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The Impact of Collaborative Learning Virtual Environments on Student's Performance

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***Abstract*—This research explored the potential of collaborative virtual environments (CVEs) in delivering and assessing course content in higher education. The study examined the role of "asymmetric" (i.e., one participant interacting within the virtual reality (VR) setting and the other "guiding" outside of it) and "symmetric" (i.e., both participants taking a quiz within the same VR setting) interactions in the overall VR experience. It also investigated participants' preferences for a collaborative VR setting over a traditional physical lab quiz. A convenience sample of 104 participants/trainees, 62 from the Computer Science and 42 from the Aviation Engineering departments of a major higher education institution in the U.A.E., was used to conduct this experiment and its quantitative part (survey) after the completion of the experiment. Results indicate a significant improvement in success rates completing the VR experiment, compared to the same experiment in single-user VR mode. They also suggest that, while participants enjoyed the VR experience, they prefer a blended approach to delivering and assessing course content in higher education. These findings have substantial implications for decision-making processes in higher education institutions.**

***Index Terms*—Virtual reality (VR), collaborative virtual environment (CVE), symmetric CVE, asymmetric CVE, number of successes, preferences.**

I. Introduction

One of the skills students are expected to develop in higher education institutions worldwide is collaboration. This skill is frequently included in the Program Learning Outcomes (PLOs) of every higher education institution. Collaborative Virtual Environments (CVEs) aim to address this need within the context of utilizing virtual reality (VR) technology for content delivery and assessment at various cognitive levels.

CVEs allow users to participate in VR settings either in the same physical location or remotely. However, it is important to avoid assuming that a CVE is the optimal choice in every course scenario. Certain reports, such as the experiment conducted by Ardal [1], suggest that many professionals prefer solo conditions over collaborative environments, depending on the user's personality. Extroverted individuals may lean towards collaborative environments, while introverted individuals may prefer solitude.

If the initial decision is whether to use CVEs, the subsequent choice is between adopting the "symmetric" or "asymmetric" mode. Studies such as that of Drey et al. [2] suggest that the "symmetric" mode is generally more preferable than the "asymmetric" mode. However, it is crucial to thoroughly consider the parameters that might affect performance.

II. Aims and Contribution

The main aim of this research study was to explore the impact of collaborative VR learning and assessment experiences—both "asymmetric" and "symmetric"—on students' performance, measured by the "number of successes" achieved during these experiences. Additionally, the study aimed to determine students' preferences, if any, for a collaborative VR setting over a physical lab when assessing tasks of different cognitive levels.

The theoretical contribution of this research lies in its potential to enhance the use of VR in collaborative training, whether in a central or complementary role, by transforming courses into highly interactive, digitally-driven collaborative learning experiences. It also suggests that, currently, collaborative VR settings should be integrated with traditional physical labs when delivering course content and conducting assessments.

The practical contribution of this research involves the development of a highly extendable collaborative VR prototype designed for training activities, customized to align with the cognitive level of specific courses. This sophisticated prototype can be easily scaled to accommodate diverse requirements across different courses and support larger team sizes.

III. Background

As early as 1998, Churchill and Snowdon [3] coined the term CVEs to describe designed spaces within VR intended for shared user-object interactions. Similarly, Grandi et al. [4] defined CVEs as "shared spaces designed to support interactions between users and objects in VR".

Additionally, Fleury et al. [5] explain collaboration in Virtual Reality Environments (VREs) as the concurrent execution of workflows by two or more users. Ideally, a well-designed CVE should enable users to discuss, edit, and validate various tasks while simultaneously creating new scenes and tasks, as demonstrated in the experiment by Ardal [1]. Furthermore, Hrimech et al. [6] identified three crucial components for designing collaborative VR experiences:

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1) The actions of the collaborating users,
2) The objectives or goals of the collaborating users, and
3) The viewpoints of the environment held by the collaborating users.

