td>1.030</td>
</tr>
<tr>
<td>Your intent or interest in taking more classes like this one.</td>
<td>136</td>
<td>3.60</td>
<td>1.201</td>
</tr>
<tr>
<td>Your interest in a STEM-related career.</td>
<td>136</td>
<td>4.02</td>
<td>1.125</td>
</tr>
<tr>
<td>You desire to complete a degree related to STEM.</td>
<td>136</td>
<td>4.16</td>
<td>1.063</td>
</tr>
</tbody>
</table>

The students’ feedback on VR lessons in context of engagement was positive. All the 10 items of the survey (a 5-point scale) registered means that were in the direction of agreeing with the items (Table III). The averages of the responses to impact on comprehension and application were the highest (3.53).

Table III: VR Lessons Feedback (N = number pf respondents, SD = standard deviation)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>There was sense of presence (being there) while learning with VR.</td>
<td>134</td>
<td>3.16</td>
<td>1.256</td>
</tr>
<tr>
<td>Using VR allowed me to be more active in the learning process.</td>
<td>134</td>
<td>3.49</td>
<td>1.243</td>
</tr>
</tbody>
</table>
Using VR allowed me to have more control over my learning. 134 3.48 1.193
Using VR helped me engage more in the learning process. 134 3.52 1.237
Using VR helped make comprehension easier. 134 3.53 1.224
Using VR helped make memorization easier. 133 3.50 1.259
Using VR helped improve the application of knowledge. 133 3.53 1.210
Using VR helped provide a better overview of the content. 134 3.51 1.237
Using VR helped to identify the critical concepts from topics in the lesson(s). 134 3.52 1.225

An important aspect of the VR lesson design was usability including opportunities for interaction with the lesson. All the 10-items of this dimension registered mean responses in the direction of agreement with the items (Table IV). The responses indicated the user interface was user friendly. The average of the responses was highest for the ability to review the lesson and understand the mistakes.

Table IV: VR Lessons Usability (N = number of respondents, SD = standard deviation)

<table>
<thead>
<tr>
<th>Description</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall, I am satisfied with how easy it was to understand the content explained with virtual reality (VR).</td>
<td>138</td>
<td>3.46</td>
<td>1.324</td>
</tr>
<tr>
<td>I was actively involved during the VR lesson(s).</td>
<td>137</td>
<td>3.55</td>
<td>1.322</td>
</tr>
<tr>
<td>I was able to effectively complete the activities in the VR lesson(s).</td>
<td>135</td>
<td>3.62</td>
<td>1.332</td>
</tr>
<tr>
<td>I was able to effectively complete the homework related to the topic(s) addressed in the VR lesson(s).</td>
<td>137</td>
<td>3.64</td>
<td>1.294</td>
</tr>
<tr>
<td>I felt comfortable exploring and interacting during the VR lesson(s).</td>
<td>136</td>
<td>3.60</td>
<td>1.302</td>
</tr>
<tr>
<td>I believe I became more confident about the content explored in the VR lesson(s).</td>
<td>135</td>
<td>3.55</td>
<td>1.286</td>
</tr>
<tr>
<td>Whenever I made a mistake, I was able to review the VR lesson(s) and correct it.</td>
<td>136</td>
<td>3.75</td>
<td>1.263</td>
</tr>
<tr>
<td>The information and instructions for the VR lesson(s) helped me explore and interact effectively with the lesson(s).</td>
<td>137</td>
<td>3.64</td>
<td>1.288</td>
</tr>
<tr>
<td>The interface of the VR lesson(s) was/were user-friendly.</td>
<td>135</td>
<td>3.65</td>
<td>1.312</td>
</tr>
<tr>
<td>Overall, I am satisfied with how VR was used to explore concepts covered in the lesson(s).</td>
<td>136</td>
<td>3.60</td>
<td>1.319</td>
</tr>
</tbody>
</table>

**Future Work**

VR lessons for additional courses are being developed. These lessons will be implemented during Spring 2021 semester. The effectiveness of the lessons will be measured.
Conclusions

The objective of this study was to determine the effectiveness of lessons that were primarily developed for use in an immersive environment but had to be implemented for use on a computer screen. The responses of the participant students indicated that even in a non-immersive environment, the ability to interact with the lesson entities and manipulating them resulted in engaging the students effectively. The overall results show that the implementation of the developed VR lessons helped students to visualize 3-dimensional objects to understand a concept.

Acknowledgement

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References


