Virtual Reality and Collaborative Learning in Engineering Education: A Systematic Review Protocol

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Abstract— **This work-in-progress research paper aims to present a protocol for a systematic review focused on recent engineering education research on collaborative learning in virtual reality (VR) platforms. Despite the growing application of collaborative VR in engineering education, research on systematic instructional methods within these environments remains limited. This work-in-progress paper details a protocol for a systematic review that aims to fill this gap by evaluating the use of collaborative VR in engineering education. We outline the methods, including search strategies and criteria for inclusion, based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. The review will focus on identifying the skills and competencies targeted by collaborative VR applications, the theoretical underpinnings employed, and the learning outcomes achieved. This systematic approach will provide a comprehensive synthesis of existing literature, offer insights into effective practices, and guide future research and instructional strategies in engineering education using VR technologies. Through this protocol, we aim to contribute to the development of evidence-based guidelines that can enhance the efficacy of collaborative VR learning environments for engineering students.**

Keywords— Virtual reality (VR), Collaborative learning, engineering education

I. Introduction

Collaborative learning allows students to learn by actively engaging with their peers to solve a problem or complete a task [1]. This approach to learning is becoming integral and vital for engineering education because of its proven benefits, such as increased student engagement and the development of collaborative skills for future careers [2, 3].

Past research suggests collaborative learning experiences support better learning outcomes. For example, the meta-analysis conducted by Kyndt et al. [4] comparing real-life classroom-based cooperative activities with traditional, lecture-based learning reports a high effect size (.54) on students' achievement. Nokes-Malach et al. [5] study on laboratory tasks problem-solving also found that collaborative groups perform better than individual groups. Researchers [6] have also shown that students active interactions and sharing of ideas with one another in a collaborative setting enhance their critical thinking.

Though various tools such as simulation-based platforms [7, 8] could be used to support collaborative learning in engineering education, virtual reality (VR) has emerged as popular in recent years [9].VR has been incorporated into engineering education as a tool for augmenting collaborative learning because VR can harness internet connectivity to enable networked solutions, allowing students to engage in collaborative learning activities and environments, regardless of their location [10, 11]. VR provides numerous affordances that make it well-suited for engineering education. It uses graphical representations to simulate real-world environments in virtual space, allowing participants to interact with the simulated environments through their senses [12]. By providing interactive learning environments, educators can tailor curricula around customized virtual worlds to achieve targeted course objectives [13, 14]. Soliman et al.'s [15] study emphasized the cognitive and pedagogical benefits of VR, leading to improved comprehension, academic performance, and grades among engineering students.

Besides, VR has been used to facilitate laboratory practices that are similar to those experienced in traditional in-person laboratories [16, 17]. VR could provide access to laboratory practices that might have been too risky, costly, or otherwise inaccessible in real life [18]. It has also been used to facilitate immersive learning experiences [16] beyond the limitations of traditional laboratories. While some may think the initial investment costs involved in setting up VR laboratories, including hardware, software, and educator training, are high, Soliman et al. [15] argue that VR implementation can ultimately reduce institutions' long-term costs by replacing expensive physical laboratories. Also, VR can foster greater accessibility and inclusivity by providing learning opportunities for distance learners who lack access to [19].

The implementation of VR for collaborative learning has shown the potential for improved effectiveness of team behavior, a richer form of learning outcome, and an enhanced form of communication among team members [20]. Collaborative VR platforms offer innovative training opportunities for engineering students, helping them to competitively prepare for future workforce needs. Within the platform, students can interact with each other while also engaging in VR learning activities, which is increasingly feasible with improvements in internetwork connectivity [21]. Mayer et al. [22], found that engineering students engaging in VR avatar-avatar collaboration is more engaging and satisfying than traditional face-to-face group work. Also, the study by Oumaima, Abdelhak, and Youssef [23] revealed that VR enhances learners' engagement and collaboration through the integration of social and inversion features.

