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Student Flow State in VR/AR Module for First-Year Architectural Engineering & Construction

C. Elizabeth George, University of Notre Dame

C. Elizabeth George is a rising senior at the University of Notre Dame studying Chemical Engineering with a minor in Engineering Corporate Practice. In the summer of 2024, she participated in the Engineering Education Research Experience for Undergraduates (NSF REU Site) program at the University of Nebraska – Lincoln (UNL). There, she worked with Dr. Heidi Diefes-Dux, Dr. Erica Ryherd, and Euclides Brandao Maluf to research flow state in VR/AR modules for first-year architectural engineering and construction students.

Prof. Heidi A. Diefes-Dux, University of Nebraska - Lincoln

Heidi A. Diefes-Dux is a Professor in Biological Systems Engineering at the University of Nebraska - Lincoln (UNL). She received her B.S. and M.S. in Food Science from Cornell University and her Ph.D. in Food Process Engineering from the Department of Agricultural and Biological Engineering at Purdue University. She was an inaugural faculty member of the School of Engineering Education at Purdue University. Her current role in the College of Engineering at UNL is to lead the disciplinary-based education research initiative, growing the research enterprise and the engineering education research graduate program. Her research focuses on the development, implementation, and assessment of modeling and design activities with authentic engineering contexts; the design and implementation of learning objective-based grading for transparent and fair assessment; and the integration of reflection to develop self-directed learners.

Euclides Maluf, University of Nebraska - Lincoln

The author is an experienced Industrial Engineer with a minor in Occupational Safety Engineering and Education. With over 10 years of expertise in training professionals across companies, educational institutions, and industries, they possess strong skills in processing, analyzing, and synthesizing large data sets. Their ability to thrive in collaborative, team-oriented environments complements their technical expertise. Currently, he is pursuing a PhD in Engineering Education at the University of Nebraska-Lincoln, where they serve as a Graduate Research Assistant. Additionally, he contribute as a visiting professor at Federal Institute of Science and Technology of Minas Gerais (IFMG-Bambuí) in Brazil. His research is centered on innovative methodologies for Engineering Education, with a particular focus on the VADERs project: Virtual/Augmented-reality Discipline Exploration Rotations. This initiative seeks to enhance self-efficacy, diversity awareness and engagement in engineering within the AEC (Architecture, Engineering, and Construction) curriculum by integrating immersive technologies into the learning experience.

Dr. Ece Erdogmus, Clemson University

Ece Erdogmus, PhD, PE is the Founding Dean of the College of Architecture, Art, and Construction at Clemson University since August 2024. Prior to this, she was the Chair of the School of Building Construction at Georgia Institute of Technology (2021-2024). Before joining Georgia Tech, she was a Professor and Associate Director at the Durham School of Architectural Engineering and Construction at the University of Nebraska-Lincoln (UNL). She has PhD and MS degrees in Architectural Engineering from the Pennsylvania State University and a bachelor's degree in architecture from the Middle East Technical University in Turkey. She is a licensed civil/structural engineer in the state of Virginia. Erdogmus' wide range of research activities cover masonry design and construction; assessment and rehabilitation of historical masonry using nondestructive testing and numerical modeling; and use of Augmented/Virtual Reality in architectural engineering and construction education. She has authored over 100 peer-reviewed technical articles and led numerous projects funded by NSF, NCMA Foundation, Nebraska DOT, and National Center for Preservation Technology.

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Abstract

Architectural Engineering and Construction (AE/C) students' self-efficacy and interest can be increased by showing engineering impacts on the real-world. Classroom access to real-world examples can be challenging, but virtual and augmented reality (VR/AR) can enable access. Virtual/Augmented-Reality-Based-Discipline Exploration Rotations (VADERs) modules used real-world engineering examples to engage students in understanding the five subdisciplines of AE/C. To maximize the benefit of VR/AR, students' immersion in these learning experiences is necessary. The purpose of this study was to determine the extent to which students experienced a flow state (absorption and fluency) in VADERs. VADER-1 was implemented in first-year AE/C introductory courses at three institutions. Cluster analysis was used to group students with similar flow states. Student demographics and their perceived difficulty with VADER-1 was used to explain flow state differences among the clusters. Results reveal varying levels of flow absorption and fluency across five clusters. Three clusters (79% of participants) agreed they experienced aspects of flow. While demographic differences amongst the clusters were not found, there were differences according to perceived difficulty of the VR/AR activities.

Keywords: Architectural engineering, construction engineering and management, first-year, virtual reality, flow, engagement

I. Introduction

Engineers are integral to the workforce in the United States especially as the demand for engineering skills continues to grow [1]. In a letter to President Biden in April 2023, the American Council of Engineering Companies (ACEC) shared 49% turned down work due to workforce shortages [2]. These facts speak to the importance of retention of engineering students to fill growing needs. However, U.S. engineering graduation rates have consistently hovered around 50%, this translates to half of entering students leave without an engineering degree [3]. Therefore, there is a need to increase the retention of undergraduate engineering students.

One reason students transfer out of an engineering program is due to a lack of interest in their chosen discipline [4]. Hence, introductory engineering courses need to provide opportunities for increased interest. According to the National Academy of Engineering [5], students are interested in making a difference in the world. Along this line, it is important that introductory engineering courses adopt approaches that engage students' interests by giving real-world examples of engineers making an impact on their communities. Providing real-world connections for first-year engineering students has long been encouraged (e.g. [6]) with evidence that these connections do mitigate retention issues (e.g., [7] [8]). An emerging way to provide students with real-world examples is through virtual reality (VR) and augmented reality (AR) experiences [9].