Collaboration in VRE can be categorized into two forms: **symmetric** and **asymmetric**, based mainly on how users perceive 3D content and the type of interaction involved. In symmetric VR collaboration, all users wear VR headsets within the same VRE, sharing the experience of the same 3D objects and potentially interacting with them simultaneously in parallel workflows [4], [7]. On the other hand, asymmetric VR collaboration involves some users wearing VR headsets while others use tablets or mobile devices. Typically, in asymmetric VR, users work in pairs: the explorer wears the Head-Mounted Displays (HMDs) and navigates within the VRE, while the navigator operates from outside using a touchscreen tablet or another monitor with a pointing device, providing a bird's-eye view [2], [4], [7].

In an experiment involving 46 participants conducted by Drey et al. [2], the authors compared symmetric collaboration with asymmetric collaboration using their VR prototype. The results indicated that both students and teachers favored symmetric collaboration, finding it more beneficial and enjoyable, thus improving their learning experience. Specifically, in the symmetric mode, users (both students and teachers) demonstrated more precise recollection of objects in the CVE. They also reported higher motivation towards the tasks and an increased sense of co-presence, communication, and immersion. In contrast, in the asymmetric mode, teachers operating outside the CVE faced orientation challenges and relied on the students' engagement within the CVE for a correct understanding of the virtual environment.

After deciding on using CVE, especially when opting for the "symmetric" mode, it is crucial to shift attention towards design aspects such as detailed representation of users' faces, bodies, facial expressions, gestural interactions, body movements, and dialogues, rather than focusing solely on the intricacies and specifics of the collaborative process [1], [8].

Creating a CVE is more complex than setting up a VRE for a single user. It requires a robust client-server architecture on a cloud platform acting as a game engine, enabling multiple users to interact symmetrically in the VRE, whether together in person or remotely. The primary technical challenge is latency, influenced by the server's power, specifications, and available internet bandwidth during the CVE session. Given that VREs heavily rely on visual, audio, and memory components, the importance of high-quality fidelity (visual and audio) is paramount. This is especially critical when CVEs operate on organizations' clouds, posing challenges in managing bandwidth. Visual effects (e.g., avatars) and audio contribute significantly to the VR experience. Synchronization of these elements occurs via time and spatial alignment of audio and video [9].

Time synchronization is crucial in VREs, as even a slight delay (e.g., 0.1 sec) between audio and video can significantly impact the user's experience [10]. Spatial synchronization is also vital, requiring alignment between audio and video positions as the user's avatar moves relative to sound-emitting objects [9]. Meeting specific specification requirements, such as a high bitrate for panoramic video, ensures adequate spatial synchronization to enhance user immersion [10].

To tackle these challenges, the following considerations should be addressed when preparing CVEs:

- Conducting a detailed analysis of the technical specifications of the online game engine is essential to ensure it can support real-time participation by the anticipated number of users effectively.
- Mitigating latency issues is crucial, as even minor delays in the order of milliseconds can disrupt the seamless and synchronized functioning of the CVE's features. Therefore, ensuring consistently sufficient bandwidth for all CVE users is imperative.

These requirements should be thoroughly examined and ensured as integral components of the preparatory activities for establishing CVEs.

Comparisons between symmetric and asymmetric collaboration within CVEs show that symmetric collaborations (where both participants interact within the same VR setting) appear better suited for precise object manipulation on a small scale than the asymmetric collaboration (where one participant interacts within VR and the other guides from outside), especially when objects are within the user's reach [6], [7].

IV. Methodology

The study consists of two main components: an experimental part and a quantitative part (evaluation and reflection survey). The experimental phase adheres to the Design Science Research (DSR) model [11] and involves developing a CVE, where pairs of students engage in teamwork to complete a quiz simulating a physical lab assessment. This quiz encompasses tasks from different departments—Computer Information Science (CIS) and Aviation Engineering (AvEng). The first task, "identification", requires students to accurately identify and place 3D object models in labeled boxes. The second task, "assembly", involves users assembling either a computer system or an airplane model.

The subsequent quantitative portion of the study involves a survey that prompts participants to reflect on their experiences and indicate their preferences among the VR experience, physical lab, or both [12].

