Impact of a VR/AR Module on First-Year Students' Understanding of Architectural Engineering: A Comparison Across Demographics

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Abstract

Architectural Engineering (AE) programs typically offer programs of study in at least two subdisciplines that relate to building design and construction. AE students may struggle to select a subdiscipline due to their low exposure and engagement with topics that would inform their decision. Previous research indicates that the immersive nature of virtual and augmented reality (VR/AR) can increase students' engagement and motivation regarding course content and discipline decisions. The purpose of this study was to investigate the impact of a pilot browser-based virtual reality intervention on first-year AE students' understanding of the AE subdisciplines and choice for future study, with particular attention to demographic subgroup differences. This pilot was a testbed for a larger set of Virtual/Augmented-Reality-Based Discipline Exploration Rotations (VADERs), which are instructional modules that engage students in authentic AE tasks. In Fall 2020, the pilot VADER-1 module was incorporated into first-year AE courses at one R1 university and one R2 historically black university. This module encouraged students to explore AE subdisciplines through the virtual design of a clinic. Pre-post intervention surveys were used to investigate change in students' understanding of AE and its subdisciplines. Students reported that their subdiscipline understanding increased significantly. Further, 74% of students reported an increase in their confidence in their choice, and over 30% of students changed their top subdiscipline choice. Some slight differences between demographic subgroups were found. VR/AR interventions hold promise for providing AE students with needed exposure to the practice of the discipline and its subdisciplines.

I. Introduction

Engineers provide vital services that stimulate the economy, assist large corporations, and carry out national interests [1]. As such, it is only natural that engineers are consistently in high demand. However, in recent years, this demand has been greater than the supply presenting the field of engineering with a major issue. Insufficient numbers of students are graduating from engineering programs to properly supply the workforce with enough engineers to meet the industry's need [2]. Engineers help support and advance local communities and the national economy, so every unfilled engineering position is a lost asset on a local, business, and national level [2]. This problem has left educators searching for ways to increase the number of engineers who complete their degree and enter the workforce each year.

This issue could be reduced by decreasing student attrition from engineering programs. Currently, nearly half of students who begin an undergraduate degree in engineering either choose a non-engineering major or drop out before graduation [2]. Attrition from engineering has been attributed to many factors, including the individualistic culture in engineering programs, difficult concepts, threat of low grades, lack of self-confidence, lack of high-school preparation, race/gender, interest/career goal differences, and poor teaching and advising [2]. This study focused on addressing the issues of students' interests and career goals.

The purpose of this study was to provide first-year engineering students with an interactive and immersive introduction to the different Architectural Engineering (AE) subdisciplines and to give them a concrete image of engineering work in the field. A Virtual Reality (VR) and Augmented Reality (AR) module was implemented in a first-year Introduction to Architectural Engineering courses to increase student motivation and engagement. It was hypothesized that the module would increase students' interest in course content through the interactive and immersive nature of VR and AR. This VR/AR enabled level of engagement was meant to help students make informed decisions regarding their AE sub-focus or future career, which could potentially lower the student attrition rate and increase the number of engineers entering the workforce. The analysis of this study's results focused primarily on the impact of a VR/AR module on student sub-focus understanding and choices, including differences across demographics.

II. Background

A. Social Cognitive Career Theory (SCCT)

This study is based on the principles of Social Cognitive Career Theory (SCCT). SCCT contains one explanation regarding people's career-related interests, choices, and performance through three interwoven variables: self-efficacy, outcome expectations, and goals [3], [4]. Self-efficacy is one's perception of their ability to complete certain tasks through learned or innate behaviors. Outcome expectations refer to the prospective results, positive or negative, that one may derive from completing those tasks [5]. Career interests are typically very fluid through adolescence but may still shift later in life. People typically form career interests around things with which they feel competent (self-efficacy) and things from which they can expect good outcomes (outcome expectations). Career choices typically stem from a combination of interests and goals, but they may be more directly influenced by the surrounding environment or circumstances, such as a desire to live in a certain place or get paid a certain amount [4].

Regarding this study, AE educators hoped to enhance first-year engineering students' interest in engineering, particularly in AE, and prepare students for future academic and career choices through VR/AR-based experiences. The VADER-1 intervention was designed to increase students' feelings of self-efficacy and generate positive outcome expectations through authentic AE subdiscipline tasks. Through SCCT, it can be reasoned that self-efficacy and outcome expectation improvements should make students feel more confident in their subdiscipline choice and pathway to graduation.

B. The Role of Introductory Courses

Academic professors should strive to educate in such a way that they give students confidence in their ability to fulfill engineering responsibilities in the workforce [5]. However, it seems that students may not even understand the careers in which they will be expected to participate [2]. Educators may attempt to provide more information about the nature of careers in their courses, but if the format of delivery does not actively engage students, many students will not pay attention. Lack of engagement leads to a reduced retention of knowledge that should be gained from classes, but the issue can be especially prevalent and detrimental in major-specific introductory courses [6]. Nearly all universities have some form of introductory courses, provided at either a large scale for entire colleges or departments or at a smaller scale for individual majors. These courses are designed to help students gain confidence in their future path in engineering, partially by explaining the different disciplines or subdisciplines available for students to pursue.

While extremely beneficial in concept, many courses are solely composed of lectures without much engagement, which makes student motivation a large issue [6]. Additionally, many students feel less stressed about the grade that they will receive in an introductory class when compared to standard engineering courses [6]. The lack of engagement and lower amounts of stress that accompany introductory courses can cause many students to gain less from or even disregard introduction courses. Yet, these courses are useful tools in students' early undergraduate education because they allow students to learn about future careers and academic pathway.

As previously discussed, the purpose of this study was to engage students in the work of the different subdisciplines present in the AE major to decrease attrition from engineering. There have been successful studies in the past correlating increased student exposure to disciplines and subdisciplines with student retention in engineering, particularly among women and minorities. For example, one study of an introductory course allowed students to participate in a laboratory section instead of the lecture section. Students who opted to take the lab section, which had a much greater level of involvement and engagement, were retained at a significantly higher n rate after three years when compared to students who were in the lecture section. Furthermore, the retention of women and minorities was raised to the same level as the general population, which was not seen prior to the lab section introduction [6]. Knowing this, it is possible to conclude that student engagement in these introductory courses is correlated to retention in their program. However, entirely separate lab sections are difficult to implement, especially since the instructor time commitment is considerably more than a lecture-based course. Thus, it is necessary to experiment with other methods of engaging students.