An example of VR/AR experiences designed for elevating students' interest in their discipline through real-world exposure to the work of engineers is the Virtual/Augmented-Reality-Based-

Discipline Exploration Rotations (VADERs) modules for Architectural Engineering and Construction (AE/C) [9] [10]. VADERs was developed through a multi-institutional NSF IUSE project (2202290) lead by author Erdogmus. VADERs has three modules: VADER-R designed to promote interest in AE/C in students at community colleges, VADER-1 designed to engage first-year AE/C students in the work of the AE/C sub-disciplines, and VADER-2 designed to further engage second-year AE/C students in the greater application of domain learning in the AE/C subdisciplines. The VADERs modules were created based on the Model of Domain Learning (MDL), which in short, explains how students experience different types of interest at different stages of the learning process. It is important to study student engagement in the VADERs modules to ensure it provides the enhancement to student learning and interest that is intended. It is also important to ensure VADERs modules allow *all* students to effectively engage with them, not just certain groups.

This study is a part of a larger research effort to enhance self-efficacy (belief is one's ability to succeed at a task) and engagement in engineering through the use of VR/AR across engineering curricula and specifically in AE/C [10]. This study specifically focuses on students' experiences with VADER-1. VADER-1 was created to support the MDL learning stages of acclimation and early competence. According to the MDL, acclimation is the initial stage of learning and competence is the longest stage and the most complex [11]. For many students, introductory courses are the first time they are learning about their major and the subdisciplines. Therefore, this is students' initial introduction to many concepts, and they start to build competency as they complete the tasks themselves. During acclimation, students demonstrate high levels of situational interest (temporary arousal imbued by specifics of tasks), but as they move into early competence, students' situational interest begins to decrease [11]. According to MDL, situational interest is characterized by spontaneous arousal and has a short timescale [11]. Therefore, since VADER-1 was created with the intention to act as the transition from acclimation to early competence, students are expected to experience maintained situational interest [10]. Therefore, the goal of VADER-1 is to provide first-year students with real-world examples of each AE/C subdiscipline to stimulate interest and ultimately contribute to their retention within engineering. However, if a student does not fully engage with the VADERs modules, they will most likely miss the opportunity to become interested in the AE/C content. One way to assess student engagement is to determine their flow states, a mental state of complete focus on an activity.

The purpose of this study was to determine the extent to which first-year AE/C students self-report experiencing a flow state while completing VADER-1. This study demonstrates the application of flow state scale to measure students' engagement in a VR/AR module. Students' demographics and their perceptions of the difficulty of using the module were used to unpack differences in students flow state levels. This study was intended to provide insights into whether or not the VADER-1 module is an effective instructional tool for stimulating engagement with content related to subdiscipline discernment in first-year AE/C engineering courses. Results may lead to improvements to VADER-1, making it more useful for other AE/C instructors to use it.

II. Background

Definitions related to real and virtual realities

There are many terms associated with real and virtual reality technologies. A summary of terms used in this work are presented here based on [9]. Virtual reality (VR) can be identified as either non-immersive virtual reality (nIVR) or as immersive virtual reality (IVR). nIVR is a virtual environment accessed through 2D-display devices. IVR is accessed using immersive display devices (e.g., goggles). AR is similar to VR except the virtual and the real are combined; virtual elements being overlayed in the user's view to enhance the real-world experience. In this study, VADERs were created as a form of nIVR due to high accessibility and low cost of implementation.

XR used in the classroom and industry

Several universities have implemented forms of extended reality in the classroom and studied student perceptions. For example, one study found that 82% of chemical engineering students found AR lessons helpful compared to conventional lessons and 92% of students were supportive of AR lessons as an additional resource to existing learning materials [12]. Such evidence suggests AR/VR learning experiences may provide AE/C students with a positive experience.

There have also been studies conducted that look at student perceptions of VR specifically in AE/C programs. Using AR/VR tools is especially helpful in AE/C because it allows students to closely observe construction site spaces while not facing the many safety concerns of an in-person space [12]. One such study uses CAVE-VR and looks at if environment enhances students' perception of essential building elements compared with the traditional environment as well as the factors that influence the student learning performance and technology acceptance in using the CAVE-VR system [13]. Most students in this study expressed positive attitudes about CAVE-VR's ease of use and usefulness. Another study, compared a VR assisted learning of complex spatial arrangements in architecture and civil engineering to the traditional 2D projection drawing-based method. Students, lecturers, and professionals in both fields rated the VR experience more enjoyable than traditional 2D mode. In post-experiment interviews, participants expressed greater understanding and enthusiasm for the topic as well as a greater desire for other topics to be presented using VR tools [14].

Not only is virtual reality used in the classroom, but it is also used in industry. For instance, Building Information Modeling (BIM) and Virtual reality (VR) has been receiving growing attention in the AE/C industry in recent years [15]. Therefore, students would benefit from becoming familiar with virtual reality as it is used in industry.

Flow

Flow is defined as full absorption in a fluid running activity in which one has control despite a high level of task demands [16]. Rheinber, Vollmeyer & Engeser [16] summarized Csikszentmihalyi's six elements of the flow experience. These six elements are: (1) a balance between task demands and skill to ensure a feeling of optimal challenge. (2) clear and unambiguous task demands and feedback, (3) perceived internal logic for the task [17], (4) high concentration attainment with no effort, (5) perceived change in sense of time or a loss of track of time, and (6) task is engrossing. The first flow model, the operational flow model, had some weaknesses associated with it. Therefore, the model was reformulated by Csikszentmihalyi and Csikszentmihalyi. The reformed model is commonly known as the four channel model or the quadrant model of flow [17]. This model consists of a Cartesian plane with skill on the x-axis and challenge on the y-axis. In the bottom left corner, apathy represents low skill and low challenge. Anxiety lies in the top left corner and relates to low skill and high challenge. Boredom/relaxation lies in the bottom right corner and relates to high skill and low challenge. Finally, flow lies in the top right corner and relates to high skill and high challenge [18]. Some studies have found a relationship between flow and performance [19], but others have not found a strong correlation [16], [18], [20-21]. Therefore, flow may be related to higher performance, but it does not necessarily cause it [18].

