

Performance Analysis of Task Distribution Mechanism in Multi-User' Collaborative Assembly Task' In 3d Virtual Environment

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CVEs are real-time, computer-simulated environments where two or more actors can mutually complete a task using synthetic objects. User performance is one of the major problems that arise due to coordination problems, a good mechanism to divide tasks, or less understanding or interaction among users collaborating. The impact of multi-user collaboration on using the task distribution mechanism remains unexplored. In this study, the impact of TDM on multi-users' collaborative virtual environment is investigated. The TDM model assigns the task to collaborating users in CVEs on a static or dynamic manner. In static distribution, there exists weak coupling, and the amount of communication during the actual execution of a task is low, while in dynamic distribution, users are tightly coupled and hence need to communicate more. To study the effect of static and dynamic task distribution strategies on user's performance in CVEs on multi users, a CVE prototype was developed using C++ and OpenGL, simulating an assembly task with distinct roles for multiple users, where twenty (20) group (each consists of two users) perform a task in collaboration under both strategies (static and dynamic) on two users and three users using arrow-casting and audio aids. The result shows that static with arrows-casting for two users takes an average time of 331.15 sec, and for three users, 321.45sec, and for audio (342.73sec and 326.34sec, respectively. Similarly, the dynamic with arrow casting for two users takes 347.76 sec, and for three users, 333.24 sec, and for audio, 350.12 sec and 344.4 sec, respectively. The findings provide valuable insights into how multi-user collaboration, task distribution methods, and cognitive aids can influence task efficiency and teamwork. However, when the number of users increased to three users, there is a chance that the performance will be degraded because, from the experimental data, a lower improvement was observed for three users than for two users. This research contributes to improving task management and collaboration in CVEs, with potential applications in training, education, and remote teamwork.

Keywords: 3D Interaction, Virtual Reality, Collaborative Virtual Environment, Awareness, User Performance.



Introduction:

Virtual reality (VR) is a computer-generated environment that immerses users in a simulated experience, making it feel like real life. It allows individuals to interact with and navigate imaginary settings as if they were part of them. In VR, virtual objects and scenarios are presented in a way that users perceive themselves actively participating in the simulated world. This computer-generated environment is commonly referred to as virtual reality (VR) [1]. VR is an advanced human-computer interface that realistically simulates real-world environments and enables interactive experiences in real time [2]. VR is one of the emerging trends in the field of Human-Computer Interaction (HCI) that offers human human-machine interface. It integrates elements of artificial intelligence, computer networking, image processing, and computer graphics to construct immersive computer-based models. The integration of these technologies in VR enables real-time interaction, creating the immersive sensation of being present within a virtual world. Consequently, this environment is due to the emergence of multiple sensory motor channels, which have been initiated. Some of the synonyms found in the current available literature for VR include Virtual Environment, imaginary, and Virtual World. [3][4].

A Collaborative Virtual Environment (CVE) allows users from different locations to work together within a shared virtual space, creating a common simulated reality for all participants. Users are provided with the opportunity to interact with one another through individual or collaborative data representations. Consequently, CVE is a virtual reality system of engaging varied users of distant geography, potentials, disciplines, and fields to collaboratively interact on static or dynamic assigned tasks [5]. Author [6] describes CVEs as distributed computer systems that allow users to collaborate across multiple networked computers, enabling communication and shared work within a defined virtual environment. In the physical world, when tasks are too huge or difficult for a person to handle, they are usually done by a group working together. For example, designing complex things like engines, airplanes, or large buildings often requires teamwork. Similarly, collaboration is crucial for activities such as performing surgeries or engaging in multiplayer games. Given the importance of teamwork in real-world scenarios, virtual environments also emphasize collaborative interaction, which is facilitated through the development of Collaborative Virtual Environments (CVEs). Virtual Reality (VR) systems are especially useful for training in situations that would be too costly or dangerous in real life. For instance, flight simulators use VR to train pilots before they fly an actual plane. Similarly, researchers are investigating how VR can be utilized for training in assembly and repair tasks, which can be performed more effectively through collaborative efforts [7]. Collaborative Virtual Systems can play a significant role in tele-therapy for stroke treatment. A major challenge in rural areas is the shortage of expert surgeons, limiting patients' access to essential care. As traveling long distances is often impractical for surgeons, tele-surgery presents a promising solution to bridge this gap. In tele-surgery, the procedure is carried out by a collaborative team of surgeons rather than just one individual. This has sparked significant interest among researchers aiming to improve access to specialized medical care [8]. To facilitate the people, enhance their efficiency and productivity, CVEs are expected to be used by the people to carry out their tasks.

