UNIVERSITY OF CALGARY

The effects of sharing viewpoints on task performance in collaborative VR applications

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER

GRADUATE PROGRAM IN COMPUTER SCIENCE

CALGARY, ALBERTA

February, 2023

Abstract

While virtual reality applications allow for face-to-face collaboration and the ability to see each other's avatars, having different graphical viewpoints can hinder task performance due to the confusion caused by left-right ambiguities and text orientation.

In this thesis, we investigate the effect of altering collaborators' viewpoints and sharing one collaborator's viewpoint with the other without moving the avatars' positions in a collaboration between two people in Virtual Reality. We created a Virtual Reality application and twelve scenarios to understand this approach's effect. Two terms were defined: Shared Viewpoint, which is when users' graphical viewpoints are decoupled from their avatars and put next to each other, and Independent Viewpoint, in which users' graphical viewpoints are where their avatars are located. A user study is conducted to gather qualitative and quantitative data. We calculated task completion time and users' preferences when they have a shared graphical viewpoint from the virtual world and object. Our findings showed that users prefer a shared viewpoint rather than independent viewpoints. Additionally, we discovered that having a shared viewpoint can either increase or decrease task completion time, depending on the relative positions of avatars around the table.

Acknowledgements

I would like to express my deepest gratitude to my supervisor, Dr. Frank Maurer, for his guidance, support, and encouragement throughout my research. Without his expertise and insights, this thesis would not have been possible.

I would also like to extend my thanks to my friends, MJ, Amin, Farnoush, Vesal, Alireza, Vahid, Farnaz, Niloufar, Saba, Shayan, Foozhan, Shaye and many others, who have been a source of support and motivation throughout the project. Their encouragement and positive attitude have helped me overcome the challenges I faced during the research.

I would also like to express my appreciation to my lab members for their support throughout this project. Their help and assistance have been crucial to the success of this research.

Thank you all for being a part of my journey and for making this project a reality.

To my parents, who despite the huge time difference, have always been a constant source of support and inspiration. I dedicate this thesis to them, in recognition of their unwavering love and encouragement throughout my academic journey. Their belief in me and constant support have been a driving force behind my success. This thesis is a testament to their sacrifices and dedication to my education despite the distance. Thank you for everything.

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Chapter 1

Introduction

Transmission of knowledge, data, skills, and information by using shared symbols and media is called communication [18]. Effective communication is an essential requirement that can affect both work efficiency and user experience in collaboration [85], meetings [1], and social interactions [60]. Collaboration is defined as individuals' collective participation and engagement in working towards a goal or resolving a problem. [64]. Collaboration can occur in various settings over space; one is collocated collaboration, which refers to the scenario where collaborators are physically located in the same place. This type of collaboration has several advantages, such as the enhancement of the focus level of the collaborators and the reduction of interruptions [81]. Another form of collaboration is remote collaboration, in which collaborators can interact with data and share their knowledge while not being physically present in the same location.

As a result of the Covid-19 pandemic, the need for efficient tools to support remote collaboration has become increasingly vital [29, 42]. While research has been conducted on the benefits of remote collaboration and its potential [24], there are still many unexplored possibilities in this field.

As internet services continue to advance, we are moving towards a world where activities in both the physical and virtual realms are becoming more seamlessly integrated [76]. Boas

Figure 1.1: Remote learning in Virtual Reality, where students look at the avatar of the teacher and the teacher looks at the avatars of the students [69].

stated that virtual reality technology has the potential to be the most powerful medium for delivering experiences [12]. Billinghurst and Kato started investigating preliminary works that have been done using collaborative mixed-reality technology. They noted that there are still many unexplored possibilities and opportunities in this field [8]. There have been various studies that have investigated the use of Mixed-reality in collaboration, such as the support of assembly tasks over the internet [2, 13], vehicle design [56], learning [36] as Figure 1.1 shows and crime scene investigation [10].

In some collaboration methods, it is necessary to have a representation of other collaborators to indicate their position and actions while working together. Avatars in virtual reality applications serve as visual representations of users and are used to facilitate interaction and communication within virtual environments. The kind of avatars and degree of realism to create those avatars can affect collaboration's quality [54]. Although face-to-face collaboration in virtual reality applications enables users to see each others' avatars, having different graphical viewpoints can negatively impact task performance because of left-right ambiguities [32]. Feick et al. found that a shared graphical viewpoint on an object make collaboration easier for users [32].

