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The Impact of Immersive Virtual Reality on Undergraduate STEM Students

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The Impact of Immersive Virtual Reality on Undergraduate STEM Students

Abstract

Virtual reality (VR) holds great potential for increasing undergraduate student learning outcomes. However, its effective integration to enhance the learning process requires recognizing and leveraging the unique affordances of a VR environment. The process of development of a well-integrated virtual reality lesson requires several steps. These steps include not only aspects of traditional instructional design but also include identification of content appropriate for utilizing the unique characteristics of VR, user interface and user experience. This paper provides details of an exploratory study of the integration of VR lessons in aerospace engineering, biology, math, and physics introductory level courses at an HBCU. The paper includes information about the software and hardware choices, and the process of development of the lessons. Data was collected to measure usability, effectiveness, engagement, and impact of the lessons. Students reported that the VR lessons were engaging and helped them getting a better overview of the content. A comparison between the student responses to implementation in a non-immersive (computer display) and immersive (with VR headsets) environment is also included.

Introduction

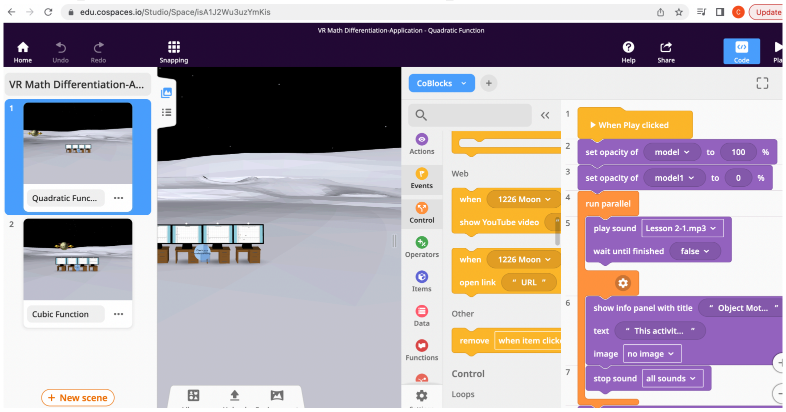
A learning environment that engages students cognitively, affectively, and behaviorally is an essential component of the larger engagement that include elements such as sense of belonging, and institutional support [1]. Cognitive engagement supports deeper understanding of the learning materials, affective engagement encourages students to be vested in their learning, and behavioral engagement fosters an environment of on-task behavior conducive to learning. The relationship between engagement and various markers of academic success and learning has been empirically studied extensively and found to be positively correlated [1] - [6]. Active learning has been reported as an effective pedagogy for cognitive engagement [7], [8]. Student motivation is closely linked with engagement [9], [10] which in turn impacts learning. It was observed by Schunk [11] that motivation and students' perception of progress and learning are correlated. Active learning which encourages cognitive engagement has been shown to impact student motivation [12].

The availability of affordable virtual reality (VR) hardware and software has burgeoned its use in multiple domains such as the entertainment industry, skills training and more recently in the classroom [13]. The affordances of a VR are unique. It allows a sense of presence in an environment that is physically not present, provides opportunity to interact and manipulate objects thus developing an understanding of spatial and functional relationships between objects and concepts which may not be possible in the physical world. This rapid increase in VR-based learning is being studied extensively to understand its impact on student learning [14] – [18]. However, there are multiple challenges associated with effectively integrating VR in a learning environment. Designing a VR-based learning environment is a complex problem along the spectrum of learning environments that ranges from a physical white board-based learning to PowerPoint to digital smart boards. The integration of digital smart boards and e-learning require the understanding of instructional design as now suddenly there is access to a large amount of information that needs to be presented to the learners in a logical and engaging manner. The success of a software solution or an App depends on its ease of use, hence the emphasis on user experience (UX) and user interface (UI) in the design process [19], [20]. Thus, designing a VR-based lesson requires an understanding of instructional design that includes a UI and UX in a three-dimensional space to make the learning an engaging experience [21].

This paper is based on the results of a study to design and implement VR-based lessons in several introductory level STEM courses. The objective of the study is to assess the impact of VR-based lessons on student engagement and understand the challenges of the design and implementation.

Method

The VR-based lessons were developed by the faculty in math, aerospace engineering, biology, and physics. The faculty were assisted by undergraduate research assistants (URA). The lessons were based on concepts selected through discussions with the URAs who had taken the courses in the past and so they suggested the topics that were challenging and/or needed review more than once. The faculty selected the concepts that were amenable to implementation in a VR environment. The interactivity, presence, and animation in the developed VR lessons were achieved through the coding environment using Cospaces software (Fig. 1) [22]. Each lesson is strategically broken down into numerous successive animated scenes (Fig. 2, Fig.3) that are designed to gradually build students' comprehension of the targeted STEM concept. The lessons also include some questions for students to test their understanding.



```
▶ When Play clicked
set opacity of model to 100 %
set opacity of model1 to 0 %
run parallel
    play sound Lesson 2-1.mp3
    wait until finished false
    show info panel with title " Object Mot... "
    text " This activit... "
    image no image
    stop sound all sounds
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when 1226 Moon
show YouTube video
when 1226 Moon
open link " URL "
remove when item click
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Figure 1: Development of a VR Lesson using Cospaces

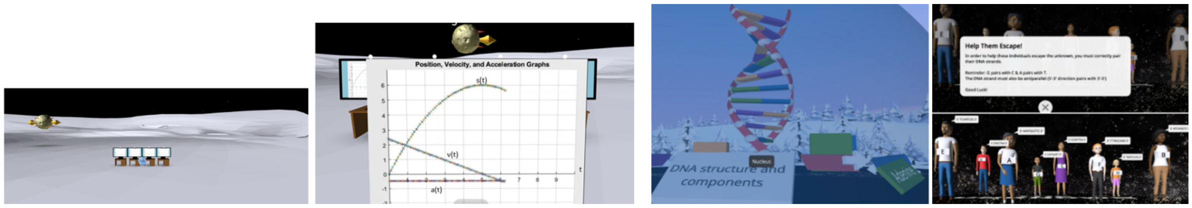

Figure 2: Math Differentiation Application and Biology DNA VR Lessons

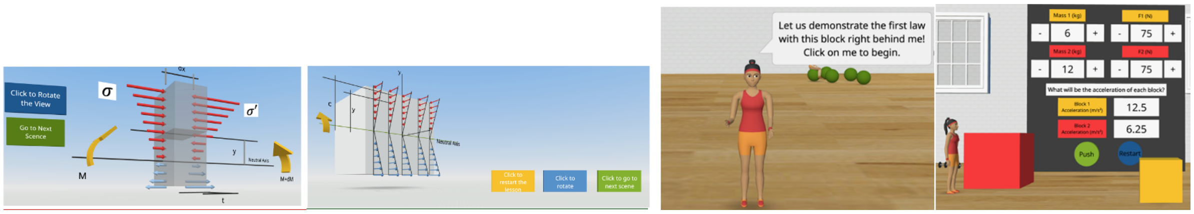

Figure 3: Aerospace Engineering Beam Bending and Physics Newton's Law VR Lessons

The high degree of complexity of each lesson required between approximately 25 - 40 hours of effort and time commitment in their development. The titles of the VR lessons and corresponding courses are given in Table I. A link to a sample lesson for each of the four majors is also provided in Table I.