Collaborative Virtual Environments (CVEs) are used to improve teamwork and efficiency by allowing users to work together on tasks, either by coordinating or dividing tasks into smaller parts. Most past studies have focused on collaboration between two users, with less attention given to how multiple users work together. While factors like communication, coordination, and interaction techniques have been studied, this research looks at multi-user collaboration in CVEs and compares it with two-user teamwork. Using Task Distribution Mechanism (TDM), with Static Task Distribution, where tasks are assigned in advance, and Dynamic Task Distribution, where users work together in real-time to complete each task. The study compares the use of cognitive aids like arrow casting and audio signals to see how they

affect performance. This study aims to identify more effective strategies for task management and collaboration in CVEs by comparing three-user versus two-user teamwork, static versus dynamic task distribution, and the use of arrows versus audio cues.

Related Work:

The researcher investigates the role of modern information and communication technologies in distance education (DE) and explores their limitations in promoting effective communication and building a sense of community. It proposes collaborative virtual environments (CVEs) as a solution to enhance DE by enabling interaction among students, virtual agents, and objects. The study highlights advancements in CVEs and computer-supported cooperative work (CSCW) while identifying areas for improvement. A well-designed CVE with interactive spaces can foster an engaging learning community that supports students' social, academic, and collaborative development [6]. VE provides guidelines to optimize cognitive load, support collaboration, and use of platform features effectively. It also presents a collaborative virtual reality environment that improves learning [9]. Author have observed online team behavior from formation to task completion within a learning environment. However, due to the small sample size, the findings have been considered an initial exploration rather than broadly generalized results. The data highlight key factors in online collaboration, including user profiles, information sharing, and the use of synchronous communication tools to mitigate the effects of the lack of face-to-face interaction. Learners and tutors can improve collaboration by effectively leveraging e-learning platforms and communication tools, especially when engaging from separate locations [10]. Author presented a virtual environment (VE) in which two users collaborate remotely using sculpting tools. Haptic feedback is employed to sense pressure on the clay and prevent simultaneous vertex editing. Additionally, vibro-tactile feedback is used to assist users with turn-taking in CVEs, although only one user has control over object manipulation at a given time. At a time, only one user of the CVE is active in manipulation, and all other users are passive and waiting for their turn [11]. Author introduce a new task distribution model for collaborative virtual environments (CVEs), defining strategies for assigning tasks either statically or dynamically. Static distribution involves less dependency and communication, while dynamic distribution requires more interaction between users. Author conducted a study with 24 teams, each comprising two users, to test both task distribution strategies. The results revealed that static distribution led to better performance. These findings can inform the development of effective CVEs in domains such as virtual assembly, repair, education, and entertainment [12].

Existing studies focus on improving collaboration and feedback mechanisms in CVEs but lack a comprehensive evaluation of task distribution strategies and their impact on user performance and interaction quality. There is also limited research on scalable, multi-user CVEs that balance dynamic interaction with usability and cognitive load.

Task Distribution Model:

CVE is a computer-aided virtual environment where more than one user responds to, coexists with, and communicates with synthetic objects. It enables users to collaborate in real-time to complete collaborative tasks within the virtual environment (as shown in Figure 1).

$$CVE = T, U, O \quad \text{Equation (1)}$$

$$T = T_1, T_2, T_3 \dots T_n \quad \text{Equation (2)}$$

$$U = U_1, U_2, U_3 \dots U_n \quad \text{Equation (3)}$$

$$O = O_1, O_2, O_3 \dots O_n \quad \text{Equation (4)}$$

T, U, and O are the set of Tasks, Users, and Objects, respectively, representing them, as given in equations 1, 2, and 3. To better understand the task distribution model, let us consider a CVE scenario in which a product, such as a complex machine, is composed of multiple sub-components. In the first phase, the individual parts are assembled, and in the second phase, they are integrated to form the final product. This task can be fulfilled in the following two ways.