A. Course Selection and Description

To enhance the generalizability of the results, two departments were involved in the experiment. The selected departments heavily incorporate interaction with 3D objects into their curricula. Specifically, the courses "Hardware and Networking" (from the CIS department) and "Sophomore Project" (from the AvEng department) were chosen for their significant reliance on 3D objects and their coverage of various cognitive levels in Bloom's taxonomy, including remembering, understanding, applying, creating, evaluating, and analyzing [13].

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B. Sampling

The study followed a non-probability convenience sampling with a total of 104 students participating (62 from the CIS and 42 from the AvEng departments respectively) fully volunteering with no compensation provided [14]. The participants were invited to participate in pairs, first utilizing the ”symmetric” mode, and then in ”asymmetric” mode, i.e., one within the VR environment as ”interactor” and the other outside of it as a ”guide”. The selection between the ”interactor” and the ”guide” (in the case of the ”asymmetric” was random. The participants had to complete both the ”identification” and the ”assembly” tasks in the same experiment.

C. Data Collection

The study obtained ethical approval from both the university in the U.K. and the university in the U.A.E. where the experiment was conducted. Participants were provided with comprehensive information via a ”Participants Information Sheet” and required to sign a ”Consent Form” prior to participating. To ensure clarity and adherence to ethical guidelines, the experiment was overseen by appropriate moderation. It took place in a standard classroom setting during regular course lectures, utilizing two ”Oculus Quest 2” HMDs and their controllers, alongside a laptop for monitoring, casting and recording the process [12]. The left image in Fig. 1 depicts two female participants from the Aviation Engineering department engaged in the experiment. The right image shows a screenshot from within said CVE.

Participants’ health and safety were ensured through continuous cleansing and sanitizing of the equipment before every new pair started the experiment. Participants were also advised to stop the experiment if they felt uncomfortable at any point. Before the actual experiment, users were given a short tutorial, up to three minutes long, to help them become familiar with the process and equipment, which was especially needed in cases where participants had no previous VR experience.

D. VRE Artifact

The main artifact of the experimental part of the study was the VRE that replicated two quizzes originally conducted in physical labs: one for the CIS department and another for the AvEng department. The functionality of the VRE included the following:

- **VR Tutorial:** A brief and limited VR experience to help familiarize students with the VR device and environment, especially those with no prior relevant experience [15].
- **”Identification” task:** Students were tasked with identifying and categorizing virtual computer components (CIS) or virtual airplane parts (AvEng) and placing them in labeled boxes on the virtual lab desk within the VRE, as illustrated in Fig. 2 (left).
- **”Assembly” task:** Students were required to assemble a PC using the computer parts (CIS) or assemble an airplane model using the airplane parts (AvEng) identified in the ”identification” task, as shown in Fig. 2 (right).

Both correct and incorrect interactions were recorded during the experiment, and participants were able to monitor their progress via a virtual board visible within the VRE in front of the practice desk (as shown in Fig. 2).

E. Evaluation - Survey Instrument

After the actual VR experiment, the participants were asked whether they preferred the VR setting over the physical lab. They were given four options to choose from, with corresponding numeric ratings in parentheses:

1) ”No”: Do not prefer the VRE over the physical lab (rated 1),
2) ”No preference”: Have no preference between the two (rated 2),
3) ”Both”: Prefer a blend of both experiences for learning and assessment (rated 3), and
4) ”Yes”: Prefer the VR setting over the physical lab (rated 4).

V. Experiment Results

The experiment took place in the regular classrooms of a major academic institution in the UAE between November 6th and November 18th, 2023. Fig. 3 illustrates the results from this experiment, and Table I presents a summary of the statistics regarding the number of successful attempts during the ”identification” and ”assembly” tasks in both ”symmetric” and ”asymmetric” collaborative modes for both CIS and AvEng students. These are compared with the respective results from the single-user VR mode as well as the results from the physical lab (which were obtained during the initial part of this study) [12].

TABLE I
Number of successes (ranging from 0 to 10).

