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Challenges and Opportunities for Virtual Reality in Higher Education

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Challenges and Opportunities for Virtual Reality in Higher Education

Abstract
Virtual reality (VR) has made a successful transition from the entertainment domain to the skills training domain. As expected, there is now considerable research being conducted on utilizing the affordances of VR in higher education. A properly designed VR-based learning environment can engage students not only cognitively but also affectively and behaviorally. This paper provides details of the process of developing VR lessons for introductory level undergraduate courses in STEM disciplines. The lessons were prepared using a web-based VR development environment. Some challenges in developing these lessons were identified, and are shared. The impact of the VR lessons on students' perceptions and attitudes was analyzed using self-reported data that were gathered through surveys. The results of the data analysis are included.

Introduction

The use of virtual reality (VR) is becoming visible outside the entertainment industry as a result of the dramatically reducing cost of hardware and relatively easy implementation of software. Thus, VR has made impressive inroads into the training domain. The affordances of VR that have been successfully exploited in the training domain include spatial relationships of objects (size, location etc.) and procedural tasks. Training can therefore be imparted for tasks that in real-life would be in hazardous conditions, or the training equipment may not be available due to various reasons such as cost etc. Xie Biao et al. [1] have provided a review of the use of VR in the training domain. The relative effectiveness of VR-based training and non-VR traditional training such as videos is still being investigated [2], [3]. VR is also being effectively used in the architectural [4], automotive [5] – [7], and aerospace [8] design to understand the spatial relations between the various aspects/components of the environment being designed [9]. It is expected that VR would eventually find its implementation at higher abstraction levels than procedural and skills training.

The importance of student engagement has been shown to be essential for learning and academic success [10]. The learning environment is effective when it supports the three dimensions of engagement, namely the behavioral, affective and cognitive domains. VR is a unique technology that can support all these three domains of engagement. However, the exploitation of the affordances of VR is not as straight forward in education and especially in STEM higher education [11], [12] as the training domain.

This paper provides details on the hardware and software used for the development of VR-based lessons in several STEM subjects, and some challenges in preparing and implementing the lessons. Assessment of students' responses to the use of VR is also discussed in this paper.

Method

The VR lessons were developed for lower-level courses in aerospace engineering, biology, electrical engineering, mathematics and physics. Five undergraduate students, one from each discipline, were hired to assist the faculty. The first step in the process of development of the VR lessons was the identification of topics of the lessons. The topics were determined through discussions between the faculty and students research assistants. The research assistants provided their input about topics they or their peers found challenging when they took those courses. These topics were then reviewed by the faculty to determine their suitability for leveraging the advantages of a virtual reality environment. The next step was selecting appropriate hardware and software, details of which are given below, followed by training on its use. The topics were storyboarded by the research assistants and reviewed by the faculty. The storyboards were then developed into VR lessons and implemented in the classroom. Due to COVID protocols, the immersive VR headsets could not be used for the lessons. The students enrolled in the courses in which the VR lessons were implemented, used the computer monitors, keyboard and mouse to interact with the lessons. The research was approved by the IRB.

Materials:

Hardware and software: The ClassVR® headsets were chosen for deploying the VR lessons. These headsets are designed specifically for a classroom learning environment with appropriate monitoring and controls for the instructor. Lessons can be deployed simultaneously to multiple headsets or to an individual headset. Communication between the instructor workstation and the headsets can be through Wi-Fi or Bluetooth. Choosing the VR lesson development software was a challenge as most software (Unity, Blender etc.) have a steep learning curve. The CoSpaces® software was chosen for its ease of use of the programing environment with sufficient controls including assigning of physics to entities in the virtual world, avatars, and the ability to upload 3-D solid models, and audio and video files.

VR Lessons: The 15 lessons developed and implemented during the Fall 2020 semester are shown in Table I. Three lessons were developed in each of the five disciplines.

Lesson	**Link**
Aerospace Engineering (AENG)	
Aircraft control surfaces and axes of rotation	https://edu.cospaces.io/HAE-BWF
Turbofan engine	https://edu.cospaces.io/DTB-FGM
Elementary potential flows	https://edu.cospaces.io/RDQ-TYX
Biology (BIOL)	
DNA model	https://edu.cospaces.io/UYE-HBU
Protein translation	https://edu.cospaces.io/PCE-QDR
Genetic engineering	https://edu.cospaces.io/EXSTRT
Electrical Engineering (EENG)	
Classification of signals	https://edu.cospaces.io/FZB-TPD
Notions of stack operation	https://edu.cospaces.io/RFQUWD
Introduction to Fourier series	https://edu.cospaces.io/FBH-SZU
Mathematics (MATH)	
Graph transformations	https://edu.cospaces.io/JPV-ZWJ
Math Differentiation-Application	https://edu.cospaces.io/KYG-SAB

2nd order ODE application - car suspension	https://edu.cospaces.io/PGY-VVU
Physics (PHYS)	
Free fall and constant acceleration	https://edu.cospaces.io/VCQLDA
Newton's laws of motion	https://edu.cospaces.io/VUQXYE
Momentum and collisions	https://edu.cospaces.io/AZDUWR

Table I: List of VR lessons

A VR lesson Example: Every developed VR lesson contains "scenes" with explanation of a selected concept, activities to reinforce the concept, and some questions for students to test their understanding. In one of the lessons in mathematics for example, a car suspension system was used to explain the application of a second order differential equation. The lesson starts with an introduction to the topic and provides several options to interact with the lesson. Figure 1 shows clickable panels to navigate to different sections of the lesson "scenes". The student can go directly to the desired section of the lesson (i. e., scene) if he/she is reviewing the VR lesson. The student is encouraged to select the first panel that takes the students to the scene containing details of a physical system modeled by a 2nd order ordinary differential equation (Fig. 2).