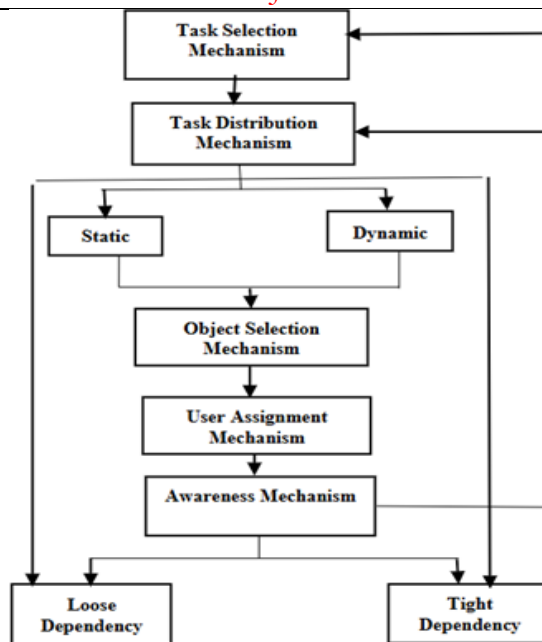


Figure 1. Task Distribution Model

Static Task Distribution:

In static task distribution, if a particular task has been chosen by the group of collaborating users, it is well understood by all users as to which sub-task is to be performed by each of them. For instance, if the task set T consists of subtasks $T_1, T_2, T_3, \dots, T_n$, and the user set U consists of $U_1, U_2, U_3, \dots, U_n$, then in static distribution, T_1 is assigned to U_1 , T_2 to U_2 , and so on. Each user is responsible for executing their assigned subtasks. The manner and level of interaction and communication among the members of the group during task performance depend on the interdependence of the tasks or subtasks. If tasks are loosely coupled with minimal dependency, less communication and lower awareness are required. However, if the tasks highly depend on each other, a higher level of awareness and a greater number of communications are needed.

Dynamic Task Distribution:

In dynamic task distribution, tasks are not assigned in advance. Instead, all users collaboratively work to complete each subtask sequentially, beginning with T_1 , then T_2 , and continuing up to T_n . For the transition to subtask T_{i+1} , all users must be aware that T_1 has been completed and that T_{i+1} is about to commence. This information must be communicated to all users in real time. The same dynamic task distribution approach applies in CVEs even when subtasks are further divided into sub-subtasks. A lot of interaction and good perception of the environment are needed during the performance of tasks in this approach. In dynamic task distribution within CVEs, users are categorized as Free Users (FU) and Busy Users (BU), as described below.

$$U = FU + BU \quad \text{Equation (5)}$$

$$FU = FU_1, FU_2, FU_3, \dots, FU_n \quad \text{Equation (6)}$$

$$BU = BU_1, BU_2, BU_3, \dots, BU_n \quad \text{Equation (7)}$$

The Objects are selected from the object set as described before in the description of equation 4. If object O_i is chosen by a user, then the user becomes busy and is included in the busy users set (BU). The rest of the free (FU) users search the remaining objects O_{j-1} . Likewise, if the busy user relinquishes the object or is done with a task, then he/she is included again in the free user set.

Awareness: Awareness is essential for improving user performance in CVEs during task execution. It refers to a user's perception of the presence and actions of others within a shared

virtual environment. More specifically, awareness includes a user's understanding of the actions, intentions, and status of other participants within the environment. It also assesses the degree, nature, and quality of interactions between users or objects in the CVE [13][14].

Audio Modality:

In Virtual Environments (VEs), audio communication enhances the realism of collaborative tasks, improving performance and increasing the co-presence of users. It allows users to coordinate and share details on different operations, including the choice or management of the objects, towards improved cooperation.

Textual/Visual Modality:

Different types of cues, inclusive of changes of shadow, changes of color, use of arrows, and the lighting, are also used in CVEs to make users more aware. Textual messaging facilitates the passing and sharing of information on things such as the release or pick of an object, hence enhancing performance and increasing the shared presence of co-users.

Experimentation and Results:

Environment:

To capture the effects of static and dynamic task distribution, we developed a CVE, illustrated in Figure 2. It has several rooms within which there is a 3D cube placed. The collaborators are represented as virtual hands inside the environment. A central room, different in color from the other rooms, where the assembly task will be completed. In both static and dynamic task distributions, the collaborators search for the objects and bring them to the central room. The goal is to arrange the objects in the central room to complete the assembly task of making the word "UNIVERSITY".



Figure 2. A CVE Scenario

Experimental Setup:

For this experiment, three laptops equipped with Core i5 processors, 4GB of RAM, and NVIDIA graphics were used. A client-server replicated environment was employed, with TCP facilitating data transmission between the stations involved in the process. The server also operated simultaneously on the other stations, allowing for real-time updates of object and user positions between the three stations. The CVE was implemented using the C++ programming language and the OpenGL graphics library (see Figure 3). For two users, one station of the network operated as the system server, and the other station was equipped with the system client. The stations were also connected through the local area network using unshielded Twisted Pair Cables. Users interacted with objects using keyboards.