A few studies have been conducted to study flow. In an art education application, differences in flow between a VR and a computer group were investigated in an art appreciation activity [22], No significant difference in flow states were found between the two groups. Another study used VR in a non-academic context with adults in local museums to see if there were any relationships between creativity, flow state, brainwave, and quality of a virtual creative product [23]. Another study related to metacognition had students build a toy car and perform other activities, either physically or virtually, to assess if problem solving is related to flow [24].

A commonly used instrument for measuring flow is the 10-item Flow Short Scale (FSS) [18] which has two factors absorption and fluency ("smooth pursuit of action" [18 p. 1]) and accounts for the elements of flow as described above. In terms of reliability, this scale, when administered with a 7-point Likert scale of Strongly Agree to Strongly Disagree, was reported to have a Cronbach's internal consistency of $\alpha = 0.90$ for the overall scale and $\alpha = 0.80$ for the absorption factor and $\alpha = 0.92$ for the fluency factor [25]. A modified version of this instrument was used in this study to measure students' perception of flow in the VADER experience.

III. Research Questions

Overall, flow, which entails absorption and fluency, is being used as an indicator of students' engagement in VADER-1. Engagement in VADER-1, as per the MDL, may lead to greater self-efficacy and situational interest which may aid in students' transition from acclimation to early competence. Further, an increase in self-efficacy and interest, according to MDL, may lead to choices to pursue or be retained in AE/C. This study focuses on students' self-reported flow in VADER-1 and an exploration of specific variables that might explain patterns in students' flow.

The primary research questions were:

1. What are the patterns in students' self-reported flow states when using VADER-1?
2. Are there differences in students' self-reported flow states with regards to students' demographics and their perceived difficulty of the VADER-1 module?

IV. Methods

A. Setting and Participations

This study was set in AE/C introductory courses in Fall 2023 at three universities including an R1 Midwestern institution, R2 Southeast HBCU, and an R1 Southeast institution. Enrollments in the course offerings at these institutions were approximately 200, 30 and 20, respectively. For the R1 Midwestern institution, the study was conducted in three first-year, first-semester, 1credit hour courses, one for each of the degree programs, architectural engineering, construction engineering, and construction management. At the R2 Southeast HBCU, the study was conducted in a first-year, first-semester, 1 credit-hour introduction to the architectural engineering profession and problem solving course. At the R1 Southeast institution, the study was conducted in a second-year, 2-credit hour course within the construction management program. While the course was situated in the third semester, it was the first time in the curriculum students were introduced to the discipline. Overall, there was a diversity of institutional contexts, including programs, courses, and students included in the study.

B. Intervention

VADERs were educational modules created to allow students the opportunity to see themselves as professionals in the AE/C industry. The inspiration for the creation of VADERs was medical school rotations which allow students to learn about each subdiscipline and how multiple subdisciplines need to be considered when making decisions in the real-world. The learning objectives of the VADER-1 intervention stated that students will be able to: (1) describe the five AE/C subdisciplines: Structures, Acoustics, Heating Ventilation and Air Conditioning (HVAC), Lighting, and Construction Management, (2) explain the relationship between the subdisciplines, and (3) visualize themselves as professionals in the AE/C industry. To work towards these objectives, students completed several assignments coordinated through a course on Canvas for Free (course management system). Table 1 briefly describes the assignments. Each instructor launched the VADER-1 intervention about halfway through the semester, and the entire project was due roughly one-and-a-half to four weeks after the launch date depending. The project was worth a varying percentage of the overall course grade ranging from 10-25%, depending on the course.

The virtual reality component of VADER-1 was set in a virtual clinic where a student's avatar meets with the project manager in a conference room before exploring five additional rooms. These additional rooms included interactive aspects where students could explore how different design decisions affect the patient rooms (Figure 1). In East 1 room, the student can hear the noise level of the MRI machine in the adjacent room, when the interior wall is constructed from grouted concrete masonry units (CMU). In East 2 room, however, the interior wall shared with the MRI room is constructed from ungrouted CMU. Between the two rooms, the student can enter the MRI room and hear the sound directly and see the machinery. The experience with the East rooms is designed for students to weigh the structural strength benefit gained from grouting of the wall with the loss in acoustic isolation and increase in construction cost, to make a design decision.

Table 1. VADER-1 module components

Assignments	Tool Type	Description
Survey A	Canvas Link	Link to Qualtrics Survey: Background & Demographics
Survey B	Canvas Link	Link to Qualtrics Survey: Study Instruments
Introduction Module	Canvas .mp4 & .pdf Files	Video on VADER access and navigation
AEC Subdiscipline Pre-Quizzes	Canvas Quizzes	Five 6-item quizzes that assess students' prior knowledge of AE/C content covered in Rotations and VR Activity
AEC Subdiscipline Rotations	Canvas Page: Embedded Videos & .pdf Files	Five Sub-discipline Videos: Structures, Acoustics, Heating Ventilation and Air Conditioning (HVAC), Lighting, Construction Management. Each provided: (1) overview of subdiscipline and (2) key concepts for completing the VADER-1 rotation.
Virtual Clinic	Canvas Page: Link to VR Experience	Virtual experience entails an interactive walk through of a single-story health clinic with five rooms to visit. East 1 and 2 Rooms and MRI Room support activities for Acoustics + Structures + Construction Management. North and West Rooms provide activities for Acoustics, HVAC, and Lighting.
AE/C Subdiscipline Post-Quizzes	Canvas Quizzes	Five 6-item quizzes that assess students' knowledge of AE/C content covered in Rotations and VR Activity (videos +VR experience)
Final Deliverable Timesheet	Canvas .ppt File	File to log time spent on VADER-1 activities
Final Deliverable Slides	Canvas .ppt File	10-slide fill-in template to capture results (design decisions and task solutions) to document learning and reflections from the VADER-1 experience
Survey C	Canvas Link	Link to Qualtrics Survey: Study Instruments & VADER-1 Evaluation