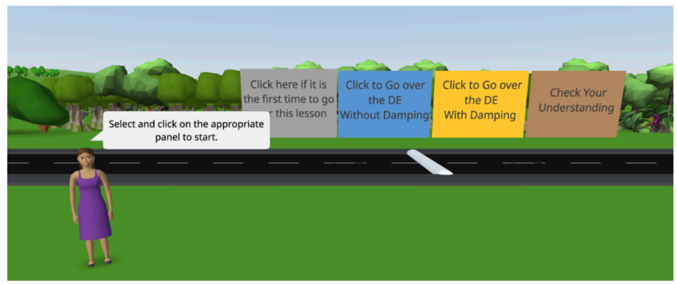


Figure 1: Selecting Desired Section of the Lesson

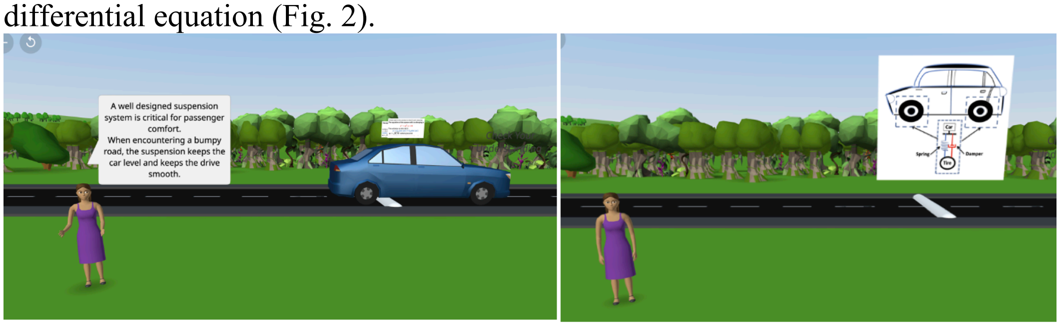


Figure 2: Mathematics Modeling

Then, activities are provided to understand how the system behaves when various combinations of the system parameters (such as mass, damping) are chosen (Fig. 3).

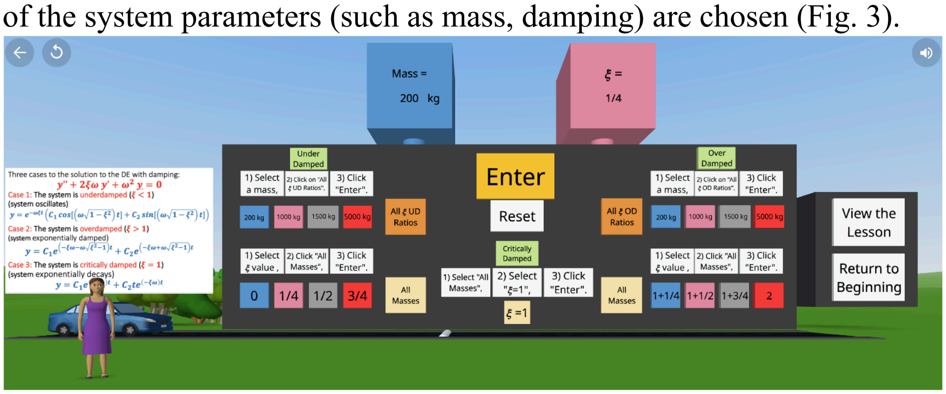


Figure 3: Interactive activity

The lesson has dynamic components such as an animation video of the suspension system and animated graphs corresponding to the selected parameters of the problem/activity (Fig. 4). In addition, the lesson allows students to test their understanding by responding to a few questions associated with the lesson. If the student gives an incorrect answer, then a review of that aspect is provided, and a second chance is given. If the student still missed the correct response, then the right answer to the question is given with explanation.