Every VR station was equipped with the means to get information from other local and distant participants. This allowed a single user to manipulate the position of two pointers (which are presented in the form of hands) in the replicated environment. If a pointer triggered any event at one station, it was reflected in real time across stations.

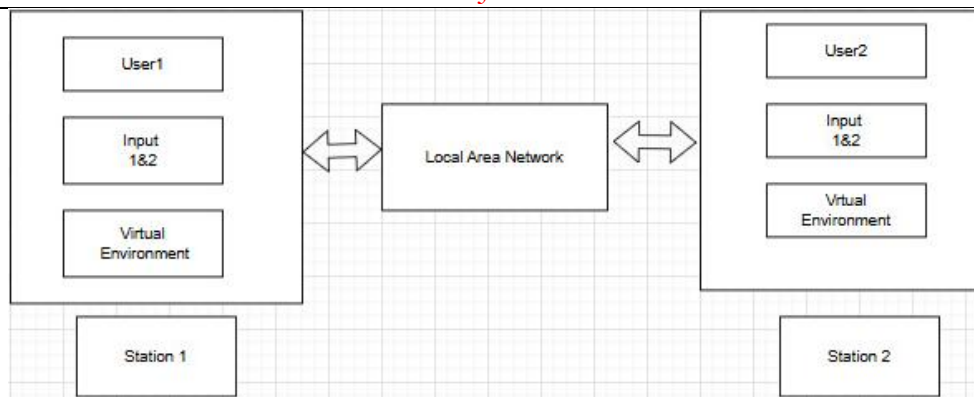


Figure 3. CVEs Environment for 2 users

For three users, one station of the network operated as the system server, and the other stations were equipped with the system as client 1 and client 2. The stations were connected via a local area network using unshielded twisted pair (UTP) cables. Users interacted with virtual objects through keyboards. Every VR station was equipped with the means to get information from other local and distant participants. This setup allowed a single user to manipulate the positions of three pointers, represented as hands, within the replicated environment. If a pointer triggered an event at one station, it was reflected in real time across all stations (see Figure 4).

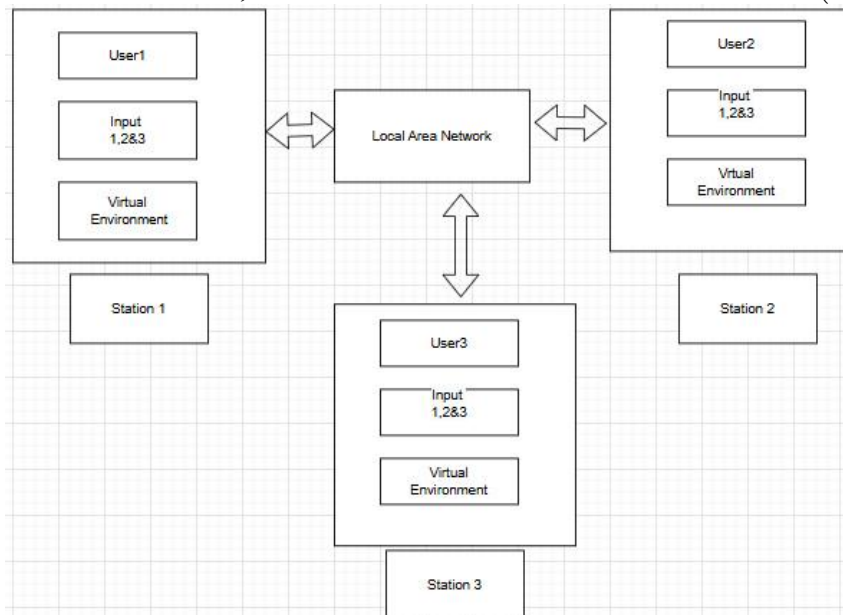


Figure 4. CVEs Environment for 3 users

Procedure:

To investigate the impact of static and dynamic task distribution on collaboration, we experimented with student participants. Twenty groups of students voluntarily agreed to participate. Most of the participants were Ph.D. and master's students, with ages ranging from 24 to 38 years. Each group consisted of two or three students. At the start of the experiment, students were given a brief orientation about the environment and the procedure to minimize confusion regarding the virtual setting, the objects, and the awareness modalities to be used. Each of the twenty groups completed five trials for both the static and dynamic task distribution experiments.