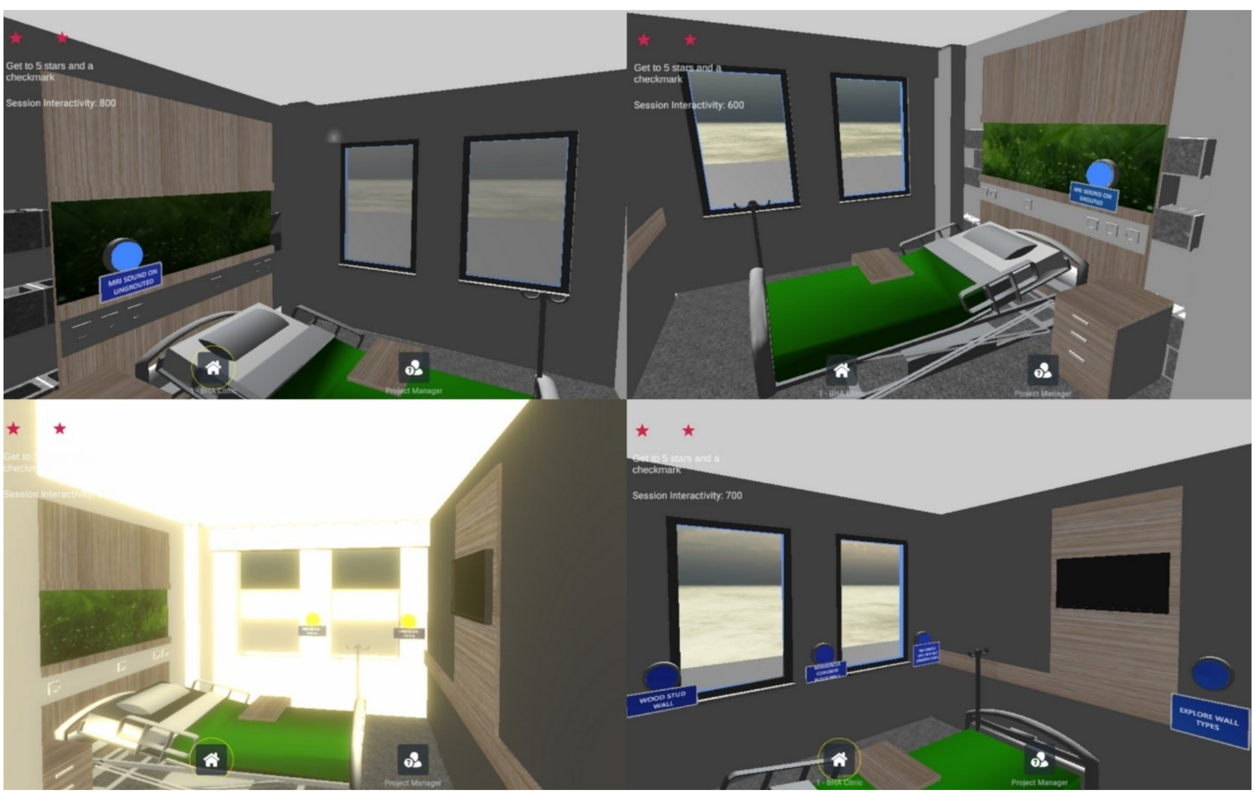

Figure 1. VADERs virtual clinic room images (clockwise from top left: East 1, East 2, North, and West rooms

North and West rooms, together, ask the students to make some design decisions weighing considerations with respect to acoustics, HVAC, lighting, and construction management. The North room features an exterior wall next to a helipad and busy street. Here, the student can explore three different wall types with different noise transmission coefficients, construction costs, and R values (a measure in heat transfer). Students can hear the noise level with each selected wall type, in addition to viewing the lighting quality in a north-facing room. In the West Room, there is lower ambient noise compared to the North room, but the default is a high glare situation due to the west facing orientation of the window. Here, the students can interact with the environment to see how different shading options affect the lighting in the patient's room. Ultimately, the students were asked to choose which of the rooms they would select as an additional patient room along with shading and wall type selections.

The overall VADER-1 mission required students to make four design decisions concerning the patient rooms. Students needed to (1) select between two interior walls, (2) select between three exterior wall options, (3) select the ideal location for an additional patient room, and (4) select a window shading, if necessary. VADER-1, designed for introduction to architectural engineering and construction management courses, emphasized the interdependence and integration of the five AE/C subdisciplines to accomplish the complex endeavor of building design. For the purposes for this introductory level exercise, only very specific elements in a building were considered (one interior wall, one exterior wall, and one space programming decision). Further, the concepts and equations were simplified to ensure that emphasis was placed on connecting the real-life example to the visualization/auralization rather than advancing knowledge on each of these subjects.

To complete the module, students watched an approximately 15-minute video for each subdiscipline. The slide decks of each of the videos were also provided. The students were instructed to enter the VR environment after watching all of the videos. Table 2 below summarizes the content taught in the videos along with the learning objectives, as well as the goal of the related experience in the VR environment.

The activities in the interactive rooms were intended to inform the task assignments (e.g. calculations to determine system characteristics) and ultimately assist the students in making the building system design decisions for the VADER-1 mission. Once all the rotation assignments were completed, the students assembled a final deliverable presentation. A PowerPoint presentation template was provided to the students to assist them in completing this final deliverable.