C. VR/AR

VR and AR are technologies that have the potential to engage participants in nearly limitless activities. Casual VR/AR systems users can play games, watch media in a new way, or enliven social events. Job trainees can virtually learn to handle dangerous chemicals or expensive equipment in a safe and cheap manner. Students can use VR/AR systems to visualize complex course content and concepts [7]. Educators can use VR/AR systems as active-learning tools to increase the motivation, engagement, performance, and spatial reasoning skills of their students [8]. A greater retention of information can largely be attributed to the immersive nature of VR/AR experiences. Some systems are even able to incorporate many of the senses, not just visual and auditory, which can further increase immersion [7]. One of the beliefs of SCCT is that learning experiences shape self-efficacy and outcome expectations [4]. VR/AR as a learning experience has the potential to improve both self-efficacy and outcome expectations through its immersive and engaging nature.

VR/AR technologies seem promising for current education systems. Currently, the demand for virtual/remote skills and technology is high in both the education system and in the workforce [8]. Research into the implementation of VR/AR tools in academic settings could make the learning process more engaging and representative of work settings.

Sadly, there do seem to be issues facing VR/AR use in schools. One valid concern with using VR/AR systems is the additional time that it takes students to familiarize themselves with the program being used, which can be time spent on course content in lectures or doing extra assignments on paper. Another potential issue is the desire of students to "play" with the educational technology due to its apparent novelty [7]. Both issues could be minimized, if not irrelevant, if VR/AR is adopted widely across courses since the novelty would diminish and students would begin successive courses already familiar with the technology.

Two other issues faced by educators wishing to implement quintessential VR/AR interactions in classrooms are student access issues and the equipment costs associated with compatible goggles. To combat these issues, educators can use less equipment-intensive VR/AR interventions, such as web-based programs. Research has suggested that the level of immersion in VR/AR experiences beyond a moderate level may be inconsequential for learning purposes [8]. This means that educators and institutions may not need to purchase expensive technology to see the results of VR/AR-assisted education. In the present study, a web-based VR/AR experience was created to ensure high accessibility and low cost.

D. Diversity and VR/AR

A persistent issue facing STEM fields is underrepresentation of women and minorities [9]. While many studies have been conducted to identify and understand this problem, environmental factors may be especially impactful to the retention of women and minorities in STEM fields [10], [11], [12]. Through the use of VR/AR, the unwelcoming environment that some underrepresented populations may perceive could be decreased by replacing white- and male-dominated environments with virtual learning environments that better express the wide range of cultural and gender diversity [13].

Mohammadi [14] provided one example of a successful VR/AR integration into a learning experience. In this study, virtual education techniques were used for workforce development in STEM fields. These virtual learning experiences, when coupled with traditional online instruction, improved retention of information for most participants. Interestingly, even greater improvement was seen in older adults, ethnic minorities, and women when compared to their demographic subgroup counterparts [14].

VR/AR learning techniques have the potential to mitigate many of the issues that women and minorities face in the classroom. For example, a virtual environment can better guarantee equal access to a professor's time and attention [13]. These environments can also expose students to professional engineers or mentors that have the same cultural or gender identity as them [15]. Such exposure can help develop students' engineering identity while maintaining their cultural and gender identity [12].

III. Research Questions

The research questions that guided this study were:

RQ1. What is the impact of a VR/AR intervention on first-year AE students' self-reported understanding of the AE subdisciplines? How does the impact vary by demographic group?

RQ2. What is the impact of a VR/AR intervention on first-year AE students' choice of subdiscipline? How does the impact vary by demographic group?

IV. Methods

A. Setting and Participations

This study took place in the AE programs at one R1 university (University 1) and one R2 historically black university (HBCU; University 2). The students participated as part of a 1-credit hour introduction to AE course during the Fall 2020 semester. Due to the semester taking place during the COVID-19 pandemic, course delivery was synchronously remote. Additionally, the semester was shortened from 15 weeks of instruction to 14 weeks.

Student participants from the two universities were pooled for this study. Active student enrollment in the course was 69 for University 1 and 25 for University 2. Table 1 provides the self-reported demographics of students included in this study. Overall, most of the student participants were male and under 20 years of age (i.e., true first-year students). As expected for an HBCU, the University 2 participants were predominantly female and African American [16], with 70% females and nearly 85%, African Americans.

Table 1. First-year AE student participant self-reported demographics.

Demographics	Pre-Survey n (%)	Project n (%)	Post-Survey n (%)
Total	85	77	67
Gender Identity			
Female	24 (28.2%)	22 (28.6%)	20 (29.9%)
Male	60 (70.6%)	54 (70.1%)	47 (70.1%)
Other	1 (1.2%)	0	0
No Response	0	1 (1.3%)	0
Race / Ethnicity			
African American	18 (21.2%)	14 (18.2%)	13 (19.3%)
White/Caucasian	54 (63.5%)	51 (66.2%)	44 (65.7%)
Other	12 (14.1%)	10 (13.0%)	9 (13.4%)
No Response	1 (1.2%)	2 (2.6%)	1 (1.5%)
Institution Attended			
University 1	66 (77.6%)	62 (80.5%)	54 (80.6%)
University 2	19 (22.4%)	14 (18.2%)	13 (19.4%)
No Response	0	1 (1.3%)	0
Age			
<20	70 (82.4%)	61 (78.3%)	53(79.1%)
≥20	15 (17.6%)	15 (21.7%)	14 (20.9%)
No Response	0	1 (1.3%)	0

B. Intervention

Virtual/Augmented-Reality-Based Discipline Exploration Rotations (VADERs) are educational modules designed for use in engineering and construction-related educational settings that incorporate various visualization and VR/AR techniques to connect classroom concepts to real-world situations. The VADER module used in this course was the first module developed in an intended series. VADER-1 was geared towards first-year students. The VADER-1 module provided students with an opportunity to engage with the different available AE subdiscipline paths in a manner different from current lessons. The additional exposure and engagement was intended to better prepare students to make an informed decision regarding their subdiscipline focus, either growing more confident in their initial choice or deciding another subdiscipline was a better fit. It is important to note that, like instructional videos used in the classroom, VADERs are not designed for use as the main source of education. Rather, they are supportive tools intended to supplement professors' lessons while increasing student engagement in course content.