Table I: Courses and VR-based lesson topics

Courses	Lessons / Link
Aerospace Engineering: Introduction to Aerospace Engineering; Intro to Aerospace Engineering Lab; Aerospace Structures-I; Aerodynamics-I	Flight control surfaces, Isometric and orthographic views, Bending stresses, Shear stresses, Potential flows https://edu.cospaces.io/DTB-FGM
Biology: Molecular Cell and Genetic Biology, Molecular Cell and Genetic Biology Lab, Cell And Genetic Biology, Genetics	DNA Structure, Cell signaling, Fusion gene, Genetic engineering, Protein translation, Chromosome Abbreviation https://edu.cospaces.io/EGL-HZY
Math: Pre-Calculus and Algebra, Pre-Calculus and Trigonometry, Calculus I, Differential Equations	Vectors, Graph transformations, Riemann Sum Application, Laplace Transform, 2nd order ODE application - car suspension, Math Differentiation-Application https://edu.cospaces.io/KYG-SAB
Physics: Elementary General Physics, General Physics Lab, Intro/Lab Work-Phys, Physics I Lab	Projectile Motion, Work and Energy, Inclined Plane, Free fall and constant acceleration, Momentum and collisions, Momentum and collisions, Newton's laws of motion https://edu.cospaces.io/VUQ-XYE

The classroom lesson implementation comprised of two modes. The first mode used a computer monitor in virtual classrooms which was necessitated by the Covid-19 protocols. The second mode was the use of immersive ClassVR [23] headsets (goggles) in face-to-face classrooms when the campus was reopened after Covid-19.

A validated survey instrument was used to measure the participants attitudes after experiencing the VR-based lessons (Appendix A). This survey instrument measured four dimensions: usability (3 items), engagement (3 items), effectiveness (14 items), and impact (9 items). The survey responses were based on a 5-point Likert scale, strongly agree (SA), agree (A), neutral (N), disagree (D), and strongly disagree (SD).

The participants of the study were undergraduate students enrolled in introductory level aerospace engineering, biology, math, and physics courses at an HBCU. A total of N =1340 students (aerospace, N = 270; biology, N = 240; math, N = 290; and physics, N = 540) were enrolled in the various courses in which VR-based lessons were implemented.

Results

A total of 854 students out of 1340 fully completed the survey. The average responses for all the 854 students who experienced the VR-based lessons are shown in Fig. 4. It was observed that the averages of the responses in all the dimensions were higher than 3 (Fig. 4a, 4b), indicating a tendency toward agreeing with the items of the survey. The aerospace students (Fig. 4a) had the highest averages for the usability, engagement, and effectiveness dimensions. The average of the responses of the biology students was the highest for the impact dimension (Fig. 4b). The lowest average for all majors was for item Q7 of effectiveness which was about the sense of presence (Fig. 4a). This was expected as a majority of the participants experienced the lessons in a non-immersive (computer display) environment due to Covid-19 protocols. The lowest average in the impact dimension was for Q3 for the students experiencing the math lessons. This could be attributed to the fact that it pertained to interest in the subject and since the majority of the math students were in pre-calculus algebra and pre-calculus trigonometry, such a response is typical.

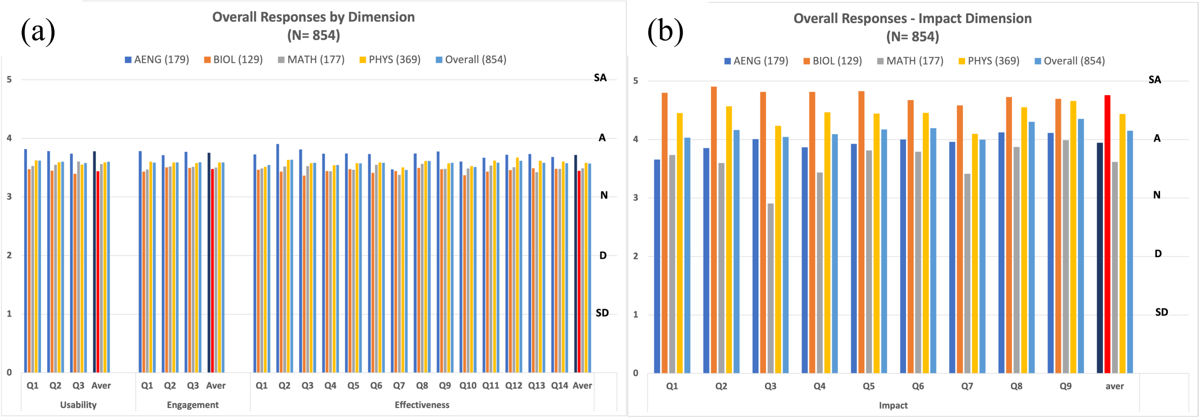

Figure 4a, 4b. Responses of all students

The overall percentage averages of all majors for all dimensions (usability, engagement, effectiveness, and impact) were about 60% strongly agree (SA) and agree (A) (Fig 4c, 4d). Of all the majors, the aerospace students had the highest percentage (70%) of responses in the SA and A category for the usability dimension (Fig. 4c). This indicates that the aerospace students felt comfortable in exploring the lessons and the instructions were easy to follow. The averages of aerospace students' SA and A responses were also the highest in the engagement and effectiveness dimensions, and slightly higher than Biology in the impact dimension.