In virtual reality, we can create a setting where two users can have a similar graphical viewpoint of virtual objects and the world by separating their viewpoints from avatars and putting viewpoints next to each other without changing avatars' positions. The aim of this thesis is to study the impact of a shared viewpoint without altering the avatars' positions in a remote collaboration setting using a collaborative virtual reality application.

1.1 Terminology

1.1.1 Shared viewpoint vs. Independent viewpoint

In this thesis, we define a shared viewpoint configuration in a virtual reality environment as a configuration in which collaborators' graphical viewpoints are decoupled from their avatars and put next to each other. In this configuration, collaborators can similarly see virtual objects and the world.

Independent viewpoint is defined as the configuration in which users' graphical viewpoints are not decoupled from avatars. In this configuration, depending on the position of collaborators' avatars, they can see the virtual objects in a same or different way.

1.2 Example

Consider the following scenario in a virtual-reality world. Figure 1.2 shows two avatars in the scene. Avatar Blue and avatar Grey are standing in front of each other around a table with a textbook on the table. Based on avatar Blue's position, the collaborator sees the text upside down. Reading the textbook might be difficult for collaborator Blue due to her viewpoint. To make reading the textbook more intuitive for her, we can separate collaborator Blue's viewpoint from her avatar and put it next to collaborator Grey's viewpoint. In Figure 1.4, although avatar Blue and avatar Grey are standing in front of each other around the