C1 = Static via Arrow-casting

C2 = Dynamic via Arrow-casting

C3 = Static via audio

C4 = Dynamic via audio

The time taken to complete the tasks was measured in each experiment that was conducted. The time stamp started when the scenario was initiated in the CVE for static and dynamic tasks and ended at task close. After completion of the task, each user was provided with a questionnaire to collect subjective feedback.

Task:

The cuboid objects are placed randomly in CVE, and users move to collect the objects for constructing the word “UNIVERSITY” under the following conditions: C1, C2, C3, and C4. In dynamic task distribution, the names of objects are communicated to collaborators using audio or arrow-casting modalities across each condition: C1, C2, C3, and C4. If a user picks up the object ‘U’, their collaborators are alerted to locate the next object, ‘N’, and so on, until the task is completed. This approach represents dynamic task distribution. In static task distribution for two users, five objects ‘U’, ‘N’, ‘I’, ‘V’, and ‘E’ are to be assigned to the first user, and the remaining objects ‘R’, ‘S’, ‘T’, ‘T’, and ‘Y’ to the second user. And for three users, four objects, i.e., ‘U’, ‘N’, ‘I’, and ‘V’ are assigned to the first user, three objects ‘E’, ‘R’, and ‘S’ to the second user, and three objects ‘T’, ‘T’, and ‘Y’ to the third user. In this approach, the task is divided so that there is minimal coupling and dependency between components throughout the execution process. In the static task distribution mechanism, each task assigned to a user can be completed individually, whereas in the dynamic approach, tasks are performed collectively. As a result, interaction is lower during the task execution phase in the static method.

Result and Analysis:

Task Completion Time (Two and Three users):

In case of a task completion time for 2 users, the value of ANOVA is $F(3, 19) = 2.182$, $p = 0.019 < 0.05$ is significant. When comparing the mean task completion times across the four conditions (C1, C2, C3, and C4), the results were as follows: C1 had a mean of 331.25 seconds with a standard deviation of 4.004; C2 had a mean of 347.76 seconds with a standard deviation of 2.796; C3 had a mean of 342.73 seconds with a standard deviation of 1.615; and C4 had a mean of 350.12 seconds with a standard deviation of 2.626. The findings indicate that among the four conditions, C1 (Static via Arrow-casting) and C3 (Static via Audio) positively influenced and enhanced user performance in the CVE. In conclusion, static task distribution positively impacts and improves user performance in CVEs, as illustrated in Figure 5.

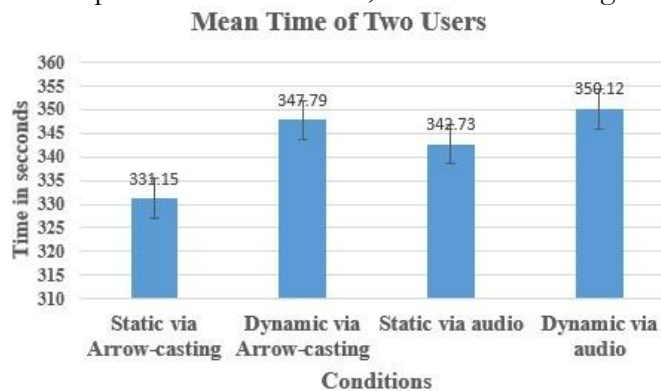


Figure 5. Task Completion Time (Two Users)

For the task completion time of three users, the ANOVA results were significant, $F(3, 19) = 14.991$, $p = 0.001 < 0.05$. The mean completion times for each condition were as follows: C1 – 322.45 seconds (SD = 2.605); C2 – 333.24 seconds (SD = 2.018); C3 – 326.34 seconds (SD = 1.332); and C4 – 344.4 seconds (SD = 1.428). The results indicate that C1 (static via Arrow-casting) and C3 (static via audio) affect performance and enhance user performance in CVE (see figure 6).

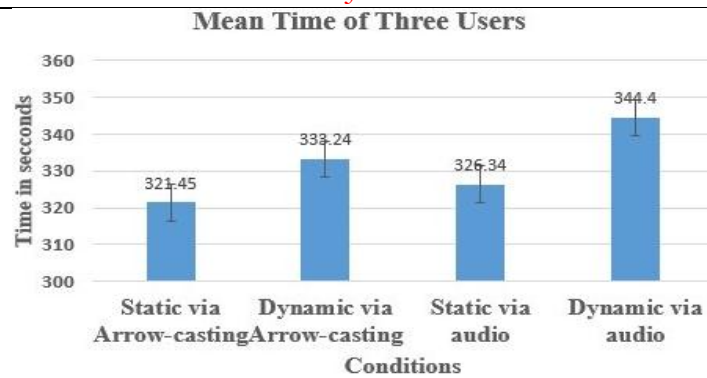


Figure 6. Task Completion Time (3Users)

Comparative Analysis (Two and Three Users):

The analysis of mean task completion times in CVEs across different conditions provides valuable insights into user performance. The task completion times of 331.15 seconds for three users and 321.45 seconds for two users indicate that the Static via Arrow-casting condition resulted in the best completion times for three-user groups. In contrast, the Dynamic via Audio condition required more time, taking 350.12 seconds for two users and 344.4 seconds for three users, as shown in Table 1.