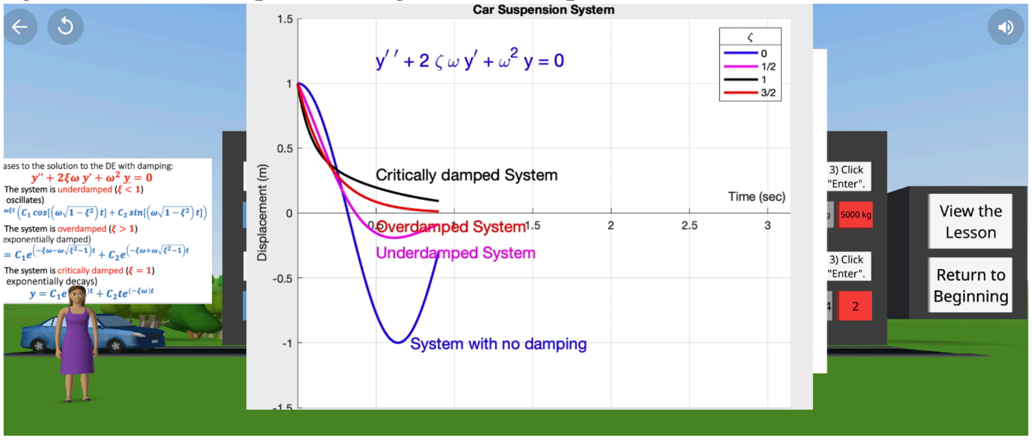


Figure 4: Explanation with Animated graphs

Assessment Instruments: The impact of the VR lessons was assessed through a survey administered at the end of the fall semester. The survey measured the usability, the engagement, effectiveness of the VR lessons, and perceived impact on outcomes associated with the VR lessons. The items on the survey (Appendix A) were extracted from a validated instrument [13] with reliabilities exceeding 0.7. The instrument consisted of 3-items for the Usability dimension, 3-items for the Engagement dimension, and 14-items for the Effectiveness dimension. The impact on the content was measured using an additional 9-item subscale. The survey items were a 5-point Likert scale with 1- Strongly Disagree (SD), 2 - Disagree (D), 3 - Neutral (N), 4 - Agree (A), 5 - Strongly Agree (SA).

Participants: The participants were undergraduate STEM students at an HBCU. A total of 205 students responded to the survey of which 60% were freshmen and sophomores, and 40% were juniors and seniors. However, a total of 166 participants fully completed the survey that was administered to them.

Results and Discussion

The VR lessons were implemented in AENG 100 (Introduction to Aerospace Engineering), AENG 244 (Aerodynamics I), BIOL 250 (Molecular Cell and Genetic Biology), BIOL 251 (Molecular Cell and Genetic Biology Lab), EENG 323 (Signals and Systems), EENG 360 (Microprocessors), Math 307 (Differential Equations), PHYS 310 (General Physics I).
The analyses of the survey data were carried out to determine the participants attitudes towards VR in general and the VR lessons in particular.

The averages of responses of the participants to the survey items gauging the VR-lessons in each of the four dimensions are given in Table II. The trend was in the direction of agreement (positive) with items of the survey. It was noted that the impact of the VR lessons on student perceptions of the course outcomes was the highest. The next highest average was that of usability of the VR lessons.

	Mean
VR – Usability	3.54
VR – Engagement	3.46
VR - Effectiveness	3.48
VR - Impact	3.86

Table II: Overall average of responses to the VR Lessons

The average of responses by all participants (N = 166) to the questions of the survey is given in Fig. 5. All the averages of the responses were in the positive direction i.e., larger than 3 (neutral).

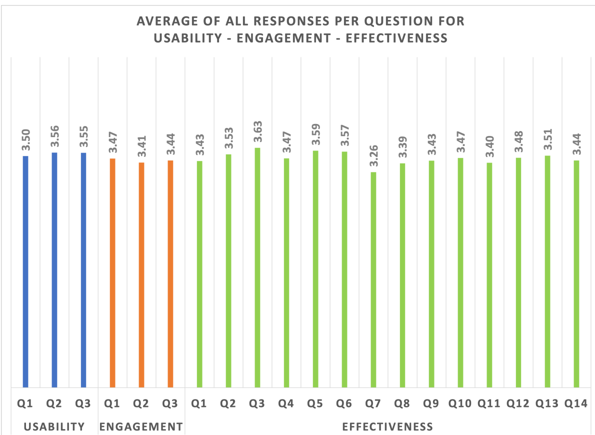


Figure 5a: Average of all responses by dimension

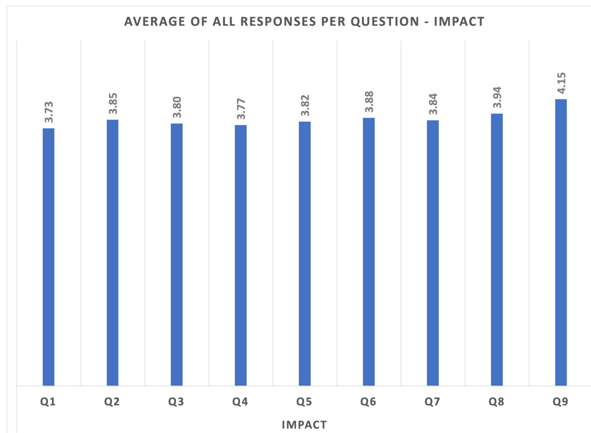
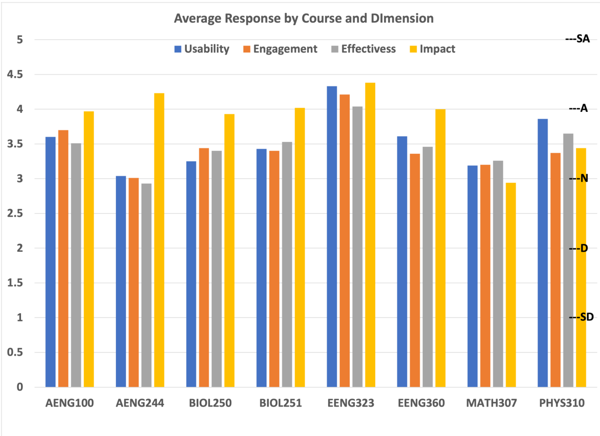