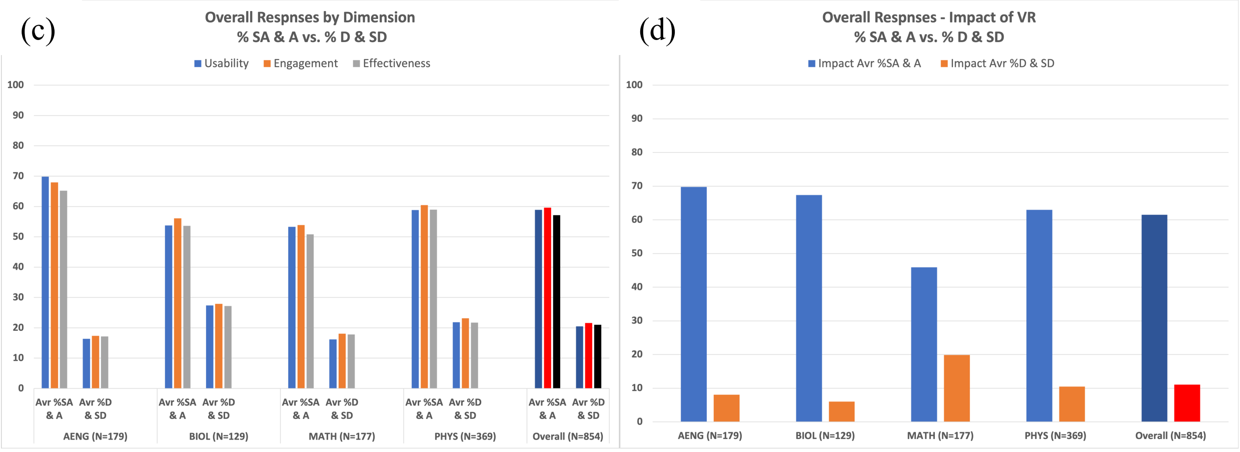

Figure 4c, 4d. Responses of all students

Implementation in Aerospace Engineering courses:

The responses of the aerospace students (N = 179) are shown in Fig. 5a and Fig. 5b. The percent responses of SA and A were compared with the SD and D. It was observed that about 70% of the responses were SA and A, while less than 20% of the responses were SD and D. The lowest percentage of responses strongly agreeing and agreeing with the items of the survey were for Q7 of the Effectiveness dimension which as pointed out previously pertained to the sense of presence.

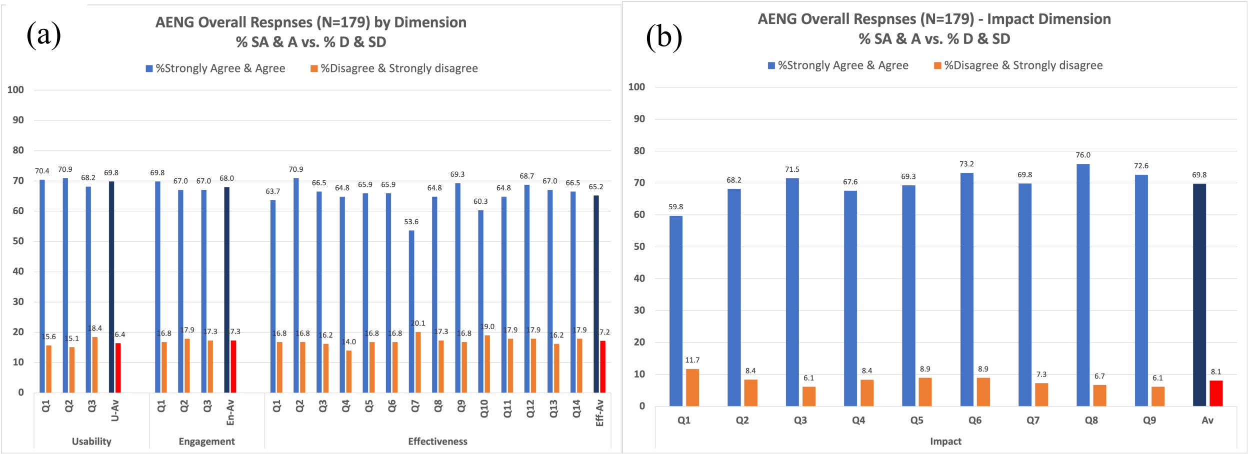

Figure 5. % Responses of aerospace engineering students

The responses of the students who experienced the lessons in a non-immersive environment i.e., on a computer monitor (during Covid-19) were compared to the responses of students who experienced the lessons in an immersive environment (Fig. 6a, 6b) using VR headsets. For students who experienced the lessons using VR headsets, the averages of the responses in all the dimensions were four or higher indicating a trend towards strong agreement with the items of the survey and were higher than the averages for the students who experienced the lessons in a non-immersive environment. The response to Q2 of the engagement dimension indicated that the use of VR goggles (immersive environment) increased active involvement in the learning process. The responses to Q7 clearly showed the impact of the immersive environment on the sense of presence.

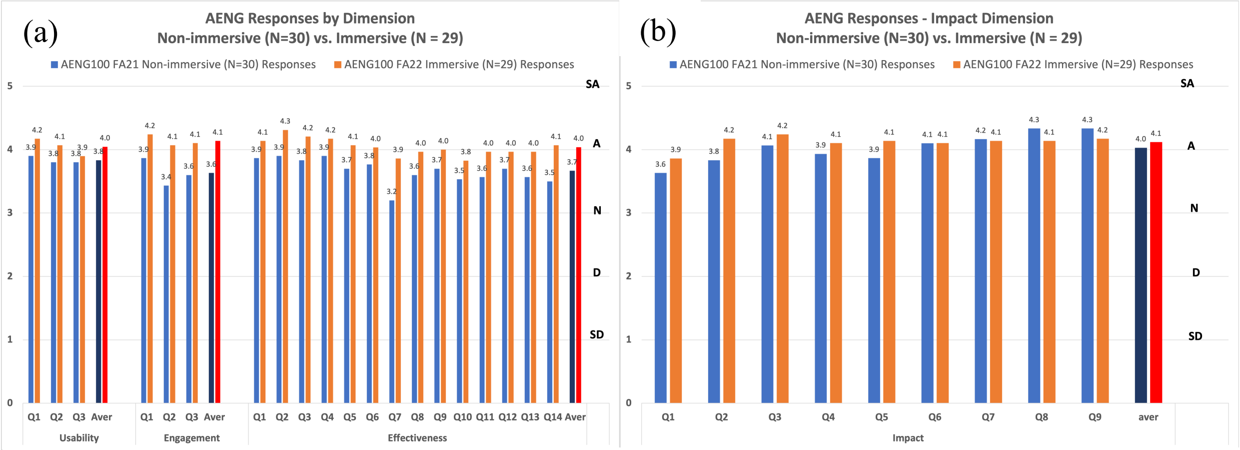

Figure 6. Comparison of responses of aerospace engineering students for immersive and non-immersive experience

The percent responses strongly agreeing (SA) and agreeing (A) with the items on the survey and the percent of responses strongly disagreeing (SD) and disagreeing (D) are given in Fig 7a, 7b. It was observed that the percent responses that strongly agreed or agreed with the items on the survey were higher for the immersive experience as compared to the non-immersive experience. The effect of the immersive environment was clearly seen in the average responses to Q7 of the effectiveness dimension, which was about the sense of presence, however the average was still the lowest as compared to other questions indicating the need for improving the lessons to be more immersive.