Table 1. Task Completion Time comparison 2 vs 3 users

Condition	Description	Mean Time (Seconds) (2 Users)	SD (2 Users)	Mean Time(sec) (3 Users)	SD (3 Users)
C1	Static via Arrow-casting	331.25	4.004	322.45	2.605
C2	Dynamic via Arrow-casting	347.76	2.796	333.24	2.018
C3	Static via Audio	342.73	1.615	326.34	1.332
C4	Dynamic via Audio	350.12	2.626	344.40	1.428

ANOVA (2 Users): $F(3, 19) = 2.182, p = 0.019 < 0.05 \rightarrow \text{Significant}$

ANOVA (3 Users): $F(3, 19) = 14.991, p = 0.001 < 0.05 \rightarrow \text{Significant}$

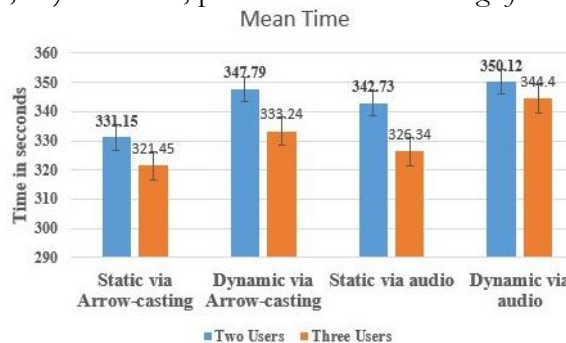


Figure 7. Comparison in terms of task completion time between two vs. three users

Static task distribution conditions (C1 and C3) consistently resulted in better performance for both two-user and three-user groups, indicating that static coordination methods positively influence user performance in collaborative virtual environments (CVEs).

Errors in Task Completion:

The errors involve either the wrong choice of an object, the incorrect placement of an object, or placing the object in a room different from the central room where it was originally located. The number of errors made during the completion of the task is recorded under each condition.

Mean Errors of Two Users:

Figure 8 illustrates the mean errors made by two users under four different conditions in the CVE. The conditions are as follows: Static via Arrow-casting – the lowest error rate (0.94); Dynamic via Arrow-casting – a higher error rate (1.31); Static via Audio – a slightly higher error rate (1.35); and Dynamic via Audio – the highest error rate (1.45).

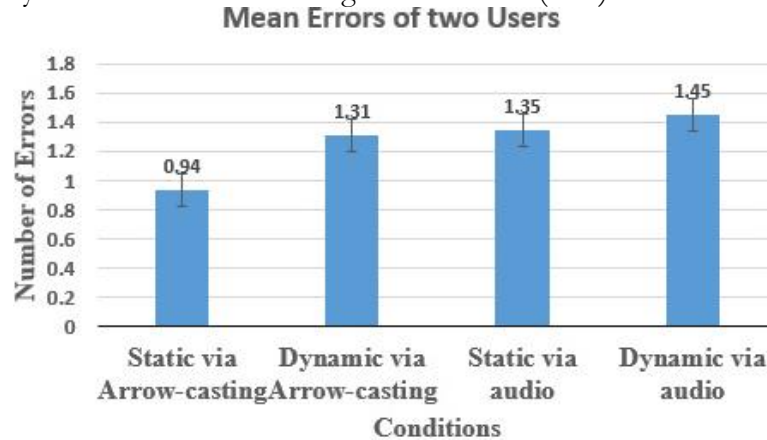


Figure 8. Mean Errors (Two users)

Mean Errors of Three Users:

Figure 9 illustrates that the mean number of errors was lowest under the Static via Arrow-casting condition (1.65), followed by Dynamic via Arrow-casting (1.87), Static via Audio (2.02), and highest under Dynamic via Audio (2.22).