Collaborative VR learning environments not only provide unique pedagogical advantages but also support international and interdisciplinary learning experiences. For instance, the study by Frydenberg and Andone [24] suggests that students working on international shared projects in VR expressed increased interest in technology after completion of the project. Also, Eiler et al. [25] study found that students who completed an interdisciplinary project in engineering and medicine using VR felt successful afterward.

In our previous studies [18, 26-28], VR learning platforms, displayed in Figures 1 and 2, were utilized to facilitate teaching-learning engineering statics and land-surveying topics. In these learning platforms, engineering students can collaboratively and interactively learn with simulated virtual environments.

Although numerous studies have explored the use of collaborative VR in engineering education, there is a significant lack of research focused on creating systematic guidelines to enhance learning and instruction within these platforms. This gap may hinder the development of effective instructional methods. To address this, we are conducting a systematic review of recent research on collaborative VR in engineering education. Our goal is to search for, evaluate, and synthesize research evidence on the use of collaborative VR in engineering education. The systematic review will summarize current knowledge, offer recommendations for practice, identify gaps in the findings, and suggest directions for future research.

This work-in-progress paper outlines our protocol for the systematic review, detailing the search terms, databases, and inclusion criteria that will guide our examination of relevant studies. By providing a clear and systematic "road map," our protocol aims to serve as a model for systematic review development in the engineering education research community.

Fig. 1 VR learning environment for teaching engineering statics

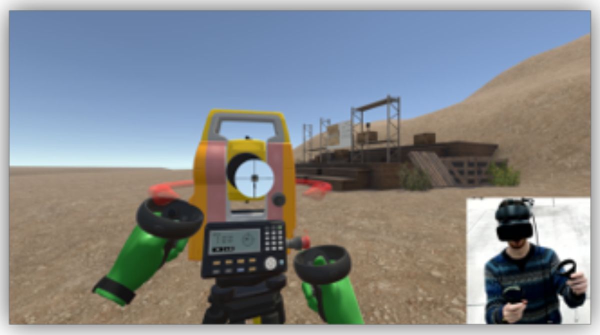

Fig. 2 VR learning environment for teaching land surveying

To accomplish our goal, the following research questions (RQ) will be answered in the systematic review:

RQ1: What skills and competencies have been explored in the literature on collaborative VR learning in engineering education?

RQ2: What theoretical underpinnings and learning paradigms have been used in the literature to examine collaborative VR learning in engineering education?

RQ3: What outcomes, measures, and key findings have been identified in the literature on collaborative VR learning in engineering education?

II. Methods

To enhance the reliability of the systematic review, we will follow the procedures of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework [28]. The framework offers a well-defined process for carrying out systematic reviews and meta-analyses, and previous research has validated its effectiveness [29].

A. Eligibility Criteria

This systematic review will include empirical studies that are publicly accessible and indexed by database studies. Furthermore, these studies must be peer-reviewed and written in English. Specifically, VR should be employed as an instructional tool within the context of engineering education. Additionally, the studies should involve collaboration among users within the VR environment.

Furthermore, studies that rely on secondary data or are non-empirical, such as reviews and meta-analyses, as well as those that merely describe a patent, opinion pieces, or duplicates or updated versions of previously included papers, will be excluded from the study.

B. Information Sources

We will gather information from electronic databases, trial registries, various forms of grey literature, and directly from researchers and authors. We will conduct an electronic search across EBSCO Library, Wiley, IEEE Xplore Digital Library, Web of Science and Engineering Village bibliographic database using appropriate combination of Boolean search syntax terms: ("virtual reality" OR "VR" OR "virtual environment" OR "virtual simulation") AND ("collaborative learning" OR "teamwork" OR "group work"

OR “peer learning” OR “group learning” OR “collaborative education”) AND “Engineering education.”

Furthermore, reference lists of pertinent articles and systematic reviews, as well as tables of contents of key journals in the field, will be scrutinized for further relevant material.

