Use of Virtual Reality to Improve Engagement and Self-Efficacy in Architectural Engineering Disciplines

Ece Erdogmus
School of Building Construction
Georgia Institute of Technology
Atlanta, NE, USA
ece.erdogmus@design.gatech.edu

Erica Ryherd
Durham School of Architectural Eng. and Construction
University of Nebraska-Lincoln
Linocln, NE, USA
eryherd@unl.edu

Heidi A. Diefes-Dux
Biological Systems Engineering
University of Nebraska-Lincoln
Lincoln, NE, USA
hdiefes-dux2@unl.edu

Catherine Armwood-Gordon
Civil and Architectural Eng.
Tennessee State University
Nashville, TN, USA
carmwood@tnstate.edu

***Abstract*— This *Innovative Practice Full Paper* presents findings from the implementation of a virtual reality-based learning module. In the Fall of 2020, a prototype for a novel intervention namely, Virtual/Augmented-Reality-Based Discipline Exploration Rotations (VADERs), was offered as part of the first-year Introduction to Architectural Engineering (AE) classes at two universities. VADERs will ultimately be a collection of modules that are designed to improve student engagement and diversity-awareness by providing interactive virtual explorations of an engineering discipline and its sub-disciplines. VADERs utilize an open source, device-agnostic, and browser-based three-dimensional Virtual Reality (VR) platform, creating unique accessibility, synchronous social affordances, and media asset flexibility. The conjecture explored in this paper is: Having first-year engineering students experience Architectural Engineering and its sub-disciplines through an interactive VADER module, will improve their self-efficacy in regards to their commitment to studying the discipline. A total of 89 students participated in the VADER pilot in Fall 2020. Complete data was collected from 67 of these participants in the form of pre- and post- surveys, and final project deliverables. Results tied to the hypothesis and recommendations for future related work are discussed.**

Keywords*— *Virtual reality, Architectural Engineering, Self-efficacy, First-year

I. Introduction

Engineering "[requires] extensive amounts of knowledge integration because [the] content and foundations draw on multiple "other" domains (e.g., biology, mathematics, physics)" [1, p. 5]. Thus, the path to proficiency in engineering is long and difficult with the first two years of study typically focused on the knowledge and skills needed to be an engineer with little display of what it would be like to be an engineer. This model can weaken students' interest (engagement) and self-efficacy in the early years of an engineering degree program resulting in students leaving engineering, regardless of them being successful in the fundamental math and science courses [2].

Research shows that altruism (i.e., a clear understanding of the impact of engineering on community well-being) is the top reason for students to persist in engineering, especially those from underrepresented groups [2,3]. In response to these challenges, Changing the Conversation [4] recommends that, to be effective in both recruiting and retaining students in engineering, "engineering should talk less about the skills needed to be an engineer and more about the impact that engineering has on the world." The traditional means of connecting engineering curricula and real-world problems has been internships and capstone projects, and their effectiveness in improving students' self-efficacy and engineering identity is well documented [2,5-8]. However, these experiences are typically situated in the last couple years of the curriculum, due to the foundational knowledge required to perform meaningful work at a company or on a real-world problem.

Virtual reality (VR) and augmented-reality (AR) have matured to a point that they offer opportunities for simulated experiences that can bring elements of the real engineering world into lower division courses. Virtual/Augmented-Reality-Based Discipline Exploration Rotations (VADERs) was envisioned as a collection of modules that provide engaging virtual or augmented explorations of an engineering discipline and its sub-disciplines that could be used to improve student engagement, self-efficacy, and, ultimately, retention, particularly among women and underrepresented minority students. In this paper, the following conjecture was explored: Having first-year engineering students experience Architectural Engineering (AE) and its sub-disciplines through an interactive VADER module; will improve their self-efficacy in regards to their commitment to studying the discipline. Results of a pilot using the first VADERs module in first-year engineering courses of an Architectural Engineering and Construction (AEC) programs at two different universities are presented. Architectural Engineering is an interdisciplinary field that is concerned with the design of buildings and building systems. Four basic architectural engineering curriculum areas are building structures, building mechanical systems (may include acoustics), building electrical systems (may include lighting), and construction/construction management.