Figure 5b: Average of all responses for impact

There was not much difference (less than 2%) between the highest (3.56) and lowest (3.50) averages to the questions of the usability dimension (Fig. 5a). A similar difference between the maximum (3.47) and minimum (3.41) averages was registered in the engagement dimension. In the effectiveness dimension, the maximum average was 3.63 while the minimum average was 3.26 (a difference of 10%). The question eliciting the minimum average was as expected "There was a sense of presence (being there) while learning with VR." The minimum average of responses was 3.73 and the maximum was 4.15 (a 10% difference) in the impact dimension (Fig. 5b). The maximum average of responses was for the question "To what extent did the VR lessons improve your desire to complete a STEM degree".

A comparison of the participants responses by course and by discipline is shown in Fig. 6a and Fig. 6b. The participants responses to usability, engagement, effectiveness, and impact of VR-lessons were positive for all classes. The highest averages in all dimensions were for the EENG 323 class, while the lowest averages were for the MATH 307 (Fig. 6a). The low number (N=12) of respondents in the MATH class may be the reason for the relatively low averages. However, when the responses were averaged over each discipline (Fig. 6b), the effect of individual courses/lessons was averaged out. Aerospace engineering and electrical engineering had the highest average for the impact dimension. Physics had the highest average in the usability dimension.



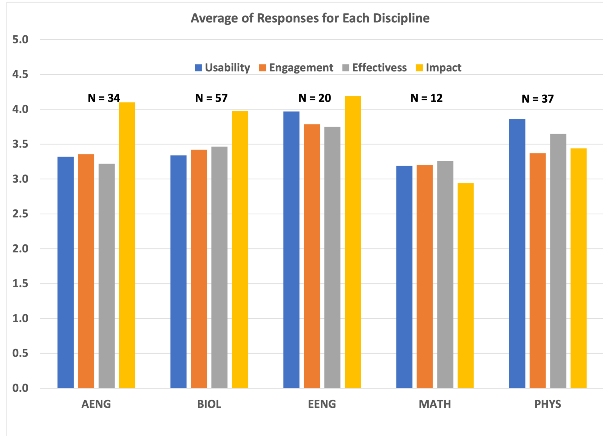


Figure 6a: Average of responses for each course **Figure 6b: Average of response for each discipline**

Implementation in Aerospace Engineering courses: The lowest average of responses for the effectiveness dimension (Fig. 7a) by the AENG 100 students was to the statement "There was a sense of presence (being there) while learning with VR" (Q#7). This response was expected as the students did not use the headsets for an immersive experience but rather experienced the lessons on a computer monitor due to COVID challenges. The students of AENG 244 rated the statement "Using VR helped make memorization easier" (Q#10) the lowest (Fig. 8a). This response indicated that the lesson was correctly designed, that is, not designed for memorization but for understanding. For the impact dimension (Fig. 7b), the lowest average of responses by the AENG 100 students was for the statement "Please indicate the extent to which the use of VR for topics in this class has improved your knowledge of course concepts (Q#1)". The AENG 100 student average of responses to the statement of the VR lessons having a positive impact on their learning (Fig. 7b) was higher as compared to the students of AENG 244 (Fig. 8b). The utility for career was rated higher by students of AENG 100 (Fig. 7b) as compared to the students of AENG 244 (Fig. 8b). The AENG 100 students also indicated a higher motivation in comparison to the students from AENG 244 to take more STEM classes as result of the use of VR.

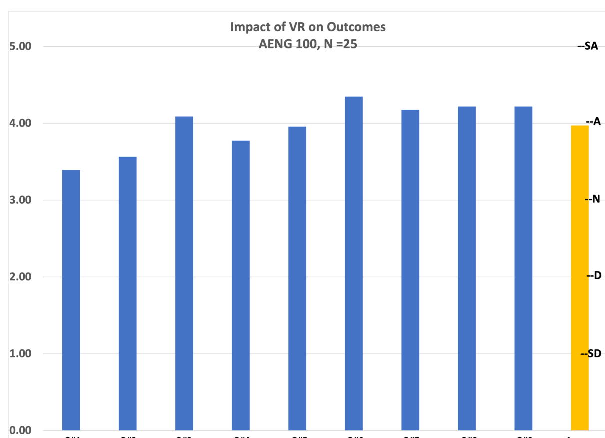


Figure 7a. Responses to VR Dimensions (AENG 100) **Figure 7b. Responses to VR Impact (AENG 100)**