	Identification task			
	Physical lab	**Single-user**	**Asymmetric**	**Symmetric**
Mean	6.43	8.43	9.58	8.89
Percentage %	64.25%	84.25%	95.76%	88.95%
Std. Deviation	3.08	2.07	1.02	1.50
Min	0	4	5	6
Max	10	10	10	10
	Assembly task			
	Physical lab	**Single-user**	**Asymmetric**	**Symmetric**
Mean	5,14	7,30	7,58	7,20
Percentage %	51.38%	73.00%	75.79%	71.97%
Std. Deviation	1.80	2.14	1.37	1.88
Min	0	3	4	3
Max	10	10	10	10

There is a significant and positive increase in the number of successes from the physical lab to the single-user VR mode (as explained in the first part of the study), which further extends to the collaborative ”asymmetric” VR mode. Additionally, in the case of the ”identification” task, there is an increase in successes even in the ”symmetric” mode (in this second part of the study). The dispersion of these results decreases towards the ’asymmetric’ VR mode.

These results have two major implications. First, it appears that ”asymmetric” collaboration through VR in a learning and

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Fig. 1. CVE symmetric collaboration in progress. On the left: Female participants from the AvEng department engaged in the experiment, both wearing ”Oculus Quest 2” headsets with controllers. On the right: Participants collaborating on the ”Assembly” task as seen within the CVE.

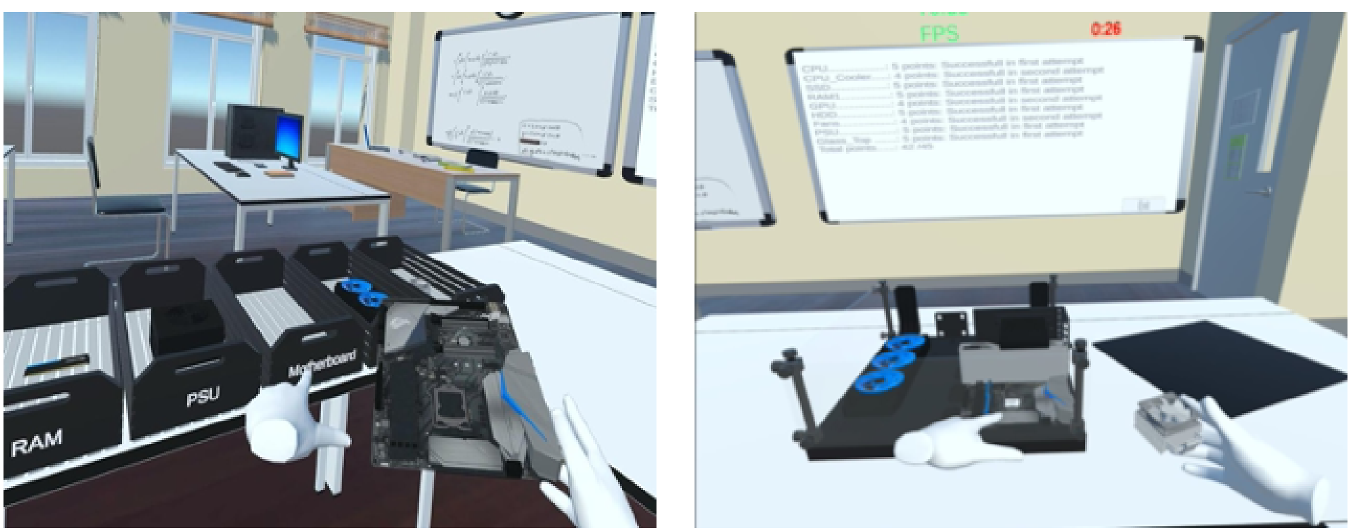

Fig. 2. On the left: ”Identification” task in progress; the ”Interactor” performs the interaction, while the ”Guide” provides support. On the right: ”Assembly” task in progress; students have switched roles, with the previous ”Interactor” now in the role of ”Guide” and vice versa.