The results of concern in this paper are the impact of the pilot on students' self-efficacy with regards to their commitment to study AE as a whole and its particular sub-disciplines.

II. Background

A. First-Year Exposure to Disciplines

General first-year engineering courses often have a goal related to helping students select or confirm their engineering major by informing them "about the nature of engineering and its specific disciplines" [9]. There is evidence to suggest that majors that have an introduction to the engineering courses are successful in this regard [e.g., 10], with students selecting majors they know little about prior to such a course [11]. Department-based first-year engineering courses often need to have a similar goal of introducing students to the breadth of the discipline, which may be divided into sub-disciplines that are distinct in terms of their knowledge-domain. Students are often not aware of these sub-disciplines or their interrelationships.

Strategies for introducing students to the engineering fields have varied over time. The lecture format in which each discipline is described by faculty, students, alumni, employers, or some combination thereof was, and to some extent continues to be, a fixture of first-year engineering courses. As the benefits of active learning became increasingly recognized, first-year engineering courses have turned to more engaging ways of enabling students to experience engineering and the disciplines. For instance, discipline-representative laboratories were found to successfully inform students about the nature of engineering and its specific disciplines [12]. As new technologies that can facilitate instruction have emerged, they too have been employed to help inform students about the engineering disciplines. For instance, the face-to-face introductory lectures have been repackaged in video format. Further, internet-based course formats were adopted as a new means to expose students to the engineering disciplines [13]. Today, virtual reality and augmented reality offer new opportunities to engage students in learning about the disciplines of engineering.

B. *Affordances of VR/AR in AEC Education*

Recent studies explored interactive instructional tools on various types of platforms, including VR/AR for teaching singular topics such as structural analysis, simulation of compression testing, construction safety, equipment and operational task training, and sustainable building designs [14-19]. Immersive gaming has also been explored as a promising technology, especially for construction safety education, because of its effective visualization and manipulation capabilities that facilitate real-world construction site experiences without exposing the students to unsafe situations [20-23]. In each of these studies, groups that used immersive technologies for learning and collaboration showed significantly higher levels of learning and content knowledge than those who used traditional methods. Utilizing immersive visualization and student-computer interaction, these studies were able to stimulate students' interests [17], enhance their knowledge acquisition [17], and improve success in creative design and planning tasks [16, 19]. However, it is suggested that most of these immersive instructional tools are stand-alone applications that focus on enhancing learning outcomes of selected topics [24], which is deemed as a deficiency in the previously studied applications of VR/AR. The design of VADERs is intended to overcome this deficiency with a goal of immersing students in an exploration of the sub-disciplines and their integration through an authentic work-like experience.

III. Theoretical Framework

This work is grounded in Social Cognitive Career Theory (SCCT) [25]. At the heart of this theory, students' self-efficacy beliefs (most simply stated, their beliefs in their ability to succeed) [26] contribute to initial interest formation followed by choice of goals, pursuit of actions to achieve the goals, and ultimately performance attainment. In this work, VR/AR enabled experiences in Architectural Engineering were aimed at increasing students' self-efficacy by improving students' exposure to the domain knowledge and contributions of the sub-disciplines of AE to an overall building design project, so that students could confirm their sub-discipline and be set on a path to being retained through to degree completion.

IV. What Are VADERs?

Virtual/Augmented-Reality-Based Discipline Exploration Rotations (VADERs) are VR/AR-based, multimedia instructional modules designed to generate and maintain students' engagement in engineering and construction disciplines. VADERs combine various visualization and VR/AR techniques with traditional engineering tasks to connect engineering education course content to real-world problems. VADERs are not "games." Also, VADERs are not stand-alone instructional tools, nor do they replace technical courses or content. Instead, they are designed and will be tested for their effectiveness in serving as a supporting intervention across a 4-year degree to keep students engaged and help them persevere within engineering curricula by offering students more authentic engineering experiences than what is typically provided through normal coursework and activities.