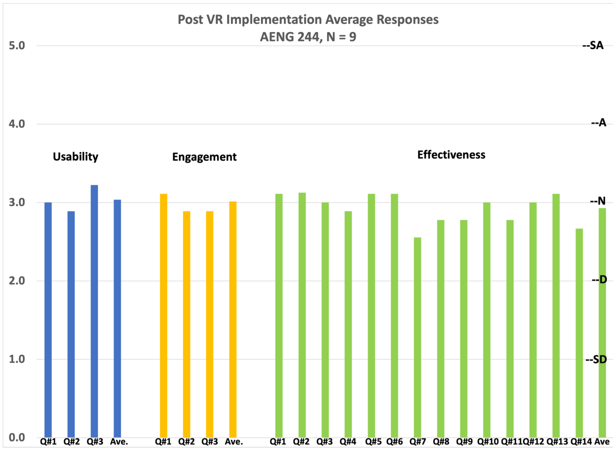


Figure 8a. Responses to VR Dimensions (AENG244)

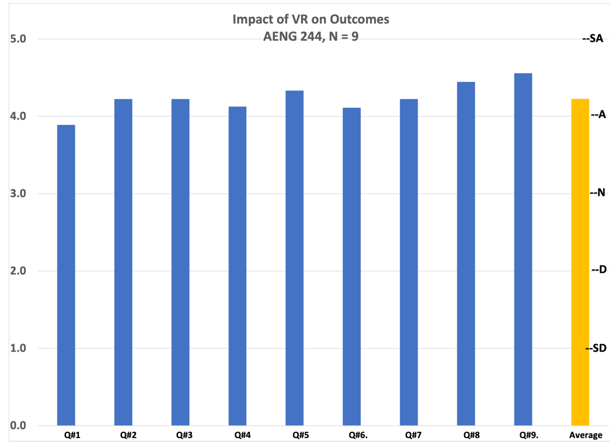


Figure 8b. Responses to VR Impact (AENG244)

Implementation in Biology courses: The highest average of responses of students of both BIOL 250 and BIOL 251 was to the statement about desire to complete a STEM related degree (Q#9, Figs. 9b, 10b). The average of the student responses in both BIOL courses to statement about the VR lessons in improving their motivation (Q#5, Figs. 9b, 10b) to learn was the lowest. The students in BIOL 250 responded most positively to the statement about VR making comprehension easier (Q# 9, effectiveness dimension, Fig. 9a).

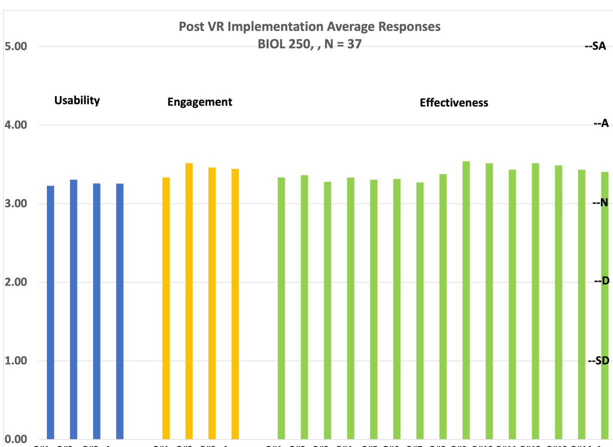


Figure 9a. Responses to VR Dimensions (BIOL250)

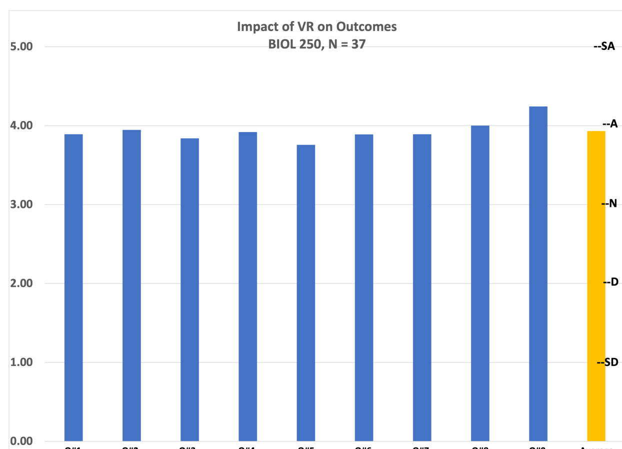


Figure 9b. Responses to VR Impact (BIOL250)

In BIOL 251, the students responded most positively to the ability to review the VR lesson in case of mistake (Q#5, effectiveness dimension, Fig. 10a).