For this pilot implementation of the VADER-1 module, students participated in eight tasks: a pre-survey, six assignments, and a post-survey. The first five assignments contributed to the sixth assignment which was the final deliverable. Completion of the module was also book-ended by pre-post intervention surveys. Table 2 outlines the module timeline including start dates and due dates. To start, the students first assignment was to maintain a time log for time spent on tasks associated with VADER-1. Students' entries were later used to determine the time spent on

VADER-1. The second assignment introduced students to VADERs. Students watched three videos containing information about the overall goals and timeline of their VADER-1 project and specific information regarding building envelopes and cavity walls. They then played a game where they familiarized themselves with cavity wall components through point-and-click style interactions. This game served as an initial VR/AR experience prior to the main VADER-1 mission. After that, students learned about the Mozilla Hubs platform through additional videos. That knowledge was necessary for future assignments which utilized those platforms. In addition, students created a virtual avatar using a self-portrait for later use. These tasks were followed by an ungraded quiz to determine readiness for future assignments.

Table 2. Assignment timeline VADER-1 pilot (Fall 2020)

Survey/Assignment	Brief Description	Start Date	Due Date
Pre-Intervention Survey	See Section V.C for details.	Oct. 23	Oct. 26
Time Sheets (*Assignment 1*)	Students record time spent working on VADER-1 related activities, including surveys.	Oct. 23	Nov. 12
VADER Introduction (*Assignment 2*)	Introductory videos, an interactive game, avatar creation, and a quiz.	Oct. 26	Oct. 29
VADER Social Hour and PE Selection/ Orientation (*Assignment 3*)	Students use the avatar from the VADER Introduction and meet/interact with other interns and engineers.	Oct. 30	
VADER Mission (*Assignment 4*)	Students watch five training videos and explore a virtual clinic. They then use this information to complete AE subdiscipline specific tasks.	Oct. 30	Nov. 12
VADER Build Sample AE Team (*Assignment 5*)	Students build a theoretical five-member team of AE experts based on a table of potential team members' qualifications. Each member should specialize in a different subdiscipline. The assembled team should be designed to complete a project regarding a clinic design.	Oct. 30	Nov. 12
Prepare/Submit Final Deliverable (Project) (*Assignment 6*)	Students use 12-slide PowerPoint template to provide their time sheet, VADER-1 mission results, and thoughts on their VADER-1 learning experience.	Oct. 30	Nov. 12
Post-Intervention Survey	See Section V.C for details.	Post-assignments	Nov.16

For the third assignment, students met online in a virtual conference room using their (or the default) avatars and interacted with other interns (students) and engineers (instructors) at a social hour (dubbed the VADER Inc. Social Hour and Intern Orientation). The fourth assignment was the primary VR/AR experience. Students first watched five training videos: Acoustics, Construction, Lighting, Mechanical Systems, and Structures. Each video introduced a specific subdiscipline and included embedded instructions to perform calculations or similar tasks. While watching the videos, students explored, analyzed, and collected data in a virtual clinic. The VR

Brain Injury Clinic entailed a small 3D building with a small lobby, four patient rooms, and an MRI machine room. There were interactive experiences available to the students such as clicking a button to hear the MRI machine sound transmitted through different types of walls, or a button to view a room to mitigate sun-light induced glare issues with different types of shading.

The students built a sample team of five AE experts based on qualifications for an example project in the fifth assignment. The last assignment in the project asked students to compile the final products from the second, fourth, and fifth assignments into a PowerPoint presentation.

C. Data Collection

The data sources for this study were students' responses to the pre-and post-intervention surveys and students' final project deliverable. The pre- and post-intervention surveys contained multiple choice, Likert scale, and open-ended items. The survey items deemed most integral to investigating the research questions are listed in Table 3. Although the three items were asked in a similar manner on the pre- and post-surveys, the differences in wordings did not allow for direct pre-post comparisons.

Table 3. Pre- and post- intervention survey items of interest to this study.

Item ID	Pre-post Intervention Survey Items	Response Type
Q1	Pre: I believe I understand what each of the Architectural Engineering subdisciplines are about	Likert Scale[1]
	Post: Compared to before the VADER mission, I believe I better understand what each of the Architectural Engineering subdisciplines are about	
Q2	Pre: I feel confident in my top choice of Architectural Engineering subdiscipline	Likert Scale[1]
	Post: Compared to before the VADER mission, I feel more confident in my top choice of Architectural Engineering subdiscipline	
Q3	Pre: What Architectural Engineering subdiscipline are you most interested in focusing on?	Multiple Choice[2]
	Post: What Architectural Engineering concentration area are you most interested in focusing on?	

[1] 6-point Likert Scale options: Strongly Disagree, Disagree, Slightly Disagree, Slightly Agree, Agree, Strongly Agree
[2] AE subdisciplines: Acoustics, Electrical, Lighting, Mechanical, Structural, Unsure

D. Data Analysis

To allow for pre-post comparisons, a given student's data were only retained in the study if the student submitted all three data sources (i.e., pre-survey, post-survey, and final project deliverable). Table 1 shows both the overall number and demographic breakdown of students retained in this study, where the 67 participants in the post- survey column represent all students that met the inclusion criteria.