Visualization and interactive VR/AR tools included in VADERs are: Mozilla Hubs rooms with spatial and audio means for social interactions of life-like avatars, an interactive building environment, interactive exercises created in Unity gaming platform, and embedded audios/videos for hearing/viewing the impact of design decisions. VADERs are inspired by other experiential learning techniques with established impact, including engineering internships [5-8], medical discipline rotations [27-31], epistemic learning environments [32-36], and industry applications to training rotations (e.g., Toyota, Caterpillar [37]). VADERs also utilize, in a limited context, research on game-based learning [38-40]. Three levels of VADERs are envisioned for implementation in engineering programs at different levels of a student's degree. One of these modules, VADER-1, has been developed and piloted. This module is the focus of this paper.

The VADER-1 level pilot module (Fig. 1) was designed for first-year students in AEC programs. This module was geared towards helping students explore the AEC subdisciplines through rotations. In the pilot, students took on roles as interns at VADER Incorporated and worked on the design of the virtual

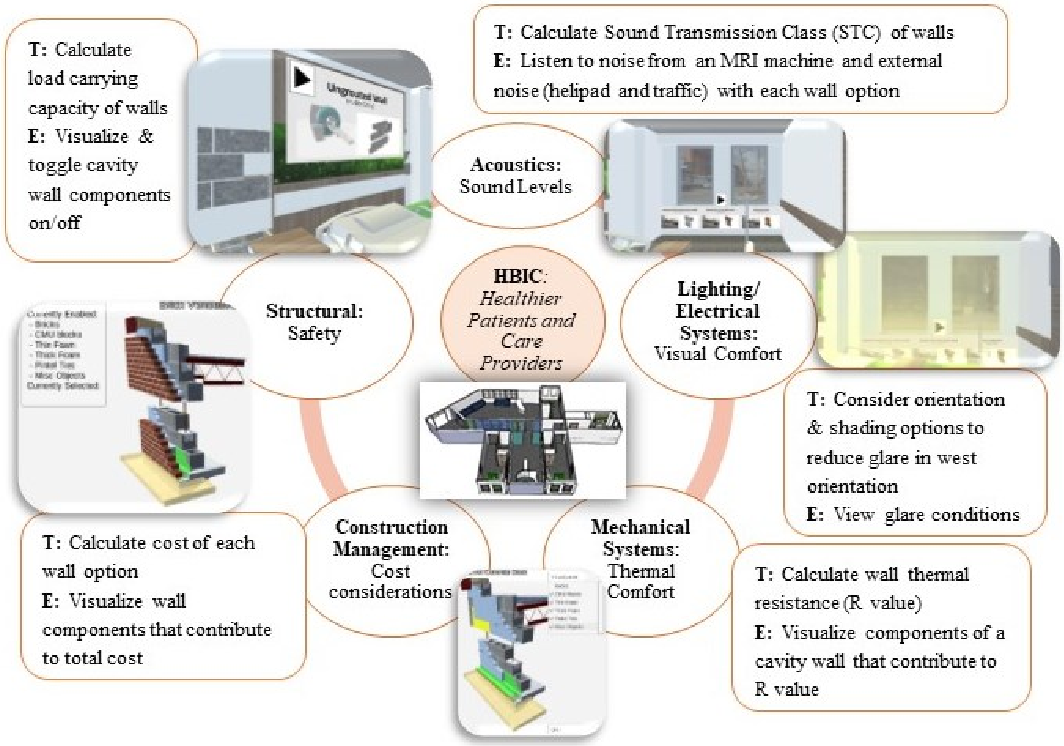

Fig. 1. VADER-1 Module rotations through five AEC disciplines completing traditional engineering tasks (T) linked with experiential, virtual world tasks (E).

Husker Brain Injury Clinic (HBIC). The selection of a healthcare setting was purposeful, showcasing how engineering can improve the human conditions by leveraging [the AEC program's] research focus on healthcare facilities. Students were then allowed to experience virtual rotations through the five sub-disciplines of AEC (acoustics, lighting/electrical, mechanical, structural, and construction management). The intervention goals were to improve student self-efficacy and retention by illuminating the purview of each sub-discipline and the relationships between them.