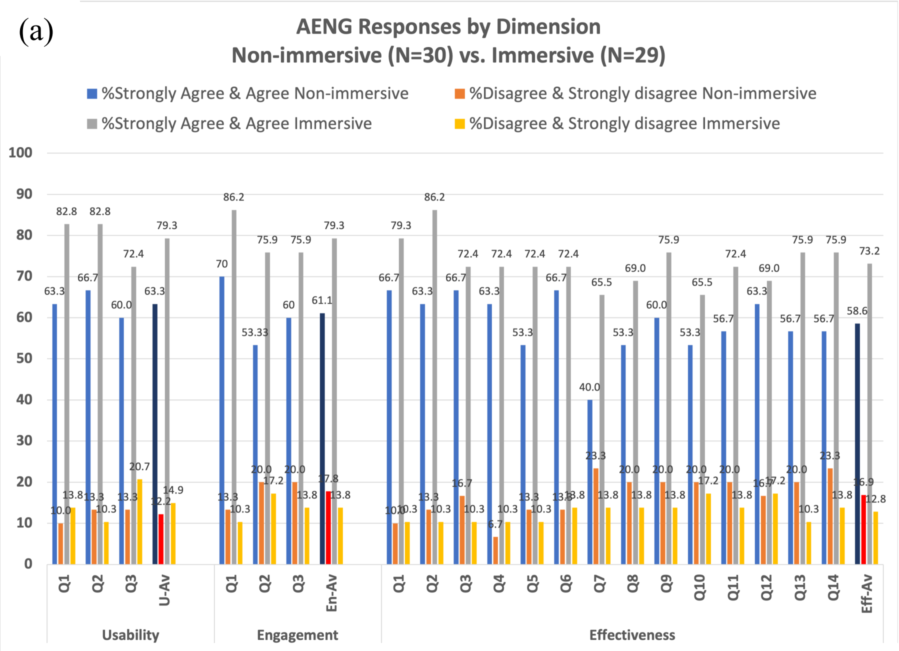

Figure 7a. Comparison of % SA & A and % SD & D responses of aerospace engineering students for immersive and non-immersive experience

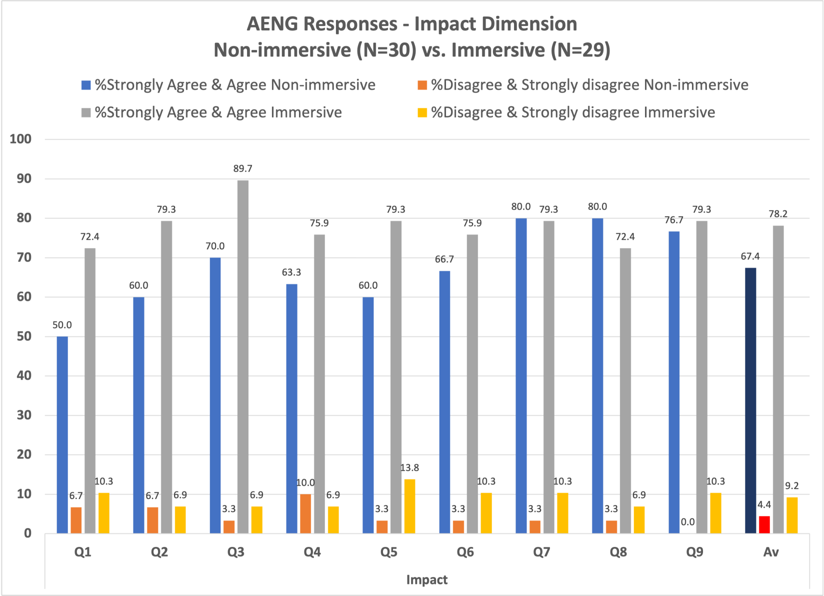

Figure 7b. Comparison of % SA & A and % SD & D responses of aerospace engineering students for immersive and non-immersive experience

Implementation in Biology courses:

The average responses for all the biology students are shown in Fig. 8a and Fig 8b. It was noted that only about 55% of the students responded SA and A to the items of the survey for the usability, engagement, and effectiveness dimensions, while about 27% of the responses were in the SD and D category. The highest percentage of SA and A responses was for Q2 of the Engagement dimension which pertains to being active in the learning process. The lowest percentage of SA and A responses was for Q3 of the Effectiveness dimension which pertains to effective completion of homework based on the concept of the VR lessons. The percentage of strong agreement or agreement was higher (67%) for the impact dimension. The percentage of strong disagreement or disagreement was also much lower at only 6%. This indicated that a large percentage (27%) of responses for the impact dimension were neutral.