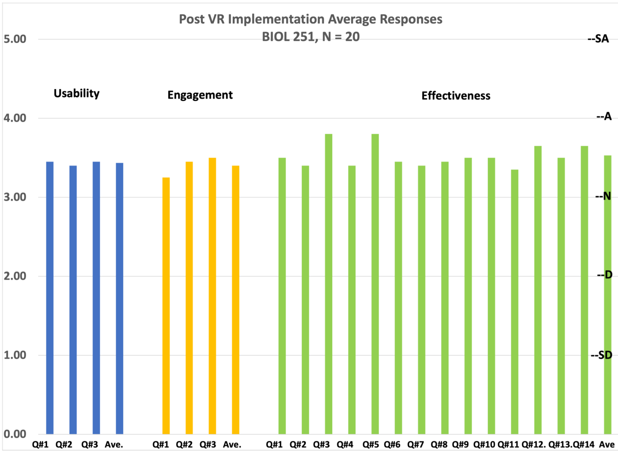


Figure 10a. Responses to VR Dimensions (BIOL251)

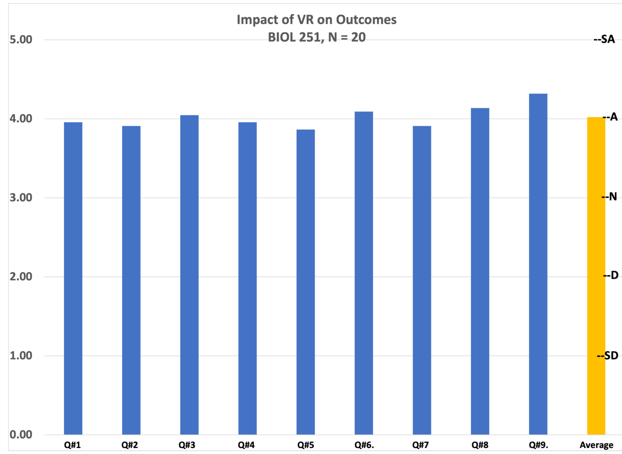


Figure 10b. Responses to impact dimensions (BIOL251)

Implementation in Electrical Engineering courses: Of all the dimensions, the responses of the EENG 323 students registered the highest average in the engagement dimension for question number 1for the statement of being actively engaged with the VR lesson (Fig. 11a). The students also indicated that they were highly satisfied with the content explanation (Q#1, effectiveness dimension, Fig. 11a) of the VR lesson. The lowest average was for the statement regarding control of learning with VR (Q#8, effectiveness dimension, Fig. 11a). Of all the questions in the impact dimensions, the average responses of the students were the highest for question number 8 which is about their interest in STEM career (Q#8, Fig. 11b) followed by question number 9 indicating their desire to complete a STEM degree (Q#9, Fig. 11b).

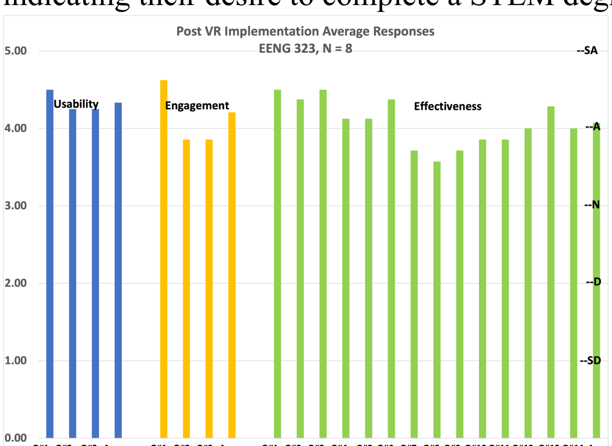


Figure 11a. Responses to VR Dimensions (EENG323)

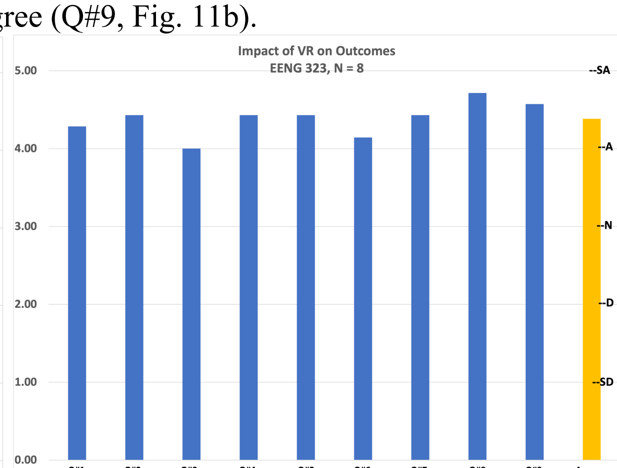
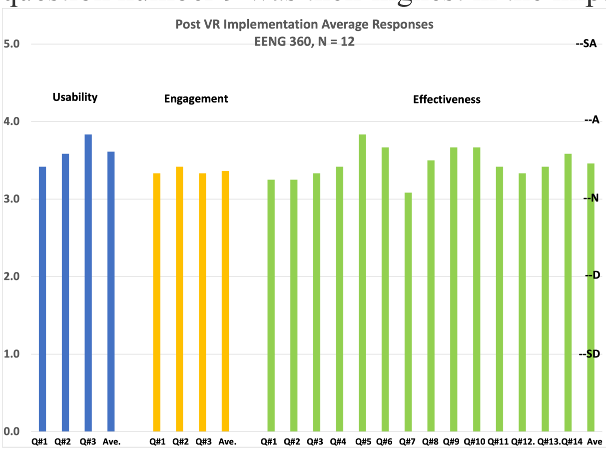


Figure 11b. Responses to VR Impact (EENG323)