Visualizations of the frequency of students' Likert scale responses to items Q1 and Q2 (Table 3) were created to show pre- and post-intervention responses and demographic differences. For quantitative analyses, the response choices were converted to numeric responses, for instance, Strongly Disagree was assigned a value of 1 and Strongly Agree was assigned a value of 6. A statistical test for significance difference between demographic subgroups was conducted using the Mann-Whitney U Test. This test focuses on the median response of each demographic subgroup and is appropriate for non-parametric data and comparing two independent samples (e.g., female versus male). Determining statistical significance between the pre- and post-intervention survey responses for certain demographic subgroups (African American, University 2, and age ≥20) was not possible due to the low sample sizes of those groups. Due to the wording of Q1 and Q2 on the two surveys, comparison between student pre-post responses was not possible.

An analysis of students' choice of subdiscipline (Q3 from Table 3) was conducted by comparing individual student responses on the pre- and post-intervention surveys. Analysis focused on how many students selected each subdiscipline and pre-post VADER-1 changes. Each student's total time spent on VADER-1 was determined using their timesheet data. The Mann-Whitney U Test was used to find any statistical significance in the time spent on the VADER-1 project between different demographic subgroups. Student Likert scale responses regarding their immersion in the VADER-1 module were also analyzed for overall participant and demographic subgroup differences.

VI. Results

Presented here are the results of the analyses of the pertinent pre- and post-intervention survey items. The results begin with an assessment of the time students spent on VADER-1 and continues with the results of the analysis of Q1 to Q3.

Students' self-reported timesheet data were used to determine the amount of time students engaged with the VADER-1 module. For the purpose of analysis, all submitted timesheets that were incomplete were discarded. Excluding the pre-post intervention surveys, this project spanned 18 days. Students self-reported that they spent an average of 6.8 hours on VADER-1 (Figure 1). A maximum of 14.2 hours and a minimum of 2.4 hours was reported. An analysis was also conducted on how time spent on the project varied between different demographic subgroups. None of the findings were significant at a level of $p<0.01$.

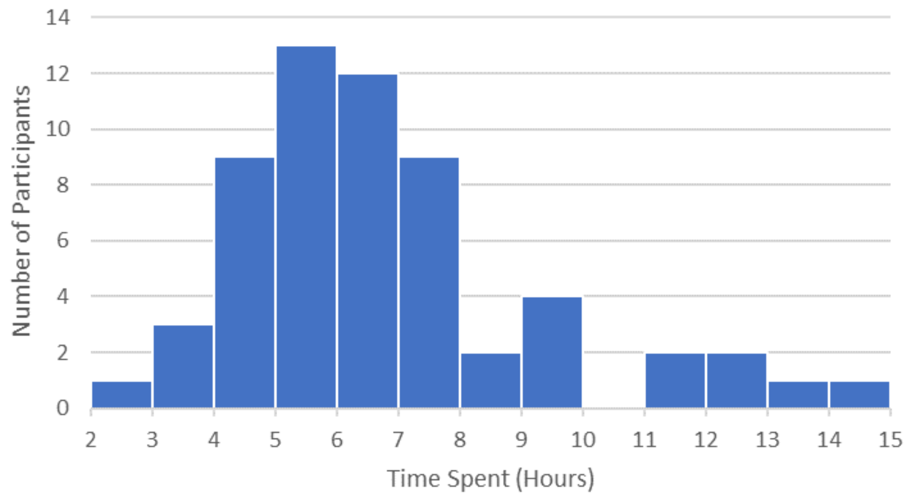


Figure 1. Students' self-reported total time spent on the VADER project (n = 60).

Nearly 80% of students agreed that they felt immersed in the VADER-1 program (Figure 2). Only 16% of students strongly agreed that they felt immersed, but most students did "agree" and "slightly agree" that they felt immersed. The proportion of students in the female, white, University 1, and the <20 year-old demographic subgroups that agreed they felt immersed in the VADER-1 module were greater than that of their demographic counterparts, although this difference was not statistically significant.

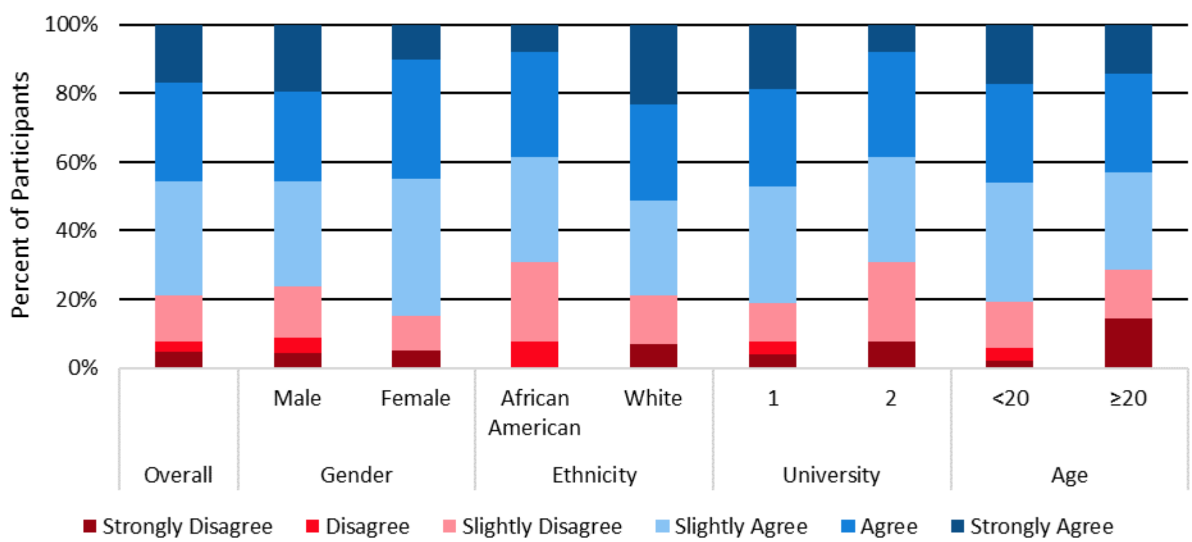
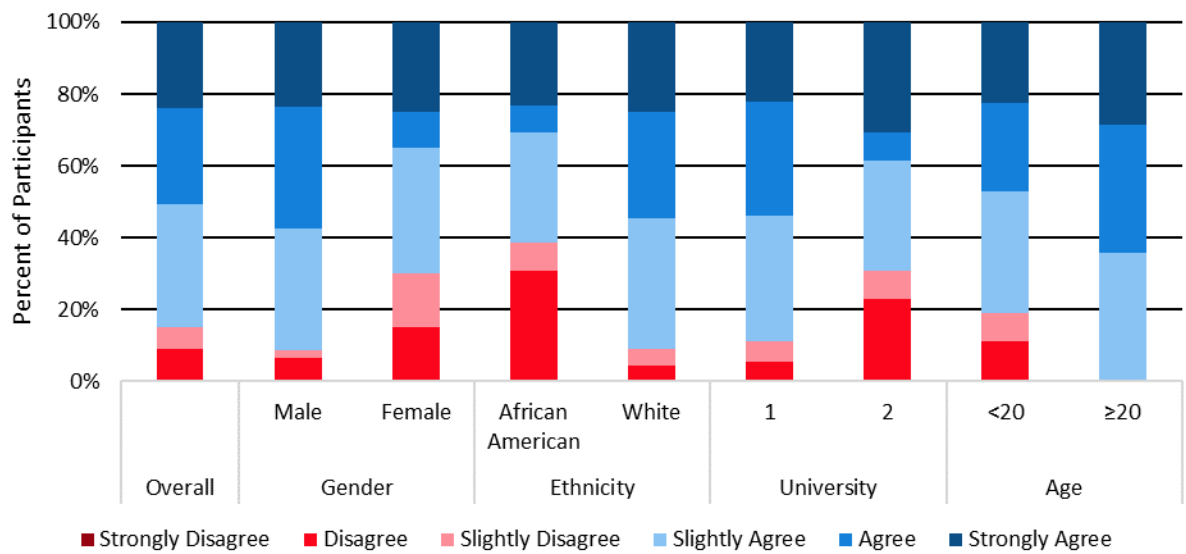