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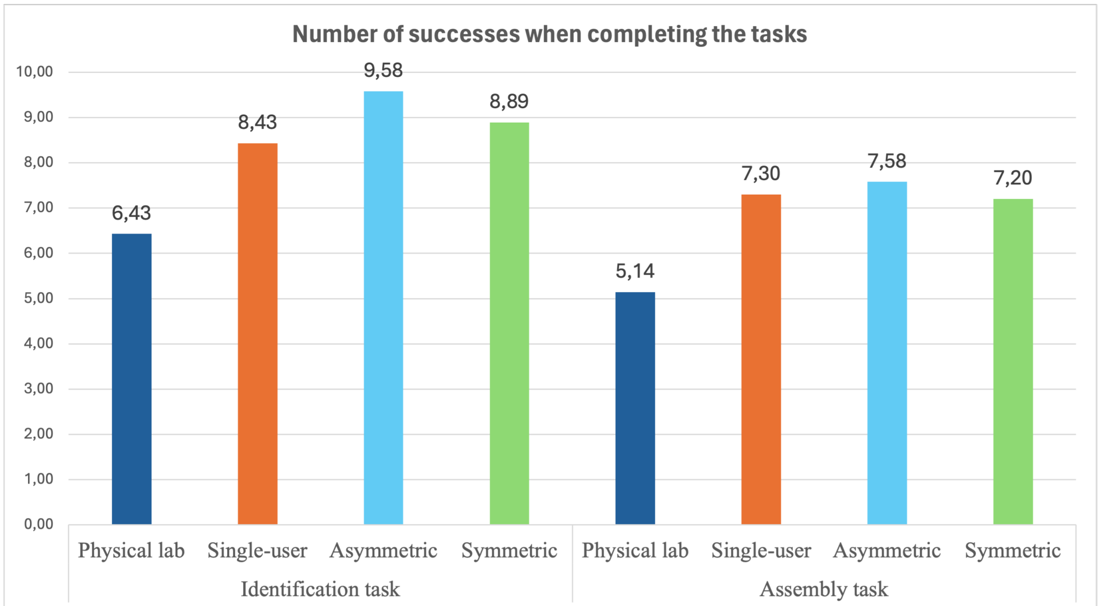

Fig. 3. Number of successes (ranging from 0 to 10) in the various experiment modes

assessment environment is more effective than ”symmetric” collaboration, suggesting that students are more comfortable with the ”interactor”-”guide” scheme of collaboration compared to the ”interactor”-”interactor” scheme, which may have caused a certain, although minor, level of confusion. This interpretation is consistent with relevant results from the ”assembly” task, indicating that the cognitive level of the task does not significantly change this impression of the participants and their overall performance.

The second implication is that collaboration further improves performance, measured by the number of successes, suggesting that collaborative learning is not only an effective learning paradigm but is also applicable when applying VR in the learning process. This has strong and positive implications for planning advanced applications of collaborative learning using VREs (i.e., CVE).

VI. Evaluation Results

As explained in the methodology section (IV-E Evaluation - Survey Instrument), the evaluation part of the study included a question about participants' preferences for a VRE in their learning over a physical lab. The results of this quantitative part of the study are summarized in Table II and illustrated in Fig. 4.

Given that rate 3 refers to participants who prefer a blend of a VRE together with the physical lab for their learning and assessment experience (CIS: 54.84%, AvEng: 47.62%), and rate 4 refers to those who clearly reported their preference for the VRE (CIS: 35.48%, AvEng: 42.86%), the average means of 3.21 (CIS) and 3.29 (AvEng) suggest that students prefer the former over the latter. This indicates that although students are comfortable using VREs during assessment, they are not ready to abandon the physical lab experience. The standard deviation further supports this, with values below 1 indicating minimal dispersion in students' responses (CIS: 0.75, AvEng: 0.77).

TABLE II
Preference of VRE over physical lab (Participants: CIS: 62, AvEng: 42).