The averages of the responses by students of the EENG 360 (Fig. 12a) to the questions of the usability dimension were not as high as the EENG 323 (Fig. 11a) students. The averages of responses to the items of the engagement dimension were also not as high (Fig. 12a) as the students of the EENG 323 students (Fig. 11a). The largest average in the effectiveness dimension was in response to the ability to review the lesson in case of mistakes (Q#5, Fig 8a, effectiveness dimension). The lowest average response was to the statement of sense of presence (Q#7, Fig. 12a, effectiveness dimension). As noted earlier, this was most probably because the lesson was experienced on a computer display and not in a VR headset due to COVID protocols. The students of EENG 360 indicated a lesser impact of the VR lesson on their interest in a STEM career (Q#8, Fig. 12b) in comparison to the EENG 323 students. However, they had a similar average of responses to the statement on the impact of the VR on their desire to complete a STEM degree (Q#9, Fig. 12b), and the average of responses of EENG 360 students to this question number 9 was their highest in the impact dimension.



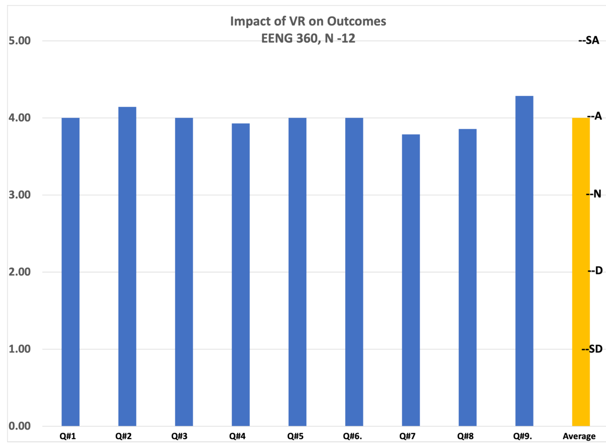
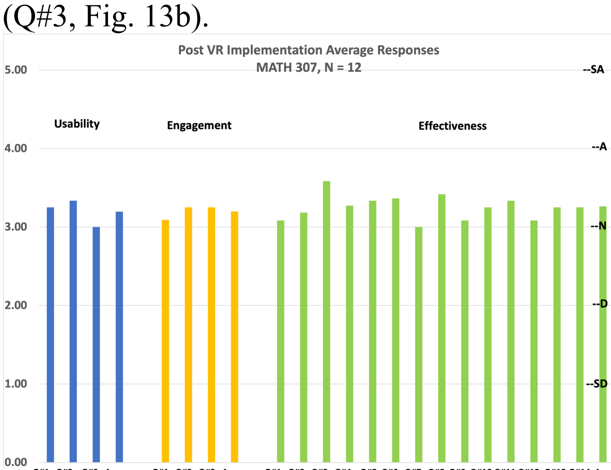


Figure 12a. Responses to VR Dimensions (EENG360) **Figure 12b. Responses to VR Impact (EENG360)**

Implementation in Mathematics course: The average responses of Math 307 students was the highest in the effectiveness dimension for the statement on effectively completing homework based on the VR lesson (Q#3, Fig. 13a). However, the average of responses to question number 7 about the sense of presence was the lowest compared to all the questions in the three dimensions. The lowest average in the usability dimension was the response to the statement on user friendliness of the interface (Q#3, usability dimension, Fig. 13a). In the engagement dimension, the lowest average was for the statement regarding active involvement with the lesson (Q#1, Fig. 13a). In the Impact dimension, the highest average was for the statement about the impact of the VR lesson on understanding the application of the concepts (Q#2, Fig. 13b). The lowest average of responses was to the statement about the impact of VR on interest in the topics of the course (Q#3, Fig. 13b).



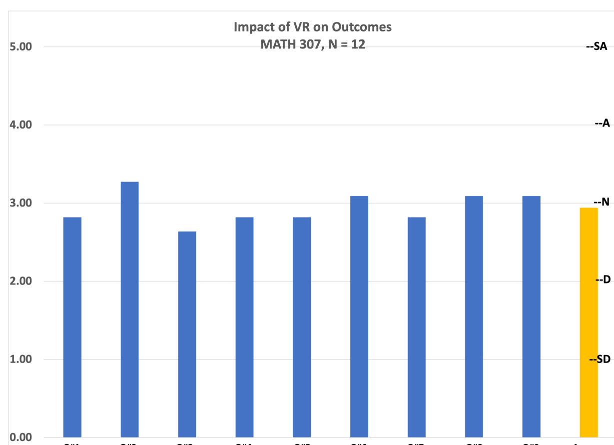


Figure 13a. Responses to VR Dimensions (MATH307) **Figure 13b. Responses to VR Impact (MATH307)**

Implementation in Physics course: Of all the dimensions, the average of the responses of the PHYS 310 students was the highest for question number 2 of the usability dimension indicating that the instructions on the use of the VR lesson were effective in exploring the lesson (Q#2, Fig. 14a). In the engagement dimension, question number 1 showing the active involvement on the students registered the highest average of the responses. The highest average in the effectiveness dimension was for the statement indicating satisfaction on how the VR lesson could be explored (Q#6, Fig. 14a). For the impact dimension, the highest average of responses was for question 9 showing their desire to complete a degree related to STEM (Q#9, Fig. 14b). The lowest average was for the impact of VR on their interest in a STEM career (Q#8, Fig. 14b).