Figure 2. Percentage of students that felt immersed in the VADER-1 module.

Figure 3 details students' responses regarding their AE subdiscipline understanding. Before the VADER-1 intervention (Figure 3a), over 80% of students believed that they were confident in their knowledge regarding each of the AE subdisciplines. Although agreements dominated Overall student responses, it is interesting to note that weak positive responses were more common than neutral positive or strong positive responses. Weak positive responses were the most common response for all demographic subgroups except University 2 students and students older than 19 years of age, where the percentage of weak positive was equivalent to the percentage of strong positive and neutral positive, respectively.



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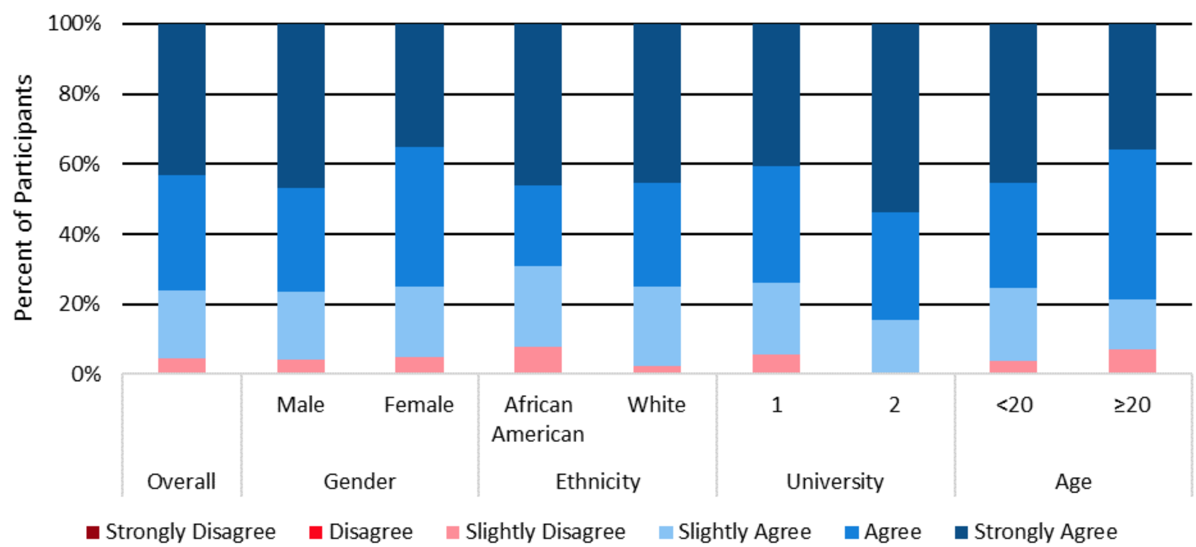

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Figure 3. Students' responses to Q1 "AE Subdiscipline Understanding": (a) pre-VADER-1 understanding and (b) better understanding than prior to VADER-1.

