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Exploring the Impact of Virtual Labs on Student Engagement and Learning Outcomes in Biological and Agricultural Engineering: A Scoping Review

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Work-in-Progress: Instructional Strategies Supporting Student Learning in Collaborative Virtual Reality

Abstract

Virtual reality (VR) is increasingly used in engineering education to support experiential and collaborative learning through realistic, technology-rich simulations. While prior research has demonstrated the potential of VR to enhance engagement and learning outcomes, less is known about how specific instructional strategies shape students' learning experiences in collaborative VR environments. This work-in-progress study examines undergraduate engineering students' perspectives on strategies that supported learning during a collaborative VR land surveying activity.

The study was conducted in a second-year civil engineering course at a large public university, where students completed a desktop-based VR simulation of professional surveying tasks while working in pairs. Semi-structured interviews were conducted with eight students following the activity. Data were analyzed using an inductive qualitative approach to identify strategies perceived as supportive of learning, engagement, and collaboration.

Findings indicate that students' learning experiences were strongly influenced by instructional design and facilitation rather than the VR technology alone. Key strategies included aligning tasks with real-world engineering practice, structuring collaboration, providing clear guidance and scaffolding, and creating opportunities for guided exploration through trial-and-error. Students reported that these strategies supported persistence, confidence, and meaningful engagement in the VR learning environment.

These findings highlight the importance of intentional pedagogical design in collaborative VR-based engineering instruction and provide practical insights and implementation considerations for educators seeking to integrate VR technologies into their courses.

Keywords: Virtual Reality (VR), Engineering Education, Instructional Strategies, Collaborative Learning, Experiential Learning

I. Introduction

Engineering education increasingly emphasizes learning environments that reflect the collaborative, technological, and applied nature of professional practice. Virtual reality (VR) has emerged as a promising instructional tool because it allows students to engage with realistic equipment, spatially complex tasks, and team-based problem-solving scenarios in areas such as surveying, structural analysis, design, and manufacturing [1-3]. Prior research shows that VR can enhance engagement, motivation, and conceptual understanding, particularly when learning activities simulate authentic engineering contexts [4-6]. These environments are especially relevant to engineering education, where teamwork, communication, and applied problem solving are central to professional practice.

However, VR does not inherently produce effective learning. In collaborative VR environments, students must simultaneously manage unfamiliar technology, complex tasks, and peer coordination, often in fast-paced and visually rich settings. Without adequate instructional support, these demands can lead to cognitive overload, ineffective collaboration, and reduced learning outcomes [7, 8]. As a result, the success of VR-based learning depends less on the technology itself and more on how learning activities are intentionally designed and facilitated.

Despite growing adoption of VR in engineering education, existing research has largely focused on technological affordances or learning outcomes rather than how instructional strategies shape students' experiences [3, 9]. This creates a critical gap. Without understanding how students experience instructional strategies in collaborative VR environments, educators risk implementing

VR in ways that hinder collaboration, increase cognitive burden, and reduce learning effectiveness [7, 10]. Addressing this gap is important for developing pedagogically grounded approaches to integrating collaborative VR in engineering education.

To address this gap, this study examines students' perspectives following a collaborative VR land surveying activity in a civil engineering course. We argue that instructional design, rather than VR technology alone, is a primary driver of learning, engagement, and collaboration in VR environments. By focusing on student-identified strategies, this work offers practical guidance for designing effective collaborative VR instruction.

Research Question

Guided by the goal of understanding instructional design and facilitation in collaborative VR environments, this study addresses the following research question:

How do students perceive instructional strategies that support learning, engagement, and collaboration in collaborative virtual reality environments?

II. Literature Review and Conceptual Framing

A. Literature Review

Virtual reality has expanded opportunities for experiential and collaborative learning in engineering education by enabling interaction with realistic tools, environments, and workflows. These environments allow students to engage with spatially complex concepts and simulate professional tasks that are often inaccessible in traditional classrooms [1, 11, 12].

Research consistently shows that VR can improve engagement and motivation, particularly when activities align with real-world engineering practice. Realistic simulations can increase perceived task value, persistence, and interest by helping students connect coursework to professional applications, especially when immersive environments support presence, agency, and meaningful task engagement [13]. In engineering contexts, VR also provides opportunities for applied learning and skill rehearsal that may otherwise be limited by cost, safety, equipment access, or logistical constraints [3, 7].

Collaboration is central to both engineering practice and VR-based learning. Grounded in social constructivist theory [14], collaborative learning emphasizes knowledge construction through interaction and shared problem-solving. VR environments can enhance collaboration by supporting real-time communication, shared spatial context, and coordinated interaction with virtual objects. These features enable co-presence and joint task engagement, which are essential for effective teamwork [8].