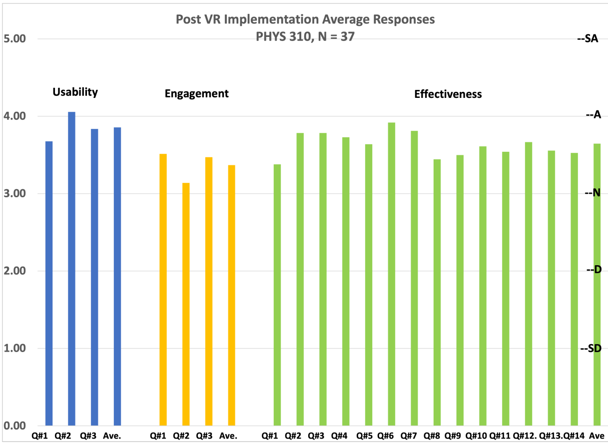


Figure 14a. Responses to VR Dimensions (PHYS310)

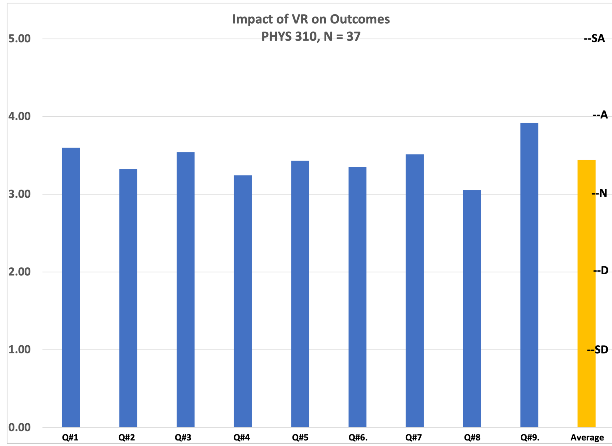


Figure 14b. Responses to VR Impact (PHYS310)

Overall, the average responses data analysis for each dimension indicated that:
(a) the VR lessons had the highest impact on students in EENG followed by the students of AENG.
(b) the students of EENG rated the usability of the VR lessons higher than the other majors.
(c) the students of EENG and PHYS had higher average than the other majors in the effectiveness dimension.
(d) the averages of MATH students in all the dimensions were lower of all the other majors.

Conclusions and Future Work

The implementation and impact of VR-based lessons for introductory undergraduate courses in engineering, mathematics, and science courses was explored at an HBCU. Selection of topics to fully utilize the advantages of VR was determined to be the most challenging aspect. Analysis of the responses to survey indicated that students were engaged with the VR-based lessons and had a positive attitude. The analyses of the data have provided the authors an informed understanding of the areas such as usability that need to be carefully re-designed to enhance the learning experience of the students. It is also expected that the next implementation of the courses which will be in Fall 2022 will use the immersive VR headsets. The use of the immersive VR headsets will potentially have a positive impact on the engagement and the effectiveness.

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Appendix A

Survey Questions

5 - Strongly Agree, 4 - Agree, 3 - Neutral, 2 - Disagree, 1 - Strongly Disagree

Usability Dimension

1. I felt comfortable exploring and interacting during the VR lesson(s).
2. The information and instructions for the VR lesson(s) helped me explore and interact effectively with the lesson(s).
3. The interface of the VR lesson(s) was/were user-friendly.

Engagement Dimension

1. I was actively involved during the VR lesson(s).
2. Using VR allowed me to be more active in the learning process.
3. Using VR helped me engage more in the learning process.

Effectiveness Dimension

1. Overall, I am satisfied with how easy it was to understand the content explained with virtual reality (VR).
2. I was able to effectively complete the activities in the VR lesson(s).
3. I was able to effectively complete the homework related to the topic(s) addressed in the VR lesson(s).
4. I believe I became more confident about the content explored in the VR lesson(s).
5. Whenever I made a mistake, I was able to review the VR lesson(s) and correct it.

6. Overall, I am satisfied with how VR was used to explore concepts covered in the lesson(s).
7. There was sense of presence (being there) while learning with VR.
8. Using VR allowed me to have more control over my learning.
9. Using VR helped make comprehension easier.
10. Using VR helped make memorization easier.
11.Using VR helped improve the application of knowledge.
12. Using VR helped provide a better overview of the content.
13. Using VR helped to identify the critical concepts from topics in the lesson(s).
14. Using VR helped in making connections among the critical concepts.

Impact Dimension
Please indicate the extent to which the use of virtual reality (VR) for topics in this class has improved each of the following
1. Your knowledge of course concepts.
2. Your understanding of how course concepts can be applied.
3. Your interest in the topics in this class.
4. Your confidence that you will understand the major concepts in this class.
5. Your motivation to learn as much as you can in this class and other related classes.
6. Your belief that the content in this class will be useful to your future career.
7. Your intent or interest in taking more classes like this one.
8. Your interest in a STEM-related career.
9. You desire to complete a degree related to STEM.