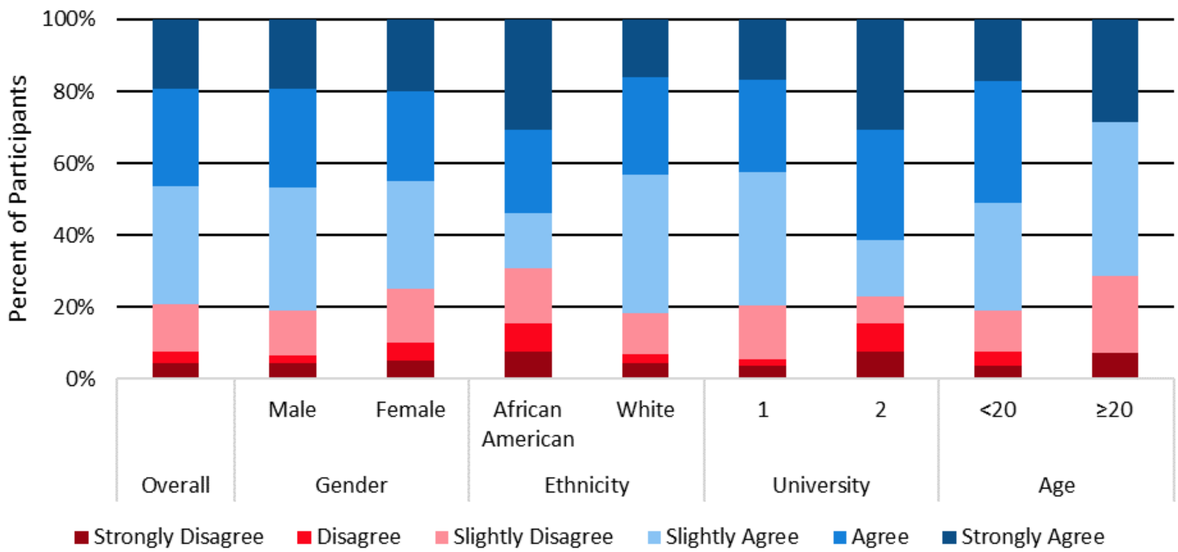
After the VADER-1 intervention (Figure 3b), approximately 95% of students agreed that they better understood each subdiscipline. Overall, responses suggest that students gained a greater understanding of the different AE subdisciplines through the VADER-1 intervention. It is also interesting to note that strong positive responses were more common than weak positive responses in the post-VADER survey. Strong positive responses were the most common response for all demographic subgroups except female students and students older than 19 years of age, where the most common responses were neutral positive.

Within survey, there was no significant difference between demographic subgroups at $p<0.05$. As this survey item was different on the pre- and post-intervention survey, no pre-post comparison of results could be made for this item.

Figure 4 shows students' responses regarding their confidence in their initial subdiscipline choices. Approximately 80% of students were confident in their subdiscipline choice prior to the VADER-1 intervention. Weak positive responses were most common overall and for all demographics other than African American, University 2, and age <20 students. Strong positive responses were the most common response for African American and University students while neutral positive responses were the most common response for age <20 students.

After the VADER-1 intervention, 75% of students overall agreed that they felt more confident in their initial choice while the remaining students disagreed with this sentiment. Interestingly, over half of the African American students gave negative responses to this item.

Once again, there was no significant difference between demographic subgroups for this item on the pre- or the post-intervention surveys. Pre-post survey response analysis was not possible due to differences in item wording.



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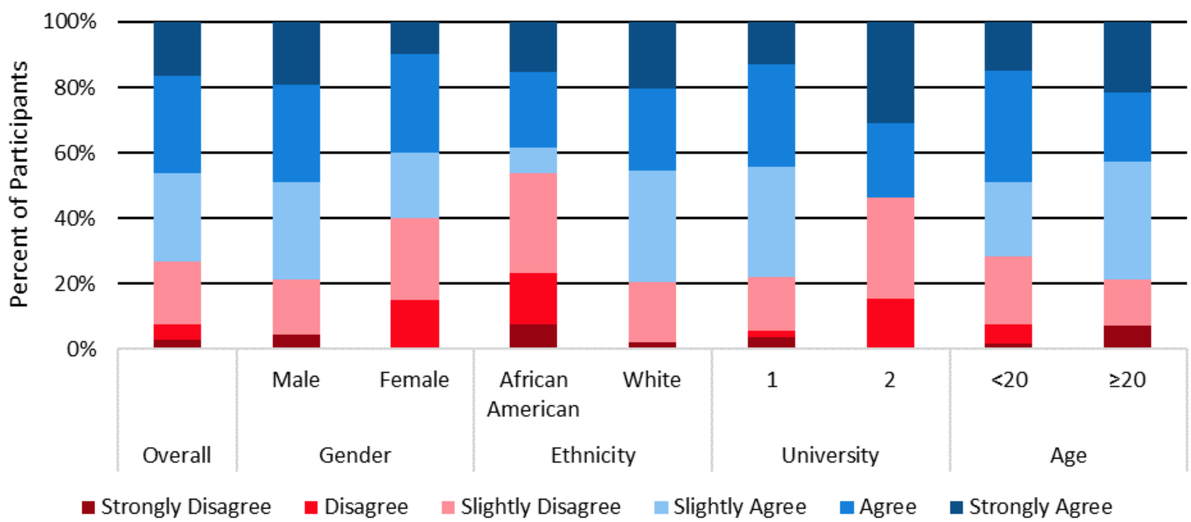

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Figure 4. Students' responses to Q2 "Confidence in Top Subdiscipline Choice" (a) pre-VADER-1 confidence and (b) post-VADER-1 more confident.

Table 4 shows which AE subdiscipline students were most interested in before and after the VADER-1 intervention. For example, five students selected the Acoustics subdiscipline as their top choice prior to the VADER-1 experience. Afterwards, one additional student reported Acoustics as their top choice. This student had original reported the Structural subdiscipline as their top choice. No students that originally selected Acoustics before VADER-1 selected a difference subdiscipline of interest after the intervention. The end result was that a total of six students reported Acoustics as the subdiscipline they were most interested in post-VADER-1.

Table 4. Student AE subdiscipline of most interest pre-post intervention.

		Post-VADER-1 Top AE Subdiscipline Choice						
		Acoustics	Electrical	Lighting	Mechanical	Structural	Unsure	Total
Pre-VADER-1 Top AE Subdiscipline Choice	Acoustics	**5**						5
	Electrical		**3**	2		1		6
	Lighting		1	**12**		1	1	15
	Mechanical		1		**2**	1	1	5
	Structural	1	1		1	**21**	4	28
	Unsure					5	**3**	8
	Total	6	6	14	3	29	9	**67**