Students completed a series of training tasks before starting their work on the VADER missions. Three VADER introduction videos explained the context, learning objectives, how to access the modules, and the tasks to be completed. A separate training video was provided to introduce the Mozilla hubs platform and how to create a self-like Avatar (if they choose to do that). Additionally, five training videos, one for each AEC sub-discipline, were provided to explain the purview of each branch of AEC as well as the basic theory needed to complete the VADER tasks. All videos were less than 15 minutes long. Finally, the lead faculty member held an online question-answer session for students that may have additional questions regarding any aspect of the project and its execution.

Within each sub-discipline, students completed a variety of traditional engineering tasks (T), such as applying equations and performing calculations, alongside virtual, experiential tasks (E) to gain a sense of the implications of their calculations/design decisions. For example, students watched a short educational video about acoustics, calculated key acoustic aspects (i.e., sound transmission of various wall types), listened to various noises in the virtual clinic (i.e., noises transmitted by various wall types), and ultimately made design decisions on the construction system based on a combination of tasks and experiences weighing in conflicts with the "best option" for other subdisciplines.

V. Methods

A. Setting and Participants

The settings for this VADER-1 pilot study in Fall 2020 were a first-year Introduction to Architectural Engineering course offered at a Midwest R1 institution (n=67) and a similar course offered at a Southeast R2 institution (n=22).

At both institutions this first-year course was a 1-credit hour course. The students represented a range of demographics, including 70% White / Caucasian, 21% Black / African American, 7% Hispanic American, 3% Asian / Pacific Islander, and 2% other / prefer not to respond. Gender identity was described as man (70%), woman (30%), and transgender (1%).

B. Implementation of VADER-1 Pilot

VADER-1 pilot was the term project assignment in both courses, and the entire duration of the project was three weeks from the initial date of assignment to the student deliverable deadline. The outside-of-class effort expected from the students totaled nine hours. The learning objectives were to: 1) Explain the purview of each of the five AEC disciplines; 2) Discuss the relationship between the AEC disciplines; and 3) Explain AEC's impact on humans. A learning management system (i.e., Canvas) was used to disseminate all necessary module information, including three introduction videos, five sub-discipline training videos, links to Mozilla Hubs rooms, links to pre- and post-surveys, and a project checklist.

Prior to beginning any activities, students completed a pre-survey that collected general demographics and included a collection of items on motivation, engagement, self-efficacy, and diversity awareness. Students were asked some questions about their gamer styles, preferences, and experiences, as well as, asked to reflect on what they hoped to learn from the VADER experience.

Following the survey, students completed the introduction portion of the project, which consisted of watching a series of three short introduction videos that provided an overview of the VADER project, introduced the mission checklist and task sheets, and explained building envelopes and cavity walls. A short cavity wall component interactive game was also included in the introduction phase. Each of the introduction videos was 15 minutes or less in duration. As part of the introduction, students were also tasked with creating their own avatar, starting a project timesheet, and practicing using Mozilla Hubs. Social hours were held to promote interactions with students from both institutions. Students interacted in small groups via their avatars and participated in various getting-to-know-you activities. The social hour was held in Mozilla Hubs virtual conference room to give students additional experience using the platform.

The next part of the project introduced students to their virtual internship. Students took on roles as interns at VADER Incorporated and worked on the design of the virtual XBIC. Students entered the virtual Hubs platform on their own via their avatar and selected a project manager from a selection of six diverse options (African American female, Middle Eastern male, White female, White male, Asian female, Hispanic male). Students were introduced to the main VADER mission by their selected project manager with a short voice-over, with representative/authentic accents/speech patterns, if applicable.

After being introduced to the mission, students worked independently to complete the VADER tasks, which consisted of virtual rotations through the five sub-disciplines of AEC (acoustics, lighting/electrical, mechanical, structural, and construction management). They watched short training videos describing each sub-discipline and sub-discipline specific content necessary for the tasks, completed various calculations, and navigated around the virtual XBIC environment to explore the impacts of various design decisions for each of the five sub-disciplines. All videos were approximately 15 minutes long. To demonstrate their knowledge of the AE subdisciplines, students were asked to assemble a design team for the project by reviewing qualifications of a fictitious slate of AE experts. Based on the many experiences provided in the VADER-1 mission, students summarized their final design decisions, selected design team, and personal observations about what they believed they learned from the experience through two deliverables: a slide deck and post-survey.