However, collaboration in VR is not inherently productive. Research suggests collaborative work in immersive environments can require additional support for coordination, role negotiation, and task management, particularly for complex or unfamiliar tasks [7, 15]. Without clear structure and guidance, collaborative VR activities can become inefficient or cognitively overwhelming. This highlights a critical point: learning outcomes in VR environments are shaped by instructional design, not by immersion alone [7, 16].

Recent studies increasingly emphasize that effective learning in VR environments depends on structured collaboration, clear expectations, and instructor facilitation [15, 17]. Instructional strategies such as scaffolding, structured collaboration, and guided exploration can help students regulate cognitive and technical demands while sustaining productive collaboration [7, 15, 18].

Together, this literature supports the central argument of this study: effective learning in collaborative VR environments depends on intentional pedagogical design rather than technological immersion alone. However, existing research provides limited insight into how students themselves experience these strategies in practice, and systematic guidance for collaborative VR instruction remains underdeveloped [19]. Addressing this gap is essential for developing effective, transferable instructional approaches for VR-based engineering education.

B. Conceptual Framing

Rather than adopting a single learning theory as a rigid analytical framework, this study is guided by a practice-oriented conceptual framing that emphasizes instructional design, collaboration, and student learning behaviors in VR learning environments. Prior research on self-regulated learning, collaborative learning, and experiential learning informs this framing by highlighting the importance of planning, engagement, adaptation, and reflection in complex learning tasks [20-23]. However, these constructs are treated as sensitizing concepts rather than prescriptive categories.

This framing recognizes that learning in collaborative VR environments is shaped by interactions among design features, technological affordances, and social dynamics. Students may navigate task expectations, coordinate with peers, respond to challenges, and reflect on outcomes, often simultaneously. By focusing on pedagogical strategies rather than individual learner traits, this study aligns with engineering education research that emphasizes the role of pedagogy and learning environments in shaping student experiences [24]. This approach supports the exploratory, work-in-progress nature of the study and provides a flexible framework for interpreting students' narratives without overextending theoretical claims.

Together, this literature review and conceptual framing position the study to contribute practical insights into how collaborative VR environments can be designed and facilitated to support student learning in engineering education.

III. Methodology

This study employed a qualitative interpretive research design [25] to explore students' perspectives on instructional strategies that supported learning in a collaborative virtual reality (VR) environment. Given the exploratory, work-in-progress nature of the study, the methodology emphasized inductive analysis to allow instructional themes to emerge directly from students' experiences.

A. Study Context and Participants

The study was conducted at a large, public land-grant R1 university in the southeastern United States within a required second-year undergraduate civil engineering course, *Geomatics and Surveying*. The course introduces foundational surveying concepts and emphasizes applied, field-based engineering practices.

As part of regular instruction, a collaborative VR-based land surveying activity was integrated into the course. The desktop-based VR simulation (See Fig. 1) replicated professional surveying tasks, including centering a total station, leveling equipment, calibrating instruments, and measuring distances and angles using a prism target. Step-by-step instructions were provided by the instructor, and students worked in pairs for approximately a 30-minute session at their convenience.

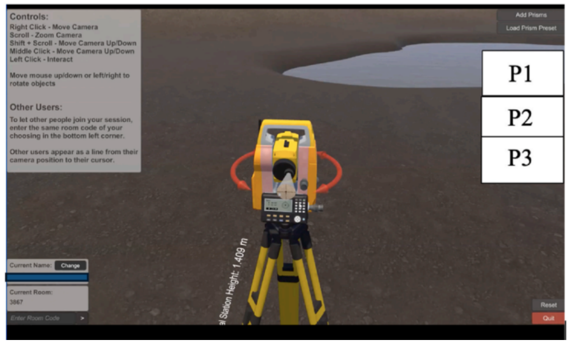

Fig. 1. Screenshot of the desktop-based virtual reality land surveying environment showing students (P1, P2, and P3) collaborating on a surveying task. Participant identifiers are anonymized.

During the Spring 2024 semester, 51 undergraduate students completed the VR activity. Following the session, students were invited in class and via email to participate in follow-up interviews. Institutional Review Board approval was obtained (blinded for review), and participation was voluntary and unrelated to course grading.

Eight students consented to participate in the semi-structured interviews. The interview sample included four male and four female students (four Asian students, three White students, and one South Asian student) between the ages of 20 and 22. Participants represented diverse racial and ethnic backgrounds and varying levels of confidence with surveying content and VR technology. By the final interviews, thematic redundancy was evident, indicating sufficient depth for the study aims.