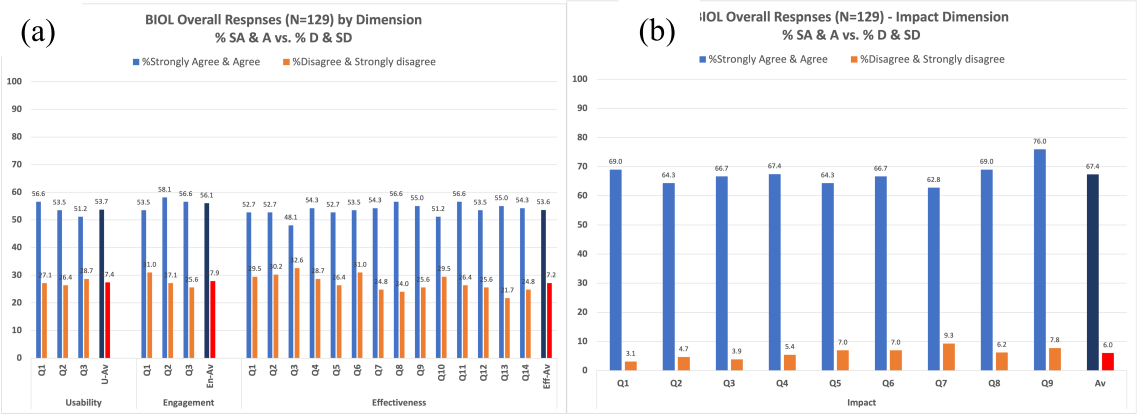

Figure 8. % Responses of biology students

The responses of the students who experienced the lessons in a non-immersive environment i.e., on a computer monitor (during Covid-19) were compared to the responses of students who experienced the lessons in an immersive environment using VR headsets (Fig. 9a, 9b). For students who experienced the lessons using VR headsets, the averages of the responses in all the dimensions were 4 or higher indicating a trend towards strong agreement with the items of the survey for the usability, engagement, and effectiveness dimensions whereas the responses of the students who experienced the lessons in a non-immersive environment was around 3 (neutral). Interestingly, the difference between the averages for the two modes of implementation for the impact dimension was not much and was close to strongly agreeing with the items of the survey.

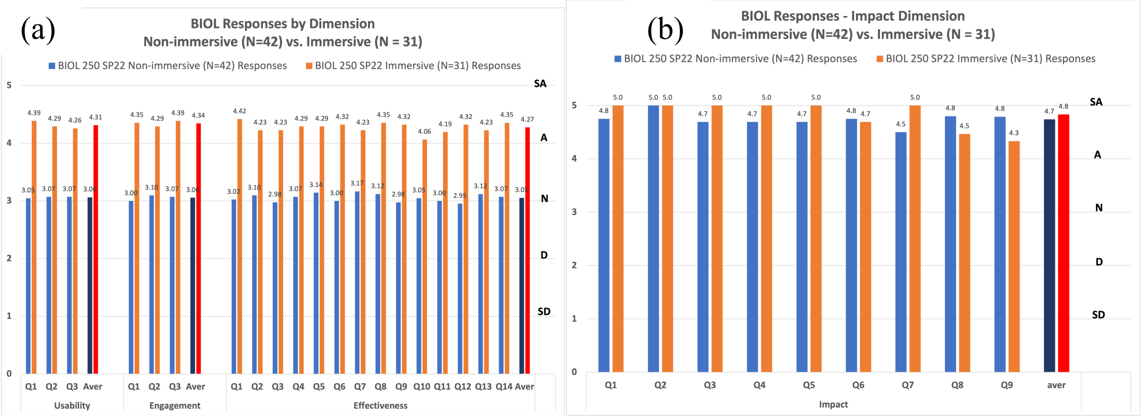

Figure 9. Comparison of responses of biology students for immersive and non-immersive experience

The responses to the immersive and non-immersive implementation modes were analyzed based on the percentage responses strongly agreeing and agreeing to the items of the survey, and strongly disagreeing and disagreeing (Fig. 10a, 10b). The positive effect of the use of VR headsets is clear from the data of the Fig. 10. The highest percentage was for Q7 of the Effectiveness dimension signifying impact of the VR-googles on the sense of presence. The percentage responses SA and A in the immersive environment were about 80% for the usability, engagement, and effectiveness dimensions. In the non-immersive environment, the percentage responses SA and A were around 40% for the usability, engagement, and effectiveness dimension while the percentage of SD and D was about 35%.

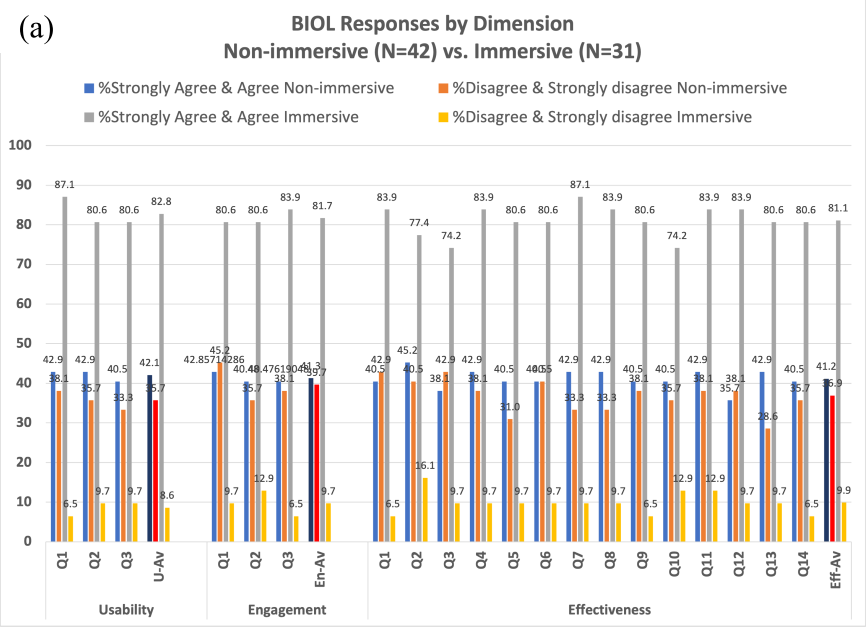

Figure 10a. Comparison of % SA & A and % SD & D responses of biology students for immersive and non-immersive experience

It is clear from the data that the use of the VR lessons in the immersive environment had a positive impact on biology students in all three dimensions of usability, engagement, and effectiveness. For the impact dimension, the percentage of SA and A was 70% and 63% for the immersive and non-immersive environment respectively.