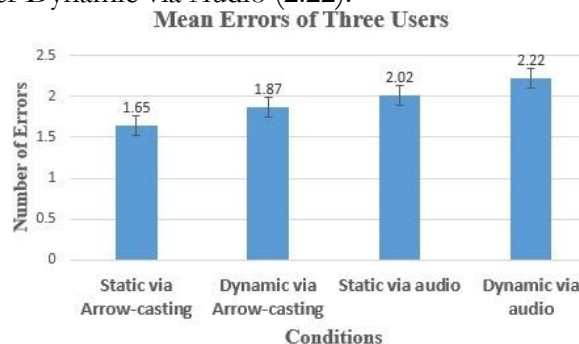


Figure 9. Mean Errors (Three Users)

Mean Error Analysis for Two- and Three-User Teams:

The analysis of mean errors in the CVE under different conditions demonstrates the influence of navigation techniques and task distribution strategies, as shown in Table 2. The Static via Arrow-casting condition produced the lowest error rates, with two-user teams averaging 0.94 errors and three-user teams 1.65 errors. Conversely, the Dynamic via Audio condition resulted in the highest error rates, with two-user teams averaging 1.45 errors and three-user teams 2.22 errors. The Dynamic via Arrow-casting and Static via Audio conditions yielded intermediate error levels, with three-user teams consistently exhibiting higher error rates than two-user teams (See Figure 10)

Table 2. Comparison of Mean Errors for Two and Three Users under Different Conditions in the CVE

Condition	Description	Mean Errors (2 Users)	Mean Errors (3 Users)
C1	Static via Arrow-casting	0.94	1.65
C2	Dynamic via Arrow-casting	1.31	1.87
C3	Static via Audio	1.35	2.02
C4	Dynamic via Audio	1.45	2.22

Across both two-user and three-user tasks, the Static via Arrow-casting (C1) condition consistently resulted in the fewest errors, indicating that static task coordination leads to more accurate performance in Collaborative Virtual Environments (CVEs). In contrast, the Dynamic via Audio (C4) condition produced the highest error rates, suggesting increased cognitive and coordination challenges in dynamic audio-based interactions.



Figure 10. Error analysis between two and Three Users

Subjective Analysis

In the questionnaire, there were five questions, each with four possible answers. The users/subjects were required to select one option for each question under the given conditions C1 to C4.

Table 3. Questionnaire Results Across Four Conditions in percentage (C1–C4)

Question	C1	C2	C3	C4
Q1. What types of CVEs encourage you to take part in more experiments?	42	17	31	10
Q2. To accomplish a task in a CVE, which feedback is easiest?	45	13	30	12
Q3. Which task distribution technique works best for CVEs?	55	14	23	8
Q4. What feedback do you find to be the most relevant?	52	10	29	9
Q5. Under which condition is task completion most difficult?	5	27	15	53

Discussion of Questionnaire Results:

The questionnaire results offer valuable insights into user preferences and perceived challenges across different CVE conditions. For Q1, most participants (42%) indicated that C1 (Static via Arrow-casting/Audio) encouraged them to participate in more experiments, suggesting that the stability and simplicity of static conditions foster greater user engagement. Similarly, for Q2, most users (45%) reported that feedback under C1 was the easiest to follow, indicating that static navigation—whether through visual or auditory cues—reduces cognitive load and enhances usability.

When evaluating task distribution techniques (Q3), C1 again received the highest support (55%), demonstrating that static approaches provide clearer and more consistent cues for coordinating collaborative tasks compared to dynamic methods. This pattern persisted in Q4, where 52% of participants identified feedback in C1 as the most relevant, further emphasizing the effectiveness of static feedback mechanisms within CVE environments.

Conversely, the most challenging condition for task completion was reported under C4 (Dynamic via Arrow-casting), with 53% of participants identifying it as the most difficult. This finding suggests that while dynamic arrow-casting may offer flexibility, it also introduces additional complexity that can hinder task execution. Meanwhile, C2 (Static via Audio) and C3 (Dynamic via Audio) received moderate ratings across questions, indicating that audio-only feedback—whether static or dynamic—may not be as intuitive or effective as visual feedback for most users (see Table 3).

Overall, the findings highlight a clear user preference for static conditions, particularly those employing arrow-casting, as these configurations minimize errors, enhance task

coordination, and promote active participation. In contrast, dynamic conditions, especially those involving arrow-casting, were perceived as more complex, underscoring the need for further refinement of dynamic feedback techniques in CVEs.