C. Data Collection

Survey data were collected through Qualtrics at three time points: at the beginning of the semester (Survey A), prior to the VADER-1 intervention (Survey B), and after the VADER-1 intervention (Survey C) (Table 1). Each survey consisted of multiple choice, Likert scaled, and open-ended items. Survey A was used to collect students' background and demographic information. Survey B and C were used to collect pre-post data relevant to the larger study. Survey C was also used to collect students' perceptions of their VADER-1 experience.

Table 2. Overview of VADER-1 rotations

Rotation	Activity	Learning Objectives & Video Content
Structures	Video	1. Define the terms of force and load 2. Describe the relationship between force, section properties, and axial stress for structural walls 3. Select a wall system by considering its structural capacity along with design criteria from other AEC disciplines Video content: overview of subdiscipline, concept of axial force on walls, ways to calculate axial strength, and overview of the structures component of the VADER-1 VR experience and final assignment
	VR	Goal: View the different wall types
Acoustics	Video	1. List key elements of building acoustics 2. Estimate sound transmission class (STC) for interior and exterior walls 3. Justify wall construction selection by comparing STC values, listening experiences, and considerations from other AEC disciplines Video content: overview of subdiscipline, concept of sound transmission, ways to calculate STC, and overview of the acoustics component of the VADER-1 VR experience and final assignment
	VR	Goal: Listen to the differences in sound levels when different ambient noise and wall types are involved
HVAC	Video	1. Recognize different heat transfer modes 2. Define thermal resistance & "R" value 3. Describe the advantages of "air film/ air gap" Video content: overview of subdiscipline, concept of heat transfer through external walls, ways to calculate R-value, and overview of the HVAC component of the VADER-1 VR experience and final assignment
	VR	Goal: View the different wall types
Lighting	Video	1. Identify the role of lighting design in a building and outline the different areas where lighting concepts are utilized in the design phase of a building 2. Assess how building orientation can impact disability glare occurrences 3. Outline roller shades and explain how openness factor and visible transmittance can determine whether a fabric is appropriate for a specific case Video content: overview of subdiscipline, concept of discomfort glare, shading options, and overview of the lighting component of the VADER-1 VR experience and final assignment
	VR	Goal: View the discomfort glare with natural lighting in west-facing wall and reduction in glare with different shading types
Construction Management	Video	1. Identify and describe the different roles of the actors in the Project Delivery Process 2. Perform wall assembly cost estimate with about 10% accuracy 3. Describe how the Project Delivery and Construction relate to the AE disciplines in the context of wall assemblies Video content: overview of subdiscipline, concept of cost estimation, ways to calculate wall construction costs, and overview of the construction management component of the VADER-1 VR experience and final assignment
	VR	Goal: View the different wall types

In this study, flow state was studied to understand whether students felt immersed in the nIRV experience. On Survey C, students completed a modified version of the Flow Short Scale (FSS) [16] after the intervention to capture self-reported flow during VADER-1. The absorption items remained the same as [16]. Three of the fluency items were modified to better fit the VADER intervention context and provide language/phrasing that would be clearer to the students: (1) "My mind is completely clear" became "I was not distracted from the activity I was engaged in", (2) "My thoughts/activities run fluidly and smoothly" became "I could navigate fluidly and smoothly through the virtual environments", and (3) "The right thoughts/movements occur of their own accord" became "The environment was responsive to the actions I performed." Rather than using the original 7-point Likert Scale with a neutral center option, a 6-point Likert Scale was used with these options: 1=Strongly Disagree, 2=Disagree, 3=Slightly Disagree, 4=Slightly Agree, 5=Agree, and 6=Strongly Agree.

On Survey C, students were additionally asked, "Using the scale below, rate the difficulty level of each of the following VADERs rotations." These rotations included Acoustics, Lighting, HVAC, Structures, and Construction. These items were on a 5-point Likert Scale with 1=Too Difficult, 3= Just Right, and 5=Too Easy.

D. Data Analysis

The data was cleaned by (1) removing the responses of students who did not consent to participate in the study and (2) eliminating duplicate responses and responses without 100% Survey C completion. To ensure data integrity, students who responded to all FSS items with the same answer choice were removed as such responses likely indicate a student's lack attention while taking the survey. This resulted in 201 unique student responses.

A deterministic approach was applied to cluster students based on their FSS item responses. This clustering approach is often used in engineering education for clustering small data sets [26]. It is a hard clustering approach, meaning each student in the dataset is assigned to one and only one cluster [27]. SPSS software (Grad Pack v. 29) was used to complete the clustering analysis. A two-step process was used as per [28]. First, the optimum number of clusters in the dataset was identified using the hierarchical clustering Ward linkage method. This method seeks to minimize the total within-cluster variance and is often used in educational research [29]. An output of hierarchical clustering is a dendrogram which is used to estimate the number of clusters. That estimate is used as input for the second step, k-mean clustering. The k-mean clustering was used to identify the student members of each cluster.

For each student, an overall FSS score was computed as well as an FSS absorption and fluency score. Then, for each cluster, these FSS scores were used to compute a cluster mean and standard deviation. Additionally, for each cluster, the mean and standard deviation was computed for each FSS item. One-way ANOVA analyses were conducted to determine whether there were differences among the clusters for students' FSS mean overall, absorption, and fluency scores. When a significant difference was found, post-hoc Tukey's Honestly Significant Difference (HSD) tests were performed to identify which clusters were significantly different.

The clusters were explored for patterns in terms of student demographics. To test for significant differences among the clusters based on demographic frequencies, a Chi-squared test was conducted when assumptions for the test were not violated.

Finally, the clusters were explored for students' perceived difficulty of each AE/C subdiscipline rotation. Here too, one-way ANOVA with post-hot Tukey's HSD tests were performed to determine whether and which clusters were showed a difference.