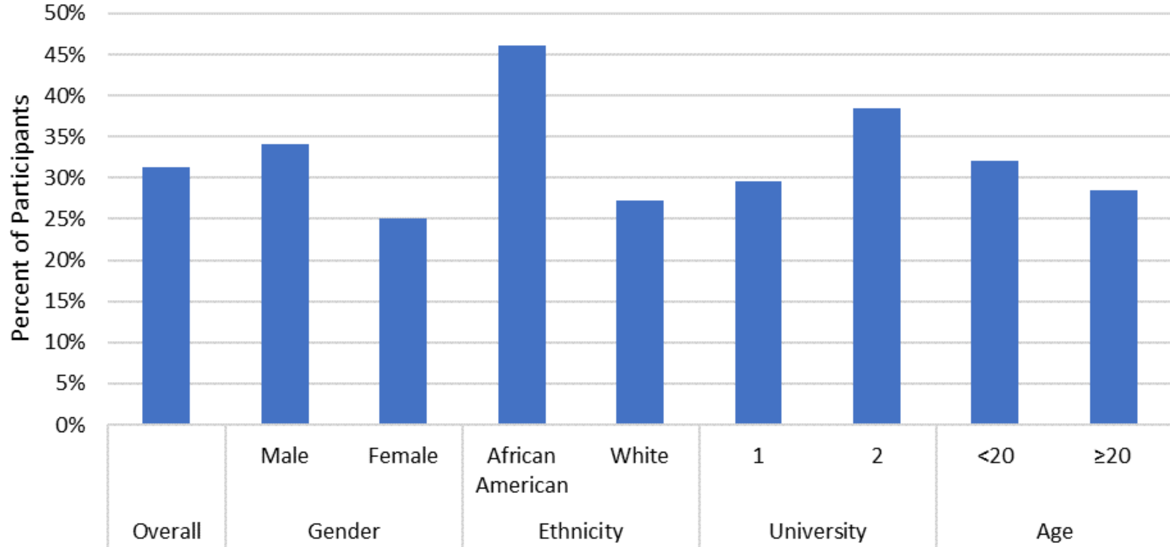
Over the course of this study, many students switched subdisciplines. Interestingly, despite movement in each subdiscipline, no single subdiscipline saw a substantial population gain or loss, including the "Unsure" group.

According to Figure 5, while approximately 70% of students maintained their subdiscipline interest, the remaining 30% selected a different AE subdiscipline. The percentage of male participants that changed their AE subdiscipline was 9% higher than female participants. The percentage of University 2 students that changed their top subdiscipline was also 9% higher when compared to University 1 students. For ethnicity, this gap was 19%, with African American students changing subdiscipline more than their white counterparts. Lastly, the gap for the age demographic subgroup was a mere 3.5%, where students younger than 20 years of age were more likely to change their initial AE subdiscipline.

V. Discussion

A. Understanding of AE Subdisciplines (RQ1)

Prior to the VADER-1 experience, most students to some degree agreed that they believed they understood what each of the different AE subdisciplines is about. When looking at demographic subgroups on the pre-intervention survey, more male students, white students, University 1 students, and ≥20-year-old students initially agreed that they felt confident in their understanding of AE subdisciplines, although not at a statistically significant level. Excluding the ≥20-year-old group, each of these demographic subgroups were the majority in their respective category. This disparity in initial understanding of the subdisciplines could provide one reason why the retention of underrepresented groups is an issue in an engineering field like AE.



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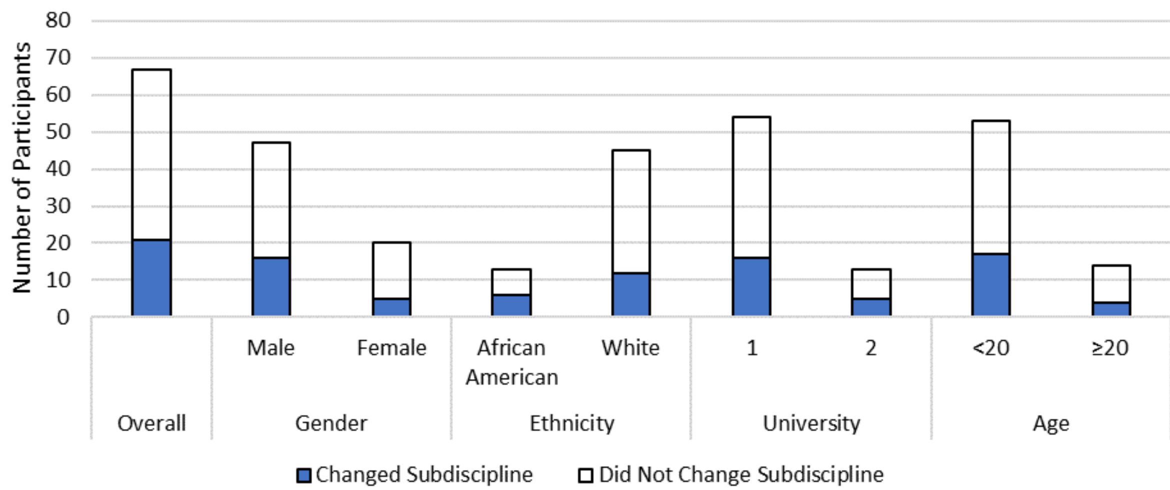

(b)

Figure 5. Students that changed their top AE subdiscipline interest after VADER-1 by (a) percent of group and (b) count of who changed (blue) and those that did not (white).

After participation in the VADER-1 module, nearly all students agreed that they better understood the different AE subdisciplines. Unlike on the pre-VADER survey, there was very little variation between demographic subgroup responses on the post-VADER survey. Each demographic subgroup overwhelmingly agreed that they believed they had a better understanding of the AE subdisciplines. Meaning the underrepresented groups reportedly gained as much understanding as majority demographic subgroups. Though, due to the wording of the post-intervention survey item, it is unknown whether the demographic subgroups were brought to parity in their belief of their understanding of the AE subdisciplines.

B. Confidence in AE Subdiscipline Choice (RQ2)

Prior to the VADER-1 module, many students felt confident in their top AE subdiscipline choice. While there were no statistically significant differences between demographic subgroups, it is evident in Figure 4(a) that female, African American, University 2, and <20-year-old students were less confident in their AE subdiscipline choice than students of the respective majority demographic subgroup.