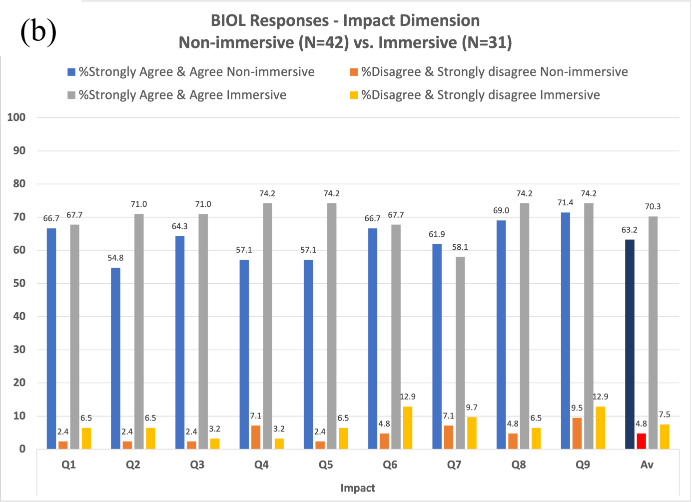

Figure 10b. Comparison of % SA & A and % SD & D responses of biology students for immersive and non-immersive experience

Implementation in Math courses: The averages of the responses to the survey of the students enrolled in the math classes are given in Fig. 11a, 11b. Over 50% responses were in the SA and A category, whereas less than 20% were in the SD or D category for survey items for the usability, engagement, and effectiveness dimensions. This indicated that almost 30% of the responses were neutral. The percentage average for the responses to the impact dimension was about 45% for SA and A, while the percentage for SD and D was 20%, again indicating that about 35% of the responses being neutral. The highest percentage was for Q8 of the Impact dimension which related to the impact of the VR-lessons on interest in STEM-related career.

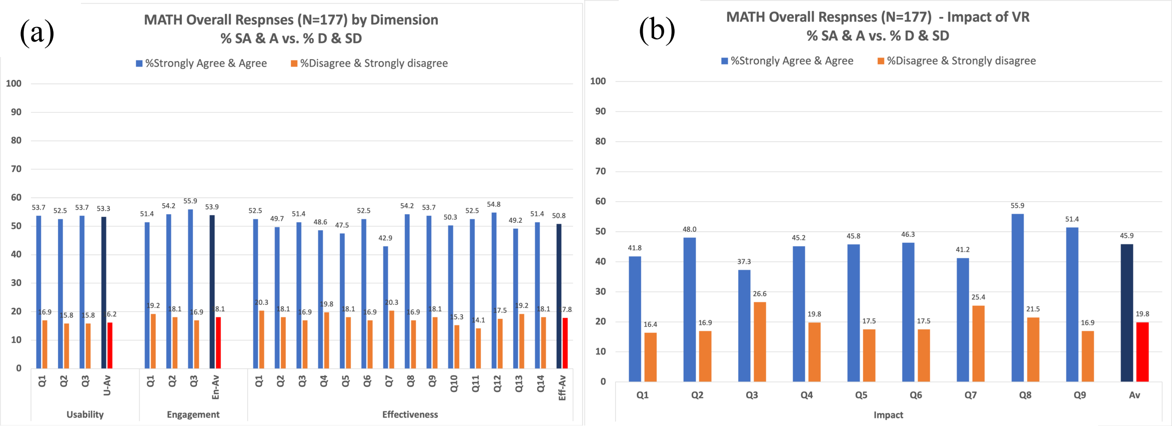

Figure 11. Comparison of % SA & A and % SD & D responses of math students

A comparison of the student responses experiencing the VR-based lessons in a non-immersive and immersive environment is shown in Fig. 12 and Fig. 13. It was observed that there was not much difference in the usability, engagement, and effectiveness dimensions between the averages of students who experienced immersive and non-immersive lessons. The largest difference in the average was for Q12 which pertained to providing a better overview of the content. The average of the responses to the impact dimension of the students experiencing the immersive modality was 4.7, very close to strong agreement and the average for the non-immersive modality was 2.9 that is neutral. All the students strongly agreed (5) to the statements of Q1, Q2, and Q4 of the Impact dimension which pertain to improvement in knowledge of concepts, application of concepts and confidence in understanding the concepts. This indicated that the immersive environment had a large influence on the impact dimension.

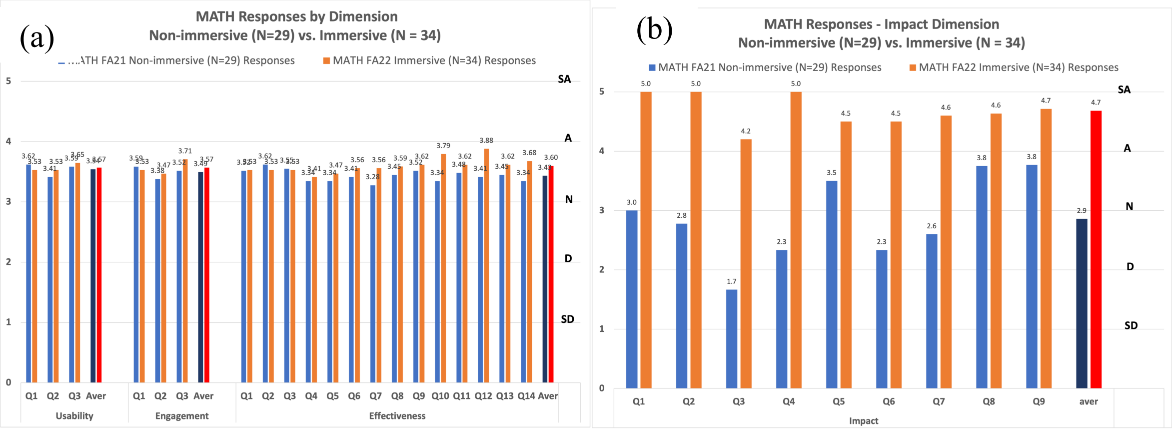

Figure 12. Comparison responses of math students for immersive and non-immersive

The average percentage responses to SA and A, and SD and D are given in Fig. 13 for the immersive and non-immersive environments. There was only a 10% difference between the responses of students in the non-immersive environment as compared to the immersive environment for the engagement and effectiveness dimensions and 20% difference for the impact dimension with the immersive environment averages being higher however less than 60%. Almost 70% of students strongly agreed or agreed that the immersive VR lesson provided a better overview of the content (Q12). For the non-immersive environment, the percentage of SD and D responses was higher than the percentage of SA and A for Q7 of the Impact dimension which asked about the interest or intent in taking more classes with the VR. However, for the same question (Q7), the percentage of SA and A is much higher than the percentage of SD and D for the immersive environment showing that students' interest or intent in taking more classes with the VR is increased in the immersive environment.