	CIS	AvEng
Mean	3.21	3.29
Std. Deviation	0.75	0.77
1=No	4.84% (3/62)	4.76% (2/42)
2=No preference	4.84% (3/62)	4.76% (2/42)
3=Both	54.84% (34/62)	47.62% (20/42)
4=Yes	35.48% (22/62)	42.86% (18/42)

The other two choices—having no preference for the VRE at all (CIS: 4.84%, AvEng: 4.76%) and having no preference between the physical lab and the VRE—received (CIS: 4.84%, AvEng: 4.76%) only a minor, almost negligible number of selections.

These results indicate that there is still progress needed if the goal is to fully replace physical labs with VREs. However, the trainees are ready to have both environments for their training, and indeed, they prefer this blended approach.

VII. Conclusions, contributions, limitations

The results clearly suggest that collaborative learning and assessment have a positive impact on performance during a collaborative VR-based quiz compared to those during a physical lab quiz. These results are even more positive than when running the same experiment in single-user VRE mode. Participants also clearly expressed a preference for a blended

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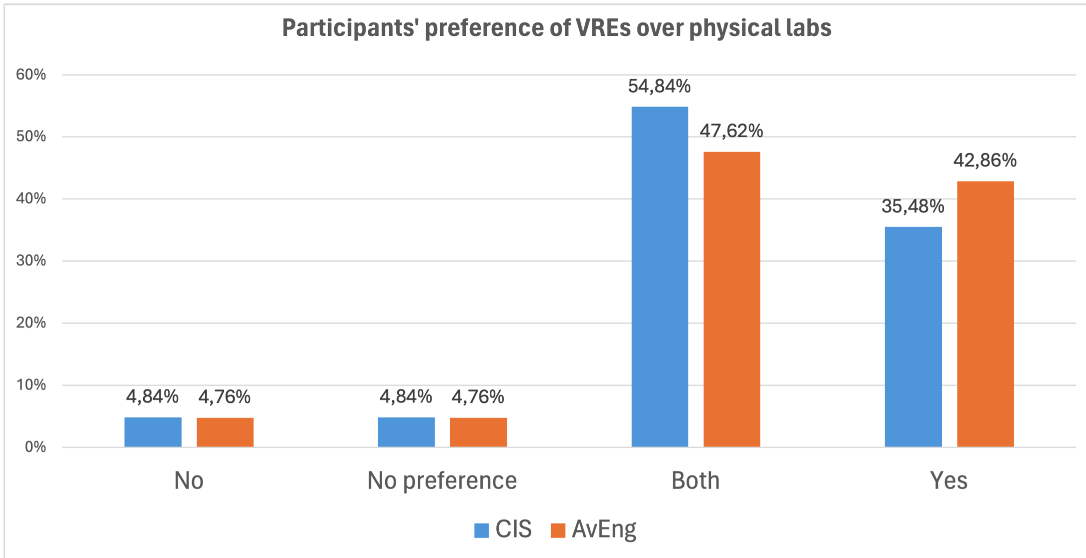

Fig. 4. Participants' preferences for VR versus physical labs (**No**: Do not prefer the VRE over the physical lab, **No preference**: Have no preference between the two, **Both**: Prefer a blend of both experiences, **Yes**: Prefer the VR setting over the physical lab).

learning and assessment experience over just the traditional physical lab, or having no preference at all.

These two findings are the main contributions of the study and can guide decision-makers in higher education in their planning towards integrating VREs to enhance students' learning and assessment experiences, highlighting the benefits of improved performance and teamwork skills, regardless of the cognitive level of the course and its assessment.

There are a few limitations in this research that suggest areas for further study. First, the study involved pairs of participants in either "asymmetric" or "symmetric" mode. It would be interesting to examine the respective results if more than two students/participants used the same CVE. Second, no major technical issues were reported during the collaborative VR experience, but there was a delay of between 55 and 60 seconds in starting the experiment, which was the time overhead to allow the two participants to join the same VRE. Third, both participants took part in the experiment from the same physical location and had direct access to each other. It would be worthwhile to examine how things would change if participants were located in different, even distant, locations, and how this might impact their overall performance.

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