V. Results

The first research question was: *What are students' self-reported flow states when using VADER-1?* To answer this question, a visual of the individual students' mean fluency versus absorption scores by cluster was created (Figure 2). In addition, mean and standard deviations for FSS items responses and overall, absorption, and fluency scores were computed for each cluster. The results are shown in Table 3, and a heat map was overlayed for ease of viewing of patterns. The red indicates a low mean, and the green indicates a high mean. A low mean corresponds to disagreement with the FSS items and therefore corresponds to students not feeling they experienced an aspect of flow state. A high mean corresponds to agreement with the FSS items and therefore corresponds to students feeling they experienced an aspect of flow.

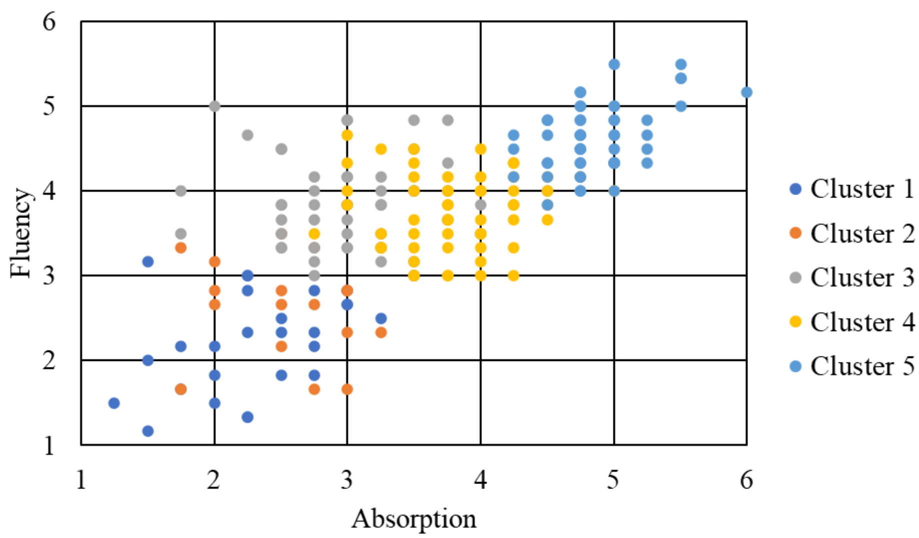

Figure 2. First-year AE/C students' mean fluency versus absorption scores (*n*=201)

Different clusters had different FSS response patterns. Students in Cluster 1 experienced low absorption and low fluency. However, students in Cluster 5 experienced high absorption and high fluency. Clusters 2-4 experienced varying levels in between. Generally, students in Cluster 2 had low absorption and low fluency, but they were completely lost in thought and could navigate in the virtual environment that they felt was responsive to the actions they performed. Generally, students in Cluster 3 had low absorption but high fluency. While their absorption scores were low, students agreed that they felt the right amount of challenge. Further, while they had high fluency scores, they did not agree that they had no difficulty concentrating or that they were not distracted from the activity. Finally, Cluster 4 students generally agreed with the absorption and fluency statements, but they did not agree to the extent that Cluster 5 did.

Table 3. First-year AE/C students' mean responses to FSS items by cluster with an overlayed heat map (*n*=201)

FSS Items	Clusters				
	1	2	3	4	5
Number of students (*n*=)	**26**	**17**	**51**	**56**	**51**
Absorption	**Rating *M*(*SD*)**				
I felt just the right amount of challenge	2.81 (1.02)	1.94 (0.97)	4.20 (0.94)	4.38 (0.89)	4.98 (0.62)
I didn't notice time passing	2.19 (0.98)	1.59 (1.00)	2.55 (1.06)	3.70 (1.04)	4.76 (0.71)
I was totally absorbed in what I was doing	2.08 (0.80)	2.24 (0.83)	2.88 (0.91)	3.91 (0.77)	4.80 (0.57)
I was completely lost in thought	2.08 (1.02)	4.35 (1.06)	2.53 (1.14)	3.30 (1.14)	3.06 (1.62)
Overall Mean (all items)	2.29 (0.54)	2.53 (0.48)	3.04 (0.56)	3.82 (0.47)	4.40 (0.53)
Fluency	**Rating *M*(*SD*)**				
I had no difficulty concentrating	1.96 (0.96)	1.88 (0.93)	3.02 (1.01)	4.20 (0.80)	4.84 (0.64)
I was not distracted from the activity I was engaged in	2.42 (1.27)	2.24 (1.15)	2.90 (0.93)	4.07 (0.87)	5.02 (0.55)
I knew what I had to do each step of the way	2.31 (1.05)	1.94 (0.66)	4.24 (1.03)	3.23 (0.85)	4.82 (0.79)
I felt that I had everything under control	2.58 (1.30)	2.12 (0.93)	4.43 (0.88)	3.52 (0.81)	4.96 (0.53)
I could navigate fluidly and smoothly through the virtual environments	2.08 (1.02)	3.24 (1.64)	4.12 (1.14)	3.66 (1.20)	4.92 (0.89)
The environment was responsive to the actions I performed	1.92 (0.93)	4.29 (0.92)	4.29 (1.08)	3.91 (0.92)	5.12 (0.62)
Overall Mean	2.21 (0.58)	2.62 (0.58)	3.85 (0.53)	3.77 (0.45)	4.95 (0.33)
Overall FSS	2.24 (0.78)	2.58 (0.36)	3.52 (0.38)	3.79 (0.34)	4.73 (0.33)

The results of the ANOVA with Tukey's HSD tests revealed significant differences among the clusters for the overall FSS scores ($F(4,196)=242.34$, $p < 0.001$) as well as the absorption scores ($F(4,196)=103.37$, $p < 0.000$) and the fluency scores ($F(4,196)=173.06$, $p < 0.000$). For the overall FSS scores, Clusters 3 and 4 were not found to be significantly different, Clusters 1 and 2 were significantly different with $p = 0.003$. All other cluster pairings were significantly different with $p < 0.001$. For the absorption scores, Clusters 1 and 2 were not found to be significantly different. This can be seen in the vertical overlap in Clusters 1 and 2 in Figure 2. Clusters 2 and 3 were significantly different with $p = 0.001$, and all other cluster pairings were significantly different with $p < 0.001$. For the fluency scores, Clusters 3 and 4 were not found to be significantly different. This lack of difference can be seen in the horizonal overlap in Clusters 3 and 4 in Figure 2. Clusters 1 and 2 were significantly different with $p = 0.007$; all other cluster pairings were significantly different with $p < 0.001$.