B. Data Collection

Semi-structured interviews were conducted after students completed the VR activity. Interview questions prompted students to reflect on their learning experiences, focusing on aspects of instruction, collaboration, task structure, challenges, and supports encountered during the activity. Interviews were video recorded and transcribed verbatim.

Transcripts were reviewed alongside recordings to ensure accuracy. Identifying information was removed, and pseudonyms were assigned to protect participant confidentiality.

C. Inductive Data Analysis

Data analysis followed an inductive qualitative coding approach [26] aimed at identifying instructional strategies that students perceived as supporting their learning in the collaborative VR environment. Rather than applying a predefined theoretical framework, analysis prioritized participants' language and descriptions to allow themes to emerge organically from the data.

The first author conducted an initial open coding pass across all transcripts, identifying meaningful segments related to instructional design, facilitation, collaboration, task engagement, and learning experiences. Codes were refined iteratively through constant comparison, with similar codes grouped into broader categories.

Through this process, several instructional supports emerged in the broader analysis, with four particularly salient strategies highlighted in the findings presented here: **real-world relevance, collaboration and peer interaction, structured guidance and scaffolding, and guided exploration through trial-and-error.** While additional supports such as instructor support, incremental task challenges, and reflection also appeared in the broader data, the four themes presented here were most prominent in participants' accounts and most directly addressed the study's research question.

To enhance credibility and trustworthiness, emerging codes and themes were discussed regularly with the third and fourth authors throughout the analysis process to refine interpretations and ensure findings remained grounded in the data.

IV. Findings and Discussion

This section presents findings from semi-structured interviews with undergraduate engineering students following a collaborative VR land surveying activity. Analysis focused on students' perspectives on instructional strategies that supported learning, engagement, and collaboration in the VR environment. **Four** particularly salient instructional strategies emerged from the analysis, highlighting how pedagogical design and facilitation shaped students' learning experiences in collaborative VR contexts.

A. Real-World Relevance as a Foundation for Engagement

Students consistently emphasized that the perceived real-world relevance of the VR activity was a primary driver of motivation and sustained engagement. When tasks were clearly connected to professional engineering practice, students reported greater willingness to persist through challenges and invest effort in understanding the activity.

Student J described the value of authenticity by stating,

"Using it as a way to prepare yourself for, you know, life after graduation… a lot of this like total station and leveling surveying would help you in your future job."

Similarly, **Student Z** explained that personal interest in the discipline made difficulties more manageable:

"Because I have an interest in civil engineering, it made the frustrations… a little bit more enjoyable… this is an aspect of a field that I care about."

Several students reflected on how VR bridged classroom learning and field practice. **Student D** noted,

"I was amazed… how you can compare the two, like a total station setup in the field versus on the computer."

These perspectives suggest that aligning VR activities with authentic professional contexts can enhance motivation and encourage students to engage more deeply with complex tasks [1].

B. Collaboration and Peer Interaction as Learning Supports

Collaboration emerged as a central instructional strategy supporting student learning in the VR environment. Students frequently described working through challenges collectively, using peer discussion to clarify understanding, troubleshoot issues, and maintain engagement.

Student D captured this collective experience, stating,

"We were all trying to figure it out together… everyone was talking. Everyone was navigating through it."

Peer interaction also supported confidence and emotional persistence**. Student S** explained,

"Talking to my partner helped me a lot. And then it gave me confidence."

While collaboration occasionally introduced frustration or disagreement, students generally viewed these moments as part of the learning process rather than barriers. **Student J** reflected,

"We ran into some disagreements… we went around that… more of a trial and error type thing."

Overall, students perceived collaboration as a key mechanism that supported problem-solving, reduced isolation, and sustained engagement throughout the VR activity, reinforcing prior research on the importance of structured peer interaction and instructional support in collaborative VR learning environments [15], [17].

C. Structured Guidance and Scaffolding to Manage Complexity

Students highlighted the importance of clear instructions and structured task design when working in the VR environment. Step-by-step guidance helped students manage the complexity of the activity and prevented them from feeling overwhelmed.

Student I described the value of incremental structure, stating, *"We were able to work through it by taking it one step at a time."*

Similarly, **Student Z** explained their methodical approach: *"I basically tried to follow those step-by-step… very methodical."*

Students also noted that clarity in instructions helped them move past initial confusion. As **Student D** shared, *"Once we figured out the instructions… it went pretty straightforward."*

These findings indicate that scaffolding plays a critical role in supporting student learning in VR, particularly when students are unfamiliar with the technology or task requirements. This supports prior work which highlights the need for clear instructions, incremental task design, and accessible support to help students manage complexity and remain focused on learning goals [27].

D. Opportunities for Guided Exploration Through Trial-and-Error

Students described guided exploration through trial-and-error as an intentional and productive approach to learning in the VR environment. Rather than perceiving mistakes as failures, participants framed experimentation as a natural way to understand the system and refine their actions.