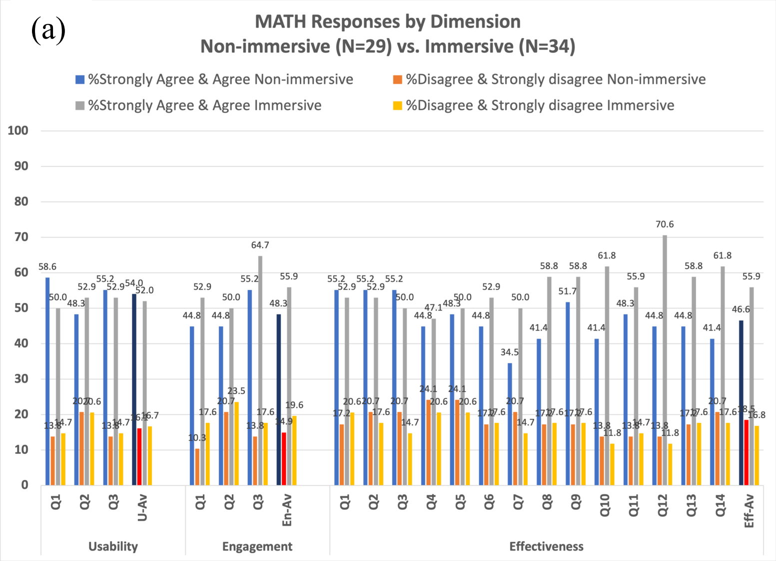

Figure 13a. Comparison of % SA & A and % SD & D Responses of math students for immersive and non-immersive experience

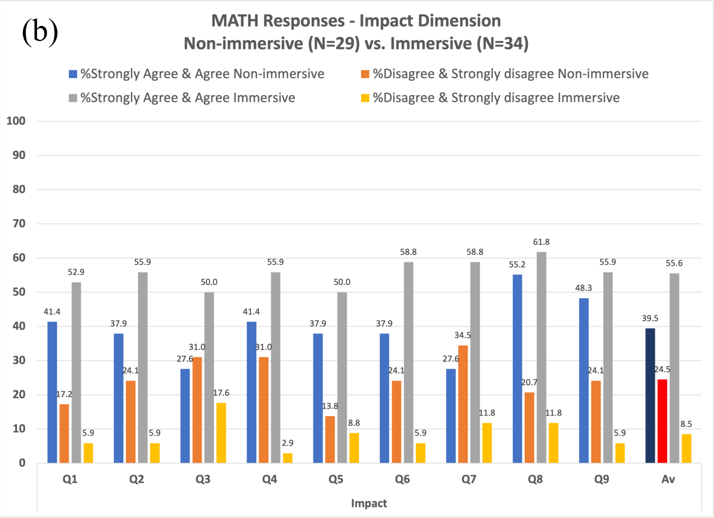

Figure 13b. Comparison of % SA & A and % SD & D responses of math students for immersive and non-immersive experience

Implementation in Physics courses: The responses of students enrolled in the physics classes who experienced the VR-based lessons are shown in Fig. 14. The averages of percent responses SA and A with the survey items for all the dimensions were about 60%. The averages percent responses SD and D were 20% for the usability, engagement, and effectiveness dimensions while for the impact dimension the average was only 10%.

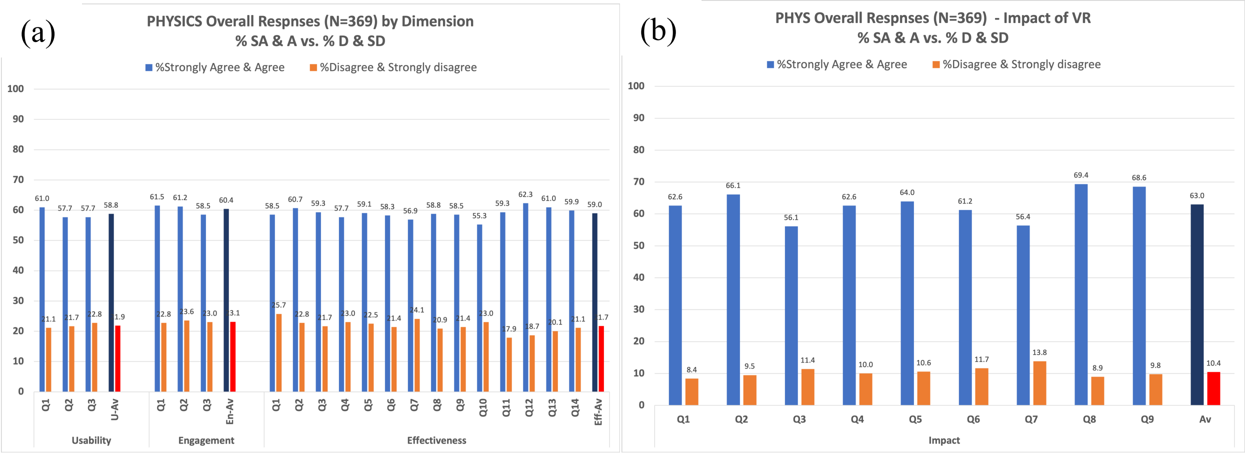

Figure14. Comparison of % SA & A and % SD & D responses of physics students

The comparison of responses for the immersive and non-immersive implementation is given in Fig. 15. The averages of the responses in all dimensions for the immersive experience were higher than for the non-immersive experience. For the usability, engagement, and effective dimensions, the averages tended towards agreement for both the immersive and non-immersive experiences. For the impact dimension, the average tended towards strongly agree for the immersive environment whereas for the non-immersive the average was towards agreement.