The second research question explored was: How are identified patterns different with regards to students' demographics and perceived difficulty of the VADERs modules? Table 4 shows the student demographics for each cluster. It is difficult to see many patterns in this data because a large percentage of the students are white males or students attending the R1 Midwestern institution. However, some key observations are that (a) a large fraction of the female students were in Cluster 4, (b) Cluster 1 was primarily made up of the R1 Midwestern institution, and (c) many students that self-identified as Hispanic or Latino were in Cluster 4. No Chi-square analyses were possible for gender, race/ethnicity, or institution because the assumption that frequency counts are at least five was violated. For intended major, the chi-square test was performed; no statical difference was found.

Table 4. Self-reported Demographics by Cluster

Category	Subgroup	No. Students in Cluster				
		1	2	3	4	5
	Number of students (*n*=)	**26**	**17**	**51**	**56**	**51**
Gender	Male	21	8	36	37	38
	Female	3	6	8	16	4
	Other	2	3	8	4	9
Race/ ethnicity[1]	Black or African American	2	3	3	8	7
	Hispanic or Latino	3	1	6	15	4
	White	20	10	38	29	31
	Other	4	5	9	7	12
Institution	R1 Midwestern institution	25	13	44	45	40
	R2 Southeast HBCU	0	1	2	5	7
	R1 Southeast institution	1	3	5	6	4
Intended Major	Architectural Engineering	8	8	21	18	18
	Construction	18	8	29	30	32
	Other	0	1	1	5	0
	Undeclared	0	0	0	3	1

[1] Counts > sample size when students selected more than one race/ethnicity option

Students' perception of the difficulty of each rotation overall and for each cluster was found (Table 4). As a reminder, these items were on a 5-point Likert Scale with options: 1=too difficult, 3=just right, and 5=too easy.

Table 6. First-year AE/C students' perception of rotation difficulty by cluster with an overlayed heat map (*n*=201).

Rotation	Overall	Cluster Ratings *M*(*SD*)				
		1	2	3	4	5
Number of students (*n*=)		**26**	**17**	**51**	**56**	**51**
HVAC	2.61 (0.79)	2.50 (0.91)	1.76 (0.75)	2.80 (0.69)	2.48 (0.71)	2.90 (0.67)
Structures	2.65 (0.95)	2.65 (1.13)	2.24 (1.03)	2.63 (0.72)	2.57 (0.95)	2.88 (0.82)
Acoustics	2.77 (0.77)	2.73 (0.92)	2.12 (0.93)	2.88 (0.62)	2.71 (0.73)	2.96 (0.69)
Lighting	3.04 (0.89)	3.04 (1.04)	2.59 (1.37)	3.08 (0.72)	3.02 (0.88)	3.20 (0.75)
Construction	3.02 (0.87)	3.15 (1.08)	2.88 (1.27)	3.16 (0.67)	2.73 (0.84)	3.16 (0.87)
Overall Difficulty		2.61 (0.67)	2.32 (0.81)	2.91 (0.45)	2.70 (0.51)	3.02 (0.51)

When looking across rotations, differences in perceived difficulty among the rotations were found ($F(4,196)=11.54$, $p < 0.001$). The perceived difficulty of the HVAC, Structures, and Acoustics rotations were significantly different (perceived as more difficult) than Lighting and Construction. In terms of overall difficulty, differences among the clusters were found ($F(4,196)=6.16$, $p < 0.001$). Cluster 2 found the rotations to be more difficult than any other cluster. This difference was significant for Clusters 2 and 3 and Clusters 2 and 5 ($p < 0.001$), Clusters 1 and 2 ($p = 0.003$), and to a lesser extent Cluster 2 and 4 ($p = 0.04$). For HVAC and Acoustics, significant differences were found among the clusters, $F(4,196) = 9.25$, $p < 0.001$ and $F(4,196) = 4.53$, $p = 0.002$, respectively. Cluster 2 alone found the rotations to be statically more difficult than each of the other clusters.

VI. Discussion

Each of the research questions are discussed below starting the patterns seen in students' self-reported flow state while engaged in the VADER-1 module. This is followed by a discussion of the differences in flow based on students' demographics and their self-reported perceived difficulty with the VADER-1 Rotations.

Overall, the results provide evidence that VADER-1 is engaging a majority of the students. Students in Clusters 3, 4, and 5, representing 79% of all participants, tended to agree that they experienced a flow state. However, students in Clusters 1 and 2 seemed to struggle with entering a flow state in terms of both absorption and fluency. In addition, students in Cluster 3 tended to disagree that they experienced absorption, though they agreed they experienced fluency. Recall the channel model of flow which describes the interplay of task challenge and learner skill level on a learners' flow state [14]. In this model, anxiety and boredom negatively impact flow state. Anxiety may be at the root of Cluster 1 and 2 students' low flow states. They indicated in their FSS responses that the challenge level was not right for them, they were unclear about what they were supposed to be doing, and they did not feel in control. For Cluster 1, anxiety may have been exacerbated by their having trouble navigating within VADER-1, as indicated by their FSS fluency responses. Navigation was not an issue indicated by Cluster 2 students.