C. *Data Collection and Analysis*

The pre- and post-intervention surveys were administered to the first-year engineering course enrollees. A total of 67 students completed both surveys across both universities (61% R1, 39% R2). The data collected for analysis in this paper were student responses to items that focused on students' understanding and confidence in selection of an AEC sub-discipline and their confidence in their selection of AEC as a degree program. To provide context, students' responses to survey items and comments on their projects about their level of engagement with the VADER-1 mission are also reported. Descriptive statistics and visualizations were used to compare students' pre- and post-survey responses to multiple-choice (i.e., Likert-scale) and multiple-select items. An inductive thematic analysis was used to explore students' responses to an open-ended item regarding two things they learned about Architectural Engineering from the VADER-1 mission. Two coders coded each of the student responses and negotiated differences in codes when they occurred.

VI. Results

A. *Student Engagement*

Students were asked to rate their level of agreement or disagreement with statements regarding their engagement with VADER-1. A 6-point Likert-Scale (1=Strongly Disagree, 6 = Strongly Agree) was used. A majority of students agreed that they "felt immersed in the virtual environment" (76%), they "lost track of time in some of the virtual elements" (61%), and "the VADER mission was fun" (78%).

Students were asked what AEC concentration area they were most interested in focusing on for their studies. Although students reported a high degree of confidence before VADERs, nearly a third (31%) of students changed their "top" choice of specialization after the VADER-1 module. The majority (73%) agreed they were more confident in their top choice compared to before VADERs.

Other impacts on students' commitment to AE and self-efficacy are shown in Fig. 2. For example, students agreed that, compared to before the VADER-1 mission, they were more likely to stay in AE and earn their degree, more confident in their abilities to succeed, and had a better understanding of what AEs do.

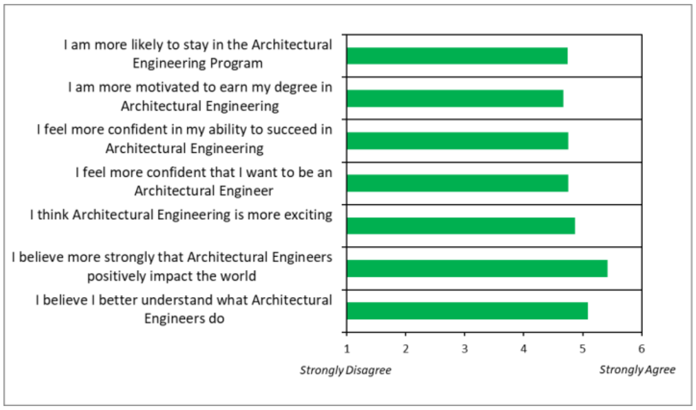

Fig. 2. Students' average response to "Compared to before the VADER mission…" (n = 67).

B. *Student Learning from VADER-1*

For students' responses to the survey prompt, "What are 2 things you didn't know about Architectural Engineering that you learned through the VADER mission?", the inductive thematic qualitative data analysis revealed eight themes (Table I). The most common responses made references to computations related to the project (Technical Equations), for instance, "I learned the basics of calculating the things that are especially important when designing a structure like axial strength or STC values." Also references to domain knowledge (Technical General) encountered in the project were common, for instance, "A lot of sound can be absorbed through empty space." Some students relayed that they learned something specific about materials, for example, "wall material type can make a huge difference in the sound level across rooms."

TABLE I. TOP THEMES CONCERNING STUDENTS' LEARNING FROM VADER-1 PILOT (*n*=67, 136 UNIQUE CODES).

Themes	**Description**	**Percent of Coded Responses**
Technical Equations	Refer to the use of equations or particular variables or doing math	20%
Technical General	Refer to some specific technical aspect they had not known before	15%
Complexity	Awareness of complexity of AE projects	11%
Decisions	Awareness of importance of decision-making and the large number of factors that must be accounted for when making decisions	11%
AE Types Coordination	Awareness of coordination needed between AE sub-disciplines within a project	10%
Materials	Specifically call out new knowledge about construction (wall) materials	8%
AE Types Differentiate	Now know there are different AE sub- disciplines	7%
Other	General insight intoAE, cost issues, time and effort, other	10%
No Response	Missing responses	7%

C. *Student Engagement*

While many of the students' responses centered on their learning of equations or technical content specific to the VADER project, some higher-level themes emerged. Some students also took away a greater understanding of the complexity of AE projects, and the importance of decision-making. One student commented on the complexity of one particular component of the VADER project, "I also learned that a wall is much more complex than I had previously imagined." Another commented on "how many decisions they [AEs] actually make at a jobsite." Bringing these ideas together, one student noted, "Some of the decisions they make on a project are more complex than what they seem upfront."