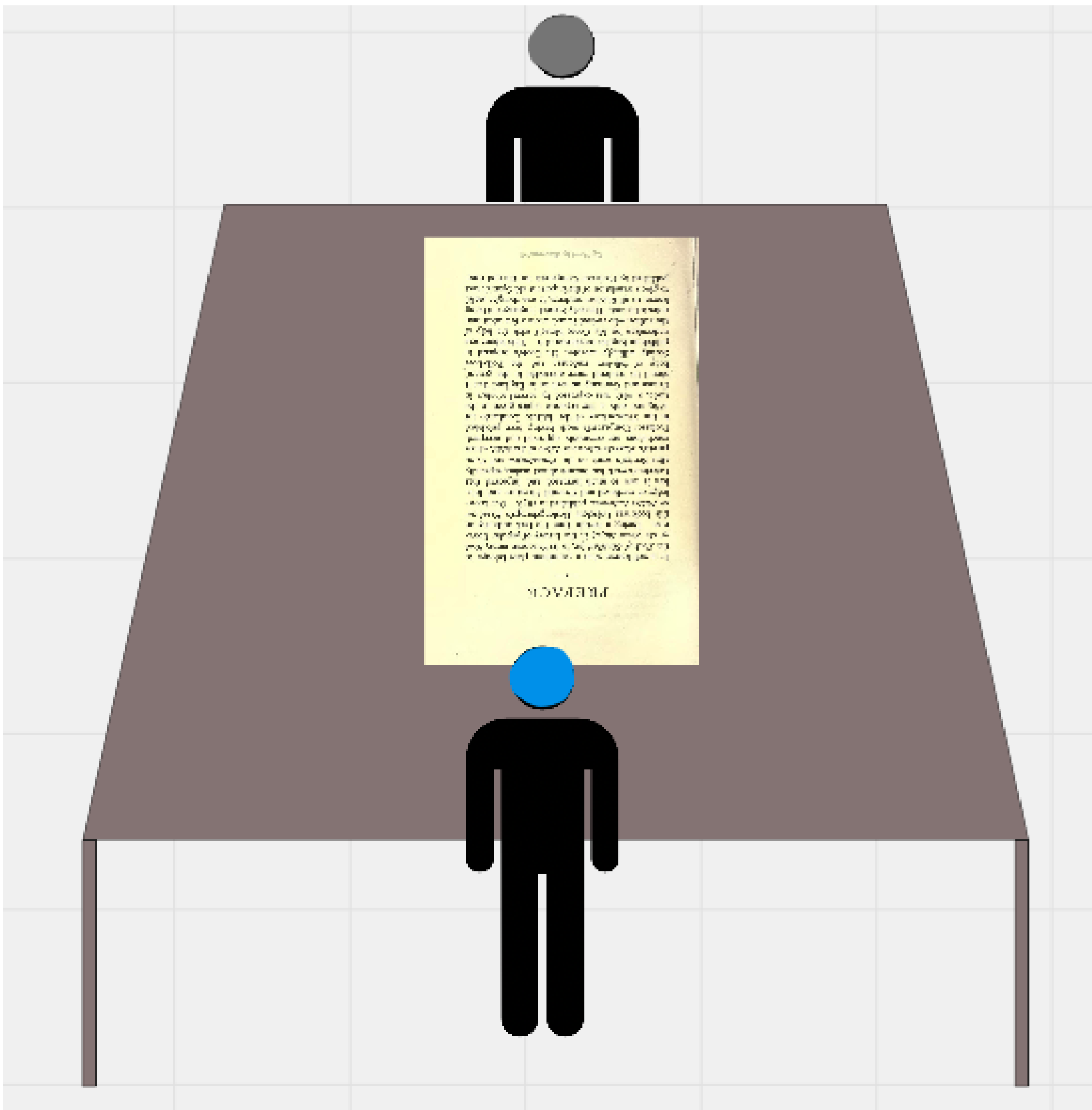

Figure 1.2: Two avatars are facing each other and trying to read a book that is on the table.