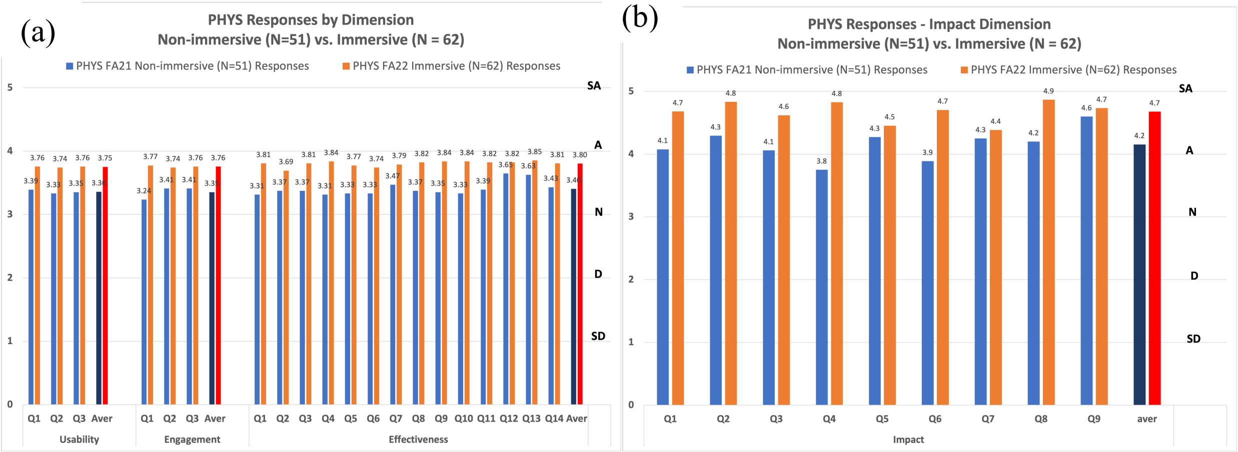

Figure 15. Comparison responses of physics students for immersive and non-immersive experience

The percentage of SA and A, and SD and D responses of students who experienced the VR-based lessons in an immersive environment were compared with the responses of students who experienced the lessons in a non-immersive environment (Fig. 16). The average of the percentages of strongly agreeing and agreeing for all the four dimensions of the immersive environment was 70%. For the non-immersive environment, the averages for SA and A were around 50% for the usability, engagement, and effective dimensions and 60% for the impact dimension. This shows that the averages of the immersive environment were about 20% SA and A higher than the averages of the non-immersive for all the three dimensions and 10% higher for the impact dimension. The item Q6 of the Effectiveness dimension which pertains to the use of VR to explore the concepts had the lowest percentage. In the Usability dimension, Q2 had the lowest percentage of SA and A responses which queried the ease of exploring and interacting with the VR lessons in the immersive environment. For the impact dimension (Fig. 16b), Q8 and Q9 had the highest percentage of SA and A responses which pertained to interest in STEM-related careers and STEM-related degree.

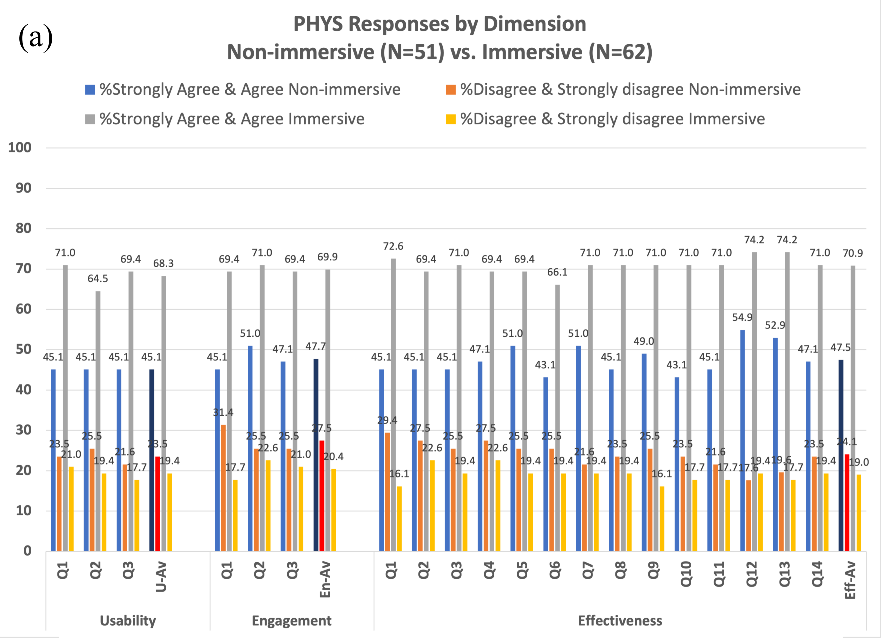

Figure 16a. Comparison of % SA & A and % SD & D responses of physics students for the immersive and non-immersive experience

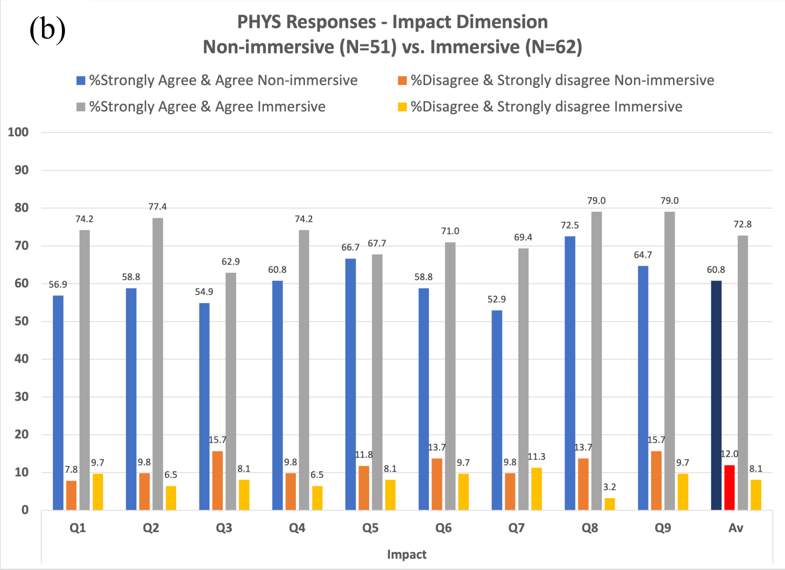

Figure 16b. Comparison of % SA & A and % SD & D responses of physics students for the immersive and non-immersive experience

Conclusions and Future Work

The implementation of VR-based lessons in introductory aerospace engineering, biology, math, and physics provided useful insight into the pedagogical opportunities and challenges. The comparative analysis of data clearly indicated the advantage of immersive over non-immersive learning environments in all disciplines where the VR lessons were implemented. The largest impact of the immersive environment was in aerospace engineering followed by biology. It was also clear from the data that the use of immersive math VR lessons registered the largest increase in the Impact dimension compared to the non-immersive implementation. In other words, the immersive math VR lessons had a large positive impact on improving knowledge, application, and confidence in understanding the concepts.

In view of the results of the study, the lessons will be redesigned to enhance the sense of presence. The lessons will also be improved for delivery via the VR headsets for a better user interface and user experience.

Acknowledgements

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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.