A number of students became aware of the need to coordinate the information or demands of all the various AE disciplines during an AE project. As one student wrote, "One thing I learned was just how much each discipline can conflict when working on a project." Another wrote, "I learned that every discipline really relies on another to work." In a related theme, students acknowledged, as one student put it, "I did not [know] that Architectural engineering had many different sub-disciplines." Another student related learning about how the AE sub-disciplines differentially contribute to a project: "Learned a lot about the considerations that each of the sub-disciplines would deal with on projects."

The concluding remarks from the students' project deliverable included multiple occurrences of words of engagement/interest such as enjoy, fun, and excite/exciting. In addition, powerful statements such as the following were made: "…contributed to my understanding of each specialization in Architectural Engineering more than any other resource I have experienced so far "and "…made me excited to keep pursuing my education in this industry. The simulation was exciting and creative and enhanced the experience."

VII. DISCUSSION

Evidence from the implementation of the VADER-1 module pilot appears to support the conjecture that having first-year engineering students experience Architectural Engineering and its sub-disciplines through an interactive VADER module will improve their self-efficacy in regards to their commitment to continuing the AE degree and studying a particular sub-discipline. According to SCCT [25], the psychological state one experiences while engaging in a task can impact self-efficacy. The VADER-1 module was intended to be a low-stakes, low-anxiety introduction to the AE disciplines where failure was considered part of the experience. SCCT goes on to link self-efficacy with increased interest in career related activities and engagement. As such, SCCT would predict that the VADER-1 module should have a positive impact on students' self-efficacy and students' commitment to AE and an AE sub-discipline.

In addition to an increase in self-efficacy and commitment to AE, the added benefits of the authenticity of the learning environment supported by the VR/AR technologies are evident. Beyond the learning of the domain content, which would be expected as a result of project work, students were seeing that the work AEs engage in professionally is complex and requires considerable coordination amongst the disciplines to successfully solve a client-driven problem. This is not a coincidence. The larger project team included at least one expert specialized in each of the five AEC sub-disciplines as well as two team leaders with degrees specifically in AE and oversaw AE curricula in each of the study site institutions. Leveraging years of collective and disciplinary experience, the main mission was carefully designed to be simple enough to be solved by first-year students (e.g., by focusing their attention on one type of element, such as a wall, and at most three possible provided solutions) but complex enough to demonstrate some conflicts between sub-disciplines. For example, the students were asked to choose a location in the building for one of the patient rooms. The western location had major glare problems (clearly visible in the VR interactions) while the northern side of the building had a helipad and a busy street, therefore the wall would transmit loud external noise. In addition, cost, structural capacity, and heat transfer of the wall options were provided to make a more complex decision matrix. Clearly, the best option was not straightforward; the pros and cons needed to be considered; and once a decision was made that caused issues with one sub-discipline, alternative solutions had to be sought (e.g., shading options, selection of a different wall type to eliminate noise). All told, the interactions of the AE sub-disciplines and their respective content through the VADER mission added to the complexity and authenticity of the learning experience.

VIII. Conclusions and Future Work

A prototype for a novel intervention namely, Virtual/Augmented-Reality-Based Discipline Exploration Rotations (VADERs), was developed and offered as part of first-year Introduction to Architectural Engineering (AE) classes. Students experienced virtual rotations across the five sub-disciplines of AEC (acoustics, lighting/electrical, mechanical, structural, and construction management). Results from 67 students indicated some potentially positive impacts on student learning, engagement, and self-efficacy in the AE degree. Additional research is underway to analyze collected diversity data, expand VADERs, and address some of the limitations in the pilot work, including developing VADER modules for other courses and/or levels of students.

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