In contrast, students in Cluster 3 agreed that the challenge was appropriate, they understood what they were supposed to do, and could navigate within VADER-1. These students, however, did not agree that they were absorbed in the VADER-1 module. These students might be indicating boredom.

The purpose of the investigation into differences in flow state among the clusters based on demographics and perceived difficulty of the VADER-1 rotations was to understand for whom a flow state was not attainable while engaged with VADER-1 and potentially whether one or more rotations might explain lower flow states. In terms of demographics, there were too few students from some groups to perform statistical analyses. However, for all demographics the trend seemed to hold that most students, regardless of demographic group, were in Clusters 3, 4, and 5. Perhaps slightly more females and those self-identifying as Hispanic or Latino were in Cluster 4. While not many studies related to educational VR and demographic groups have been conducted, there have been a few gaming studies conducted that look at gender differences. Results have been mixed. On the one hand, Yang and Quadir [30], found that gender differences played a significant role in the game flow experience. Inal and Cagiltay [31] suggested girls achieved more gaming flow experience than boys in game narratives, perhaps, as others suggest, because females were likely to concentrate on the completion of assignments [32]. On the other hand, Hoffman and Nadelson [33] found that males were likely to be twice as engaged as females whereas Bressler and Bodzin [34] found gender was not an influential factor in predicting flow experience.

A lack of correlation between students' flow state and their demographics is desirable from a VR learning experience development standpoint. A lack of correlation would indicate that VADER-1 is not dis-advantaging traditionally underserved demographic groups. As a core motivator for the larger VADER project was to provide an immersive environment to stimulate *all* students' interest in AE/C, this preliminary finding is encouraging. However, as VADER-1 implementation continues, a combined larger sample size will allow a more rigorous examination of the relationship between students' flow state and demographic group.

The results concerning students' perceived difficulty of each rotation, placing the HVAC as the most difficult and Construction the least difficult, may be explained by the inherent differences in the five AE/C subdisciplines represented in the VADER-1 virtual environment. First, the level of potential engagement that could be offered in the VR experience varied between AE/C subdisciplines. The discipline experts on the research team could identify much more engaging activities for the lighting and acoustics subdisciplines than the structures, HVAC, and construction management subdisciplines (Table 2). While visualizing different types of walls in 3D and in the context of a completed building was an improvement over simply presenting the equations (i.e., R-value for HVAC, axial strength for structures, and cost estimate for CM) in a traditional lecture, there was not much interaction the students could engage in to visualize the changes in parameters.

Second, in terms of the final deliverable, the challenge associated with the rotations differed. HVAC rotation video presented equations that could have been intimidating to a first-year student. Even though the use of these equations were simplified and students could ultimately pick items from a table to do a one-step calculation to find the answer, it is possible that the table included too many options or the existence of the complex equations in the instruction confused them. Acoustics was similar in that ultimately students had to use a table to determine the final answers, but the parameter considered is relatively complex. In the Structures rotation, the students had to apply equations they were seeing for the first time. While they were explained step by step in the video and were simplified for the purpose of this first-year student experience, it could have been perceived as intimidating.

Finally, overall, it is not surprising that the students found HVAC rotation the most difficult, followed by Structures and Acoustics rotations. This is aligned by the observations of one of the authors, who was deeply involved in the curricula development for AE/C specialization for over 15 years. These three subdisciplines tend to be more calculus and physics intensive. In fact, especially for structural engineering, while this is not a licensure requirement, most employers feel the need to hire master's degree graduates to ensure competency in this complex and life-safety affecting field. On the other hand, the exercises offered in the Lighting and Construction Management subdisciplines were more intuitive and relate closely to students' daily use of the built environment and their basic life skills. Discomfort from glare is a common experience, and students could likely connect the activity to their life experiences of closing the shutters due to daylight in their rooms. Similarly, estimating the cost of a wall construction using the cost of each element is not very different than personal finance, such as monthly budgeting.

The low flow state reported by Cluster 2 students may be related to the difficulty they perceived having in the rotations. As Lemmens [35] found, "there is a significantly higher sense of flow in matching game difficulty in comparison to gameplay that is too challenging, but not when compared to easy gameplay." This could also help to explain why Cluster 3-5 experienced a higher sense of flow; the students viewed the game difficulty on average as "just right." This potential relationship does not bear out for Cluster 1; these students self-reported similar rotation difficulty to students in Clusters 3, 4, and 5, yet these students experienced an overall low flow state. Perhaps, for Cluster 1, the VADER-1 fluency issues influenced their negative perception of the challenge of the VADER-1 module.

While the perceived difficulty results inform potential revisions to the VADER-1 rotations, they do not provide much in the way of explanation for the difference in flow states across all of the Clusters. According to [36], [37], and [38], individual differences in the extent to people seek and attain flow can be significant. Future work may look at other variables for explanation. For instance, students' VR and gamer background and their Bartle's gamer type [39] might explain students' navigation experience in VADER-1. Other variables might include students' certainty in the AE/C major choice and interest in the subdisciplines. These variables might explain students' absorption.

VII. Conclusion

This study investigated first-year engineering students self-reported flow state in the VADER-1 module, an AE/C introduction to the subdisciplines that included an nIRV experience. Patterns in students' flow state while completing the VADER-1 module were sought. Students' demographics and their perceived difficulty of the subdiscipline rotations were examined to help explain the patterns in students' flow state. Five different patterns (clusters) were found in students' flow states. Just over three-quarters of the participants in three clusters self-report experiencing a flow state while completing VADER-1. Explanations related to students' demographic groups could not be fully explored due to low sample sizes for most groups, though preliminary finds suggested no correlation. Students' perceived difficulty of the VADER-1 module might explain the low flow state experienced by one cluster. Overall, further research needs to be done to understand the flow state patterns. This work would include a larger, more diverse set of participants and the exploration of other variables that may explain the differences.

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