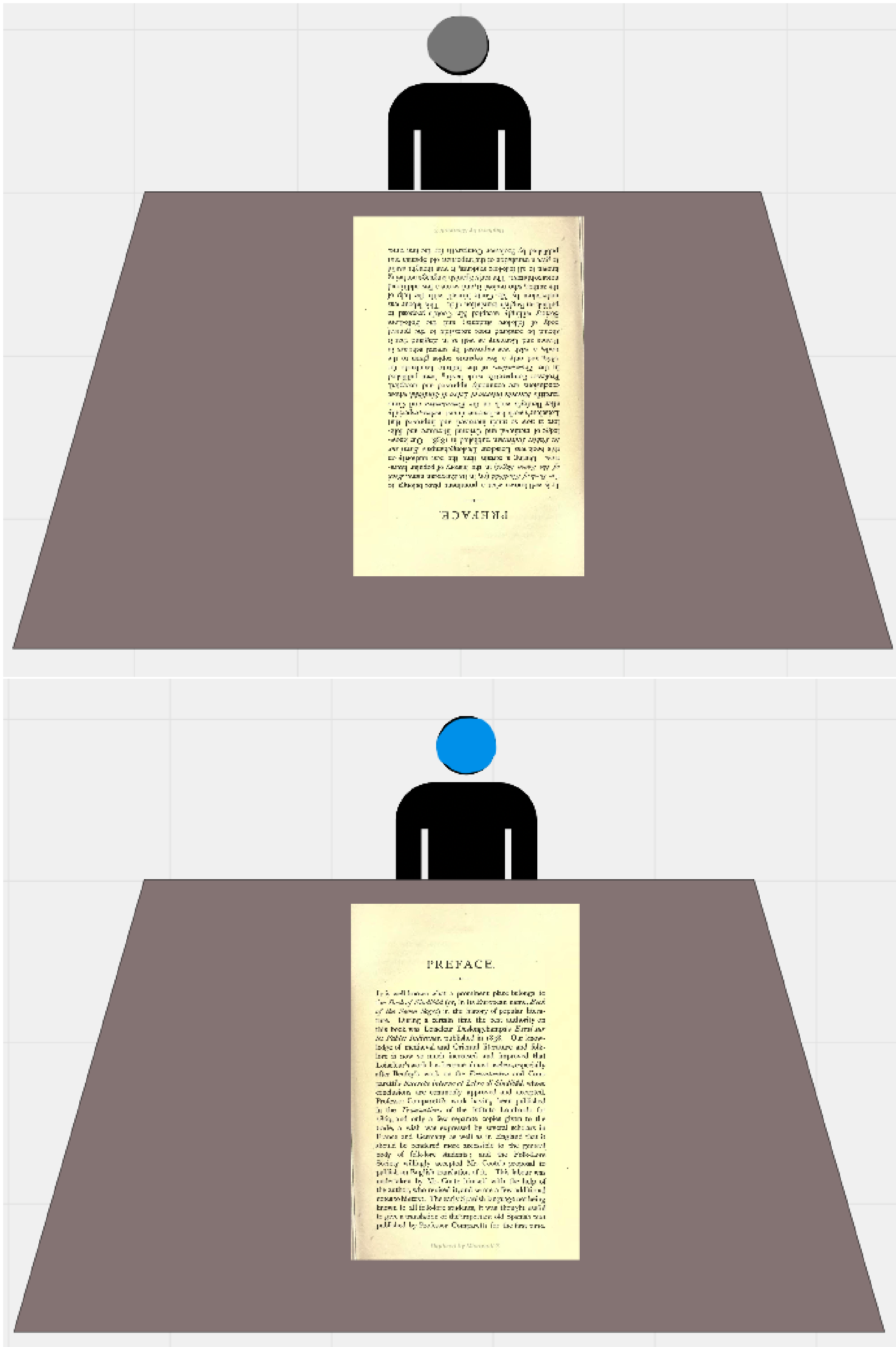

Figure 1.3: Top: Collaborator Blue's viewpoint. She can see avatar Grey in front of herself. She can see the text upside down. Bottom: Collaborator Grey's viewpoint. She can see avatar Blue in front herself. She can see the text in a proper orientation.

table, we changed collaborator Blue's viewpoint position and moved that next to collaborator Grey. Moreover, we hide collaborator Blue's avatar for herself. Now, collaborator Blue and Grey have a shared viewpoint, and their avatars' positions are untouched. Having a shared viewpoint enables collaborator Blue and Grey to be able to read the text and view the virtual world similarly.

A commonly used method for creating a shared viewpoint in virtual reality environments is to bring collaborators close to each other by teleporting. However, this might lead to the issue of avatars overlapping and blocking each other's view, which needs to be addressed. A solution to the problem of avatar overlap is to keep the avatars in their original positions and instead shift the viewpoints of the collaborators closer to each other by separating viewpoints from avatars. Additionally, when avatars are teleported close to each other, participants cannot see each other's avatars, leading to a loss of information that can only be obtained by observing each other's avatars such as tracking each other's eye gaze. However, keeping the avatars in their original positions and moving the viewpoints close to each other enables participants to view each other's avatars when necessary.

Additionally, teleportation may not be a viable option in collaborative mixed-reality applications. For instance, teleportation is not feasible when using augmented reality devices where each user sees the other collaborator's body instead of an avatar. Hence, separating viewpoints from avatars to create a shared viewpoint can be a starting point for achieving a shared viewpoint in various collaborative mixed-reality applications.

To test the effects of having a shared viewpoint without moving avatars' positions, we implemented a collaborative virtual reality application with the ability to share one collaborator's viewpoint with the other one without changing avatars' positions. The avatar whose viewpoint is moved next to the other collaborator will be hidden for the owner of the avatar but visible for the collaborator whose viewpoint is shared. When the collaborator, whose viewpoint is moved, rotates her head and looks at different objects in the virtual world, her avatar rotates, and her avatar's eye gaze points to the object she is looking at. A user study