Student H summarized this sentiment succinctly: *"Trial and error just helped a lot."*

Other students echoed this exploratory mindset. **Student D** noted, "*If I don't understand a task, I just play around with it."*

The hands-on nature of VR supported this approach. **Student Z** highlighted the value of physical interaction, stating*, "I like the tactile, hands-on aspect of it… if I get stuck, I can still just wiggle some stuff around."*

These findings suggest that allowing space for exploration within structured boundaries can support active engagement and learning in collaborative VR settings.

V. Design Implications for Collaborative VR Instruction

The findings of this study suggest that effective collaborative VR instruction depends not simply on immersive technology, but on intentional pedagogical choices that support engagement, collaboration, and learning. Rather than treating authenticity, collaboration, scaffolding, and exploration as isolated features, the findings indicate these strategies work together to shape productive learning experiences in VR environments. Building on the themes identified in the findings, the following implications translate these results into practical considerations for instructors implementing collaborative VR activities.

A. Authenticity and Real-World Relevance

A key implication of this study is that collaborative VR activities should be grounded in authentic engineering practice. Students reported stronger motivation and persistence when tasks reflected professional tools, workflows, and decision-making processes. This suggests that VR instruction should prioritize simulations that mirror industry-relevant practices and explicitly connect virtual activities to professional engineering applications [1], [7].

Instructors can support authenticity through pre-activity discussions, comparisons to field procedures, and reflective prompts that help students relate simulated tasks to professional practice. In this study, the VR land surveying activity's alignment with real instrumentation procedures contributed to students perceiving the experience as meaningful preparation for future engineering work.

B. Structured Collaboration

The findings also highlight collaboration as a design feature that benefits from intentional structure. Students described peer interaction as supporting problem-solving, confidence, and persistence, while prior research suggests collaboration in VR does not organize itself automatically [15], [17].

Instructional designs can support structured collaboration by assigning complementary roles (e.g., equipment operator, navigator, recorder), incorporating collaboration prompts grounded in cooperative learning principles [28], and building in partner check-ins during activities. These supports can help sustain shared responsibility, communication, and productive interaction in unfamiliar virtual environments.

C. Scaffolding and Guided Support

Students consistently emphasized the importance of clear instructions and structured guidance for managing the cognitive and technical demands of the VR task. This suggests scaffolding should be treated as a core instructional component of collaborative VR design rather than an optional supplement.

Practical supports may include step-by-step instructions, task checklists, instructor walkthroughs, demonstration videos, or milestone-based progression [7], [27]. Such supports can help students focus on learning goals while reducing confusion or overload associated with navigating both disciplinary content and the VR environment.

D. Opportunities for Guided Exploration Through Trial-and-Error

The findings further suggest collaborative VR activities should provide opportunities for guided exploration through trial-and-error rather than overly constraining student action. Students often described experimentation and iterative problem-solving as productive aspects of learning, particularly when mistakes could be made without penalty.

Designing time and space for low-stakes experimentation, retries, and exploration can support confidence-building and deeper engagement [7], [13]. Importantly, exploration appeared most beneficial when situated within clear instructional boundaries, reinforcing that discovery and structure are complementary rather than competing design features.

Taken together, these implications suggest effective collaborative VR instruction emerges through the intentional integration of authenticity, structured collaboration, scaffolding, and opportunities for guided exploration. By embedding these supports into activity design, instructors can create VR learning experiences that promote engagement, persistence, and meaningful learning rather than relying on immersion alone.

VI. Conclusion

This study examined undergraduate civil engineering students' perspectives on instructional practices that supported learning during a collaborative virtual reality land surveying activity. By foregrounding student experiences, the study provides practice-oriented insights into how VR learning technologies can be effectively integrated into engineering education.

The findings indicate that student learning in collaborative VR environments is shaped by instructional choices rather than technology alone. Strategies such as aligning tasks with professional practice, structuring collaboration, providing clear guidance, and creating opportunities for guided exploration through trial-and-error collectively influenced students' engagement, confidence, and persistence during the VR learning task.

Rather than positioning VR as a stand-alone solution, this work emphasizes that pedagogical design and facilitation are central to the success of VR learning experiences. When VR activities are thoughtfully designed and supported, they can create meaningful opportunities for students to engage with complex, authentic engineering tasks in collaborative settings.

As a work-in-progress, this study offers exploratory insights based on a single implementation and a limited sample. The findings are intended to inform instructional practice and guide future research rather than to provide definitive claims about learning outcomes. Future work will extend this research by examining how these pedagogical strategies can be adapted across disciplines, scaled to larger courses, and refined to support diverse learners.

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