Influence of Group Users on Task Performance:

Table 4. Group users influence user experiences and task performance in Collaborative Virtual Environments

Q. No	Question	Two Users	Three Users	No Difference
1	Which type of CVE setup encourages you to participate more actively?	50%	45%	5%
2	When working on a task in CVE, which group size makes it easier to understand and process feedback?	46%	51%	3%
3	In which group setting do you receive more helpful and relevant feedback?	47%	46%	7%
4	Which group size do you prefer for completing complex tasks in CVEs?	40%	55%	5%
5	Which CVE setup provides a better balance between collaboration and individual control over tasks?	50%	44%	6%

Discussion:

The findings of this study offer valuable insights into how group size affects user experiences and task performance in Collaborative Virtual Environments (CVEs). In response to Question 1, most participants (50%) indicated that they felt more motivated to actively engage in a two-user CVE setup. This suggests that smaller groups may reduce social inhibition, allowing participants to communicate more openly and develop closer working relationships. In contrast, three-user configurations appeared to impose slightly higher cognitive load or foster unequal participation levels. The low percentage of participants indicating “No Difference” (5%) further reinforces the notion that group size significantly affects perceived levels of engagement.

Interestingly, the responses to Question 2 indicate a slight preference for three-user groups (51%) when it comes to understanding and processing feedback, as opposed to two-user groups (46%). This preference may be attributed to the availability of multiple perspectives that can clarify concepts and enrich feedback. However, the relatively small difference between the two configurations suggests that personal factors such as task type and communication styles might influence these preferences.

For Question 3, the results reveal an almost equal distribution of opinions, with a slight preference for two-user groups (47% vs. 46%). This suggests that in smaller groups, feedback may be more focused and context-specific. However, the near-equal responses also suggest that users perceive both configurations as equally capable of producing useful input, depending on factors such as group dynamics, communication patterns, and the nature of the task.

In Question 4, a notable majority (55%) preferred three-user groups for completing complex tasks. This trend implies that larger groups are advantageous when tasks demand diverse skills, ideas, and problem-solving strategies. While two-user configurations seem to foster more active engagement, three-user groups appear better suited for distributing workload and leveraging varied expertise in complex situations.

Finally, responses to Question 5 reveal a slight preference for two-user groups (50%) as offering a better balance between collaboration and individual control. The smaller group size may simplify coordination, minimize task interference, and enhance individual autonomy while still maintaining cooperative interaction (Shown in Table 4).

Collectively, these results suggest that two-user CVE configurations are generally preferred when tasks demand active participation and greater individual control, whereas three-

user configurations are perceived as more effective for tasks requiring complex problem-solving and the integration of diverse feedback. Notably, both configurations were rated similarly in terms of feedback quality, and the relatively low “No Difference” responses across all questions underscore that group size has a meaningful impact on user experience. Therefore, the optimal group size in CVEs appears to be context-dependent: two-user setups are more suitable for simpler or faster tasks, while three-user configurations are better aligned with collaborative tasks that involve higher complexity and coordination.

Conclusion:

This study investigated the impact of static and dynamic task distribution, awareness modalities, and group size on collaboration in Collaborative Virtual Environments (CVEs). The results demonstrate that static task distribution, particularly when supported with visual guidance through arrow-casting, consistently improved task completion time, reduced errors, and enhanced user experience compared to dynamic distribution and audio-based feedback. Users perceived static arrow-casting as the most effective and relevant feedback modality, while dynamic audio guidance was considered the most difficult due to increased cognitive load.

Furthermore, the comparison between two-user and three-user groups revealed that two-user configurations promote active participation and better individual control, whereas three-user configurations are more effective for handling complex tasks and processing feedback collaboratively. This highlights the importance of aligning group size with task complexity in CVEs.

Overall, the findings suggest that effective CVE design should prioritize structured task allocation, visual feedback mechanisms, and adaptive group sizing depending on task requirements. These insights contribute to the development of more efficient and user-friendly collaborative virtual systems, with potential applications in education, training, healthcare, and distributed teamwork.

Future Recommendations:

A promising future direction for this work is to extend the study beyond two- and three-user groups by exploring larger and more diverse team configurations in CVEs, as real-world collaborative tasks often involve multiple participants with varying expertise. Further research could investigate adaptive task distribution models that dynamically balance workload based on user skills, roles, and performance in real time, supported by intelligent agents or AI-driven decision mechanisms. Additionally, incorporating advanced modalities such as haptic feedback, immersive VR headsets, and multimodal awareness cues could provide deeper insights into improving collaboration and reducing cognitive load. Finally, applying and validating the proposed models in domain-specific applications such as remote medical training, virtual assembly, education, and tele-surgery would enhance the generalizability and practical impact of this work.

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Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this manuscript in the International Journal of Innovations in Science & Technology

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