Compared to before the VADER-1 experience, three-quarters of the students believed they felt more confident in their top AE subdiscipline choice. This data also means that a quarter of the students did not believe their confidence in their AE subdiscipline top choice had increased. Due to the wording of the post-Q2 item it is unknown whether students were similarly or less confident in their top choice after the VADER-1 intervention. Compared to before the VADER-1 experience, three-quarters of the students believed they felt more confident in their top AE subdiscipline choice. This data also means that a quarter of the students did not believe their confidence in their AE subdiscipline top choice had increased. Due to the wording of the post-Q2 item it is unknown whether students were similarly or less confident in their top choice after the VADER-1 intervention.

It can be seen in Figure 4(b), that underrepresented students more often disagreed with the postintervention confidence gain statement. Female more than male students, African American students more than white students, and University 2 more than University 1 students disagreed to some extent that they were more confident in their top subdiscipline choice after the VADER-1 intervention.

Approximately 30% of participants found an AE subdiscipline that interested them over the duration of the VADER-1 intervention. Male, University 2, African American, and <20 year-old demographic subgroups were more likely to change their top choice of AE subdiscipline. One interesting connection to draw is that African American students and, by extension, the students at the HBCU University 2 were more likely to disagree that they were more confident in their top subdiscipline on the post-VADER survey and were more likely to change their top subdiscipline over the course of the VADER-1 modules. The latter result may have impacted student responses on the former, where a student may rate their subdiscipline confidence poorly since they just became interested in that focus.

Another explanation for the tendency of University 2 students to disagree that they were confident in their top AE subdiscipline choice is that the subdiscipline offerings available to University 2 students were different. Instead of Acoustics, Electrical, Lighting, Mechanical, and Structural subdisciplines at University 1, the subdiscipline options available to University 2 students were Structures, Mechanical/Electrical/Lighting, and Construction/Facilities Management. Notable differences are the combination of Mechanical, Electrical, and Lighting into one subdiscipline and the exclusion of Acoustics as an option at University 2. These differences in offerings were not accounted for in the pre-post survey wording of Q3, which may have caused some confusion for University 2 students.

C. Overall

Hoit and Ohland's 1998 study [6] found that student retention in engineering programs increased when there was an opportunity for greater engagement in courses that introduced disciplines to students. The thinking behind the intervention employ in the current study was rooted in this finding, that increasing students' engagement in discipline-oriented activities could achieve the larger goal of minimizing student attrition from engineering programs. Where this study differed was the method of engagement. In Hoit and Ohland's 1998 study [6] the engagement was the result of replacing a lecture-based introductory course with a laboratory-based course, while in this study the VADER-1 intervention was integrated into the introductory course taken by all students. Both studies found success in increased student understanding in course material. In the case of the present study there was an increased understanding of the AE subdisciplines.

An overwhelming number of students' subdiscipline decisions were positively influenced by this study. In total, 49 of the 67 students grew more confident in their top choice of AE subdiscipline and 21 students changed their subdiscipline over the course of the VADER-1 intervention. Additionally, through their submitted project work and other post-VADER-1 survey responses, common themes of increased AE subdiscipline experience and an appreciation of AE project work were seen [17].

The results of this study demonstrate that the pilot VADER-1 program strengthened student understanding of each AE subdiscipline and influenced the majority of student subdiscipline choices (either changing their top choice or increasing confidence in their original choice). These outcomes should assist students with the difficulty and uncertainty of choosing an interest and career goal, which is one of the issues that leads to student attrition from engineering undergraduate programs suggested by Geisinger and Raman [2].

VI. Future Work

Future studies will entail additional analysis of the pilot study data, longitudinal tracking of participants' retention in AE, and revision and further implementation of VADER-1 in first-year AE courses. Further analysis of the pilot study would entail looking at students' learning by demographic subgroup. Longitudinal tracking would entail tracking students' enrollment in the AE program and subdiscipline option through to graduation. A comparison group that introduced students to the subdisciplines without the VADER-1 would also clarify the impact of the VR/AR intervention in the short and long term. Findings from the pilot will be used to make revisions to the VADER-1 module. The pre-post surveys will also be better aligned to SCCT for more meaningful results.

VII. Limitations

Low sample sizes greatly hindered analysis of the data by demographics and could have influenced the results. There are some demographic subgroup comparisons that were not possible due to low sample size, particularly in pre-VADER to post-VADER comparisons between

African Americans, University 2, and the ≥20 age range. It is likely that other comparisons involving these groups (e.g., comparing University 1 Q1 data to University 2 Q1 data) may have resulted in statistical significance with a larger sample size. The small sample of students also prevented intersectionality analysis (e.g., African American females). Additional demographic subgroups (e.g., Hispanic, "Other" gender, etc.) were excluded from analysis altogether due to exceedingly low sample size.

As is evident in Table 1, the number of participants that completed the pre-VADER survey, project, and post-VADER survey were different. This variance made initial data comparison between individual demographic subgroups and for the entire population both difficult and unreliable. The researchers decided to exclude any participant that did not have submissions in all three categories. This decision prevented the data from becoming skewed by students who completed the pre-VADER survey but did not complete the VADER mission. Overall, the omission of those students resulted in a 21.2% loss in pre-VADER survey responses. Some demographic subgroup losses of note include African American (27.8%), University 2 (31.6%), and <20 (24.3%). To combat this loss in future iterations of this study, the surveys could be consistently integrated as assignments in the course instead of being voluntary.

Lastly, it would be inappropriate to not mention the state of education during this study. Since VADER-1 was implemented during the COVID-19 pandemic, students did not participate in a typical classroom environment. The online nature of the class as a whole may have influenced students' reception to the VADER-1 module.

VIII. Conclusion

This study showcased the promising potential of VR/AR interventions in engineering education. In this case, it was shown that rotating VR/AR modules that were designed to engage students in authentic tasks associated with the different AE subdisciplines overall increased first-year AE students' understanding of the AE subdisciplines and improved their confidence in their top AE choice. However, these increases were not indicated by all students. In particular, female and African American students tended to disagree that they were more confident in their top AE choice. In the long-term, this study provides instructors with another tool to convey course content to students, particularly regarding the sub-focuses of engineering disciplines. In future studies, VADER modules will continue to be developed and used to increase students' understanding of and interest in AE and combat undergraduate student attrition from engineering programs.

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