C. Data Management

We will document every detail of the review such as the total number of retrieved, the number count of full text acquired, and the tally of articles included and excluded. This data will be meticulously organized using Rayyan software. The retrieved articles will be filtered based on the eligibility criteria (Described in A above), initially examining their titles and abstracts during the initial stage of screening, followed by a detailed review of the article texts during the secondary screening stage. Any rationale for excluding full-text studies will be clearly elucidated in the final review.

D. Coding the articles

To ensure the coding process's reliability and validity, two researchers will participate in the process. We will follow the coding procedure highlighted in a similar review by Haoming and Wei [29]. Firstly, the primary researcher will thoroughly review the selected literature and record pertinent information related to the research questions in an MS Office Excel spreadsheet. Secondly, a secondary researcher will meticulously review the articles and cross-reference the content within the spreadsheet crafted by the primary researcher. Following this, both researchers will convene numerous meetings to address and resolve any discrepancies in their findings. Lastly, after exhaustive deliberations, a consensus regarding the coding outcomes will be achieved.

The content analysis method, previously successful in other review articles [30], will be used to interpret and analyze the articles included. Content analysis allows for systematic reduction of large volumes of text into a smaller number of content categories based on explicit coding rules [31] . Each article will be coded to extract the following information: title of the paper, author name(s), year type (journal or conference paper), nationality domain, subject or area of discipline, research purpose and/or question and/or hypothesis, theoretical or conceptual framework or learning paradigms used in the study, form of collaboration among the participants, outcome measures and key findings.

E. Reporting

Following the coding of the articles described above, the final report will be drafted adhering to PRISMA guidelines.

Before answering the study research questions, we are going to report the overview of the literature based on their geographic location and domains, subject domains and disciplines of the studies and the technologies and systems that have been developed and/or established in the literature.

We will answer research question 1 based on the procedure highlighted by the study by Van der Meer et al. [32] by categorizing the skills and competences explored in the literature into categories such as cultural skills, domain-specific skills, learning skills, physical skills, and social skills.

Research question 2 will be answered by following the process of a similar study [33] by quantifying the identified learning theories and theoretical paradigms and making case for their integration into collaborative VR design.

We will answer research question 3 adapting the pattern of a similar study by Akcayir and Akcayir [30]. The learning outcomes and key findings of the literature will be categorized into themes, and possible sub-categories of the themes will also be identified and quantified. The identified themes and sub-categories of outcomes measures and key findings will be discussed with respect to their implication for engineering education practice and future research.

III. Findings to Date

In our initial analysis of the systematic review, we retrieved a combined total of 1,635 articles across all databases. Of these, 1,335 articles were deemed irrelevant and excluded during the initial screening stage. Subsequently, during the secondary screening stage, 269 additional articles were eliminated, leaving 28 articles slated for inclusion in the final iteration of the systematic review. With regards to research question 1, based on our preliminary findings, show examples of cultural skills (such as literary skills), domain-specific skills (such as skills for electrical engineering and civil engineering), learning skills (such as analytical skills and conceptual learning), physical skills (such as safety and construction skills), and social skills (such as collaboration and communication skills). Furthermore, the features of the VR learning environments that support the skills and competencies will be reported.

Our preliminary analysis related to research question 2 identified some of the following theories: constructivist theory, collaborative learning theory, community of inquiry framework, Interactive-Constructive-Active-Passive (ICAP) framework, Experiential Learning theory, connectivism, and Tuckman's model of small-group development.

IV. Conclusion

This systematic review protocol provides a crucial step towards advancing our understanding of collaborative learning in VR platforms within the context of engineering education. By proposing a systematic approach to synthesizing existing research findings and identifying gaps in the literature, this protocol will provide valuable guidelines for a systematic review we are conducting. The review aims to provide valuable insights and guidelines for educators, researchers, and practitioners seeking to leverage VR technology to enhance collaborative learning experiences for engineering students.

Moreover, this study will significantly contribute to the ongoing research on the integration of VR technology into engineering education while also serving as an exemplary protocol for researchers conducting future systematic reviews.

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