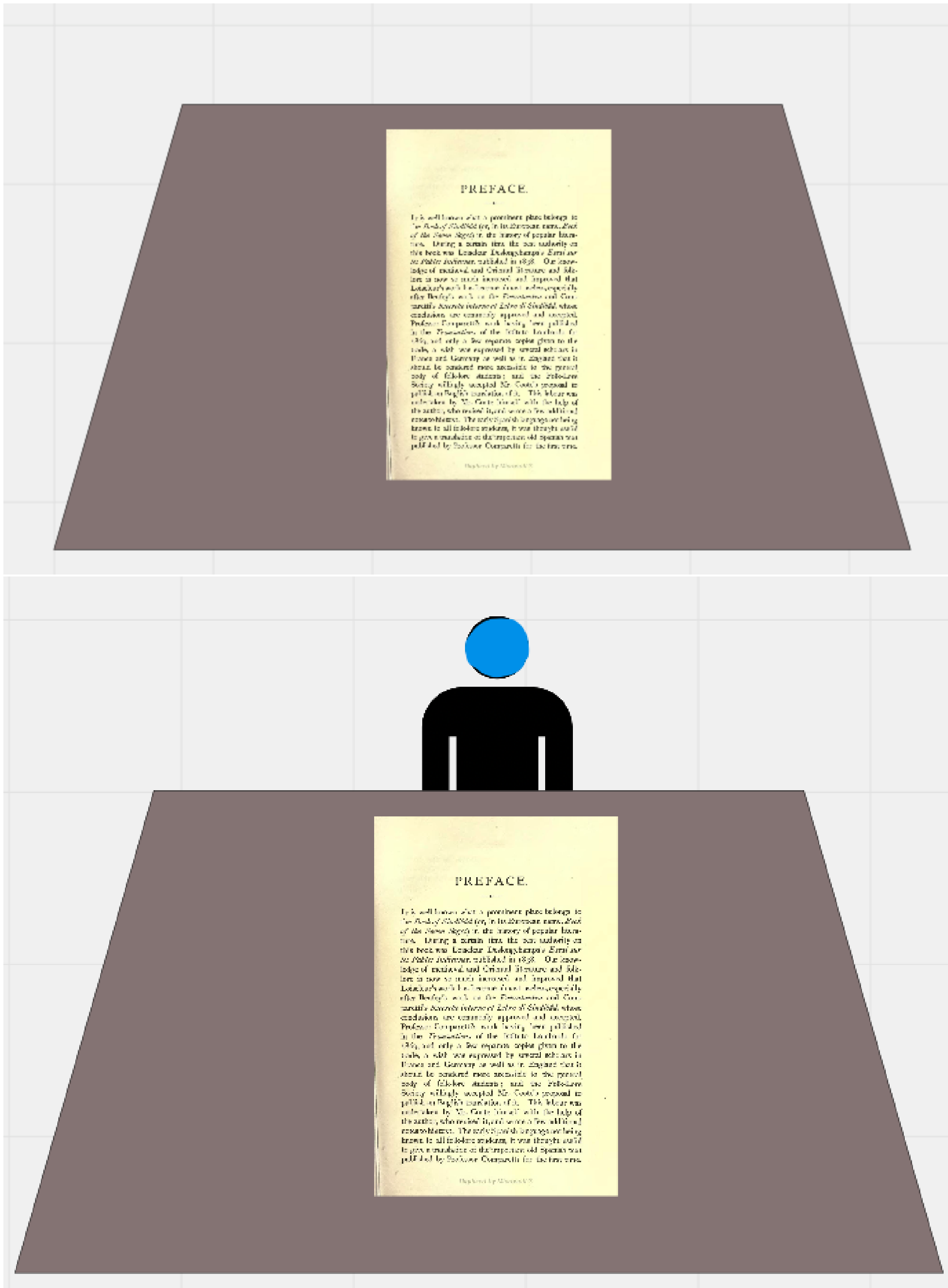

Figure 1.4: Both collaborators have a shared viewpoint. Top: Collaborator Blue's viewpoint. Her viewpoint is moved next to collaborator Grey's avatar. Now she can read the text in a proper orientation. Bottom: Collaborator Grey's viewpoint. She can see collaborator Blue's avatar in front of herself and her viewpoint is shared.

is conducted to evaluate the impact of having a shared viewpoint by separating viewpoints from avatars in a collaborative virtual reality application.

1.3 Research Questions

In this thesis, we are going to answer the following research questions:

1. Do users prefer a shared viewpoint by separating viewpoints from avatars in a collaborative virtual reality application while collaborating to complete a task?

2. Does sharing a viewpoint between two collaborators by separating viewpoints from avatars decrease task completion time in a collaborative virtual reality application?

1.4 The Objectives and Contributions

To answer the research questions discussed in this chapter, this thesis aims to create a collaborative virtual reality program to create settings where users have a shared viewpoint or independent viewpoints and evaluate it by providing qualitative and quantitative data gathered by conducting a user study. Collaboration ability and scenarios should be added to the program to address research questions. With this in mind, the contributions of this thesis are as follows:

- A collaborative virtual reality application is designed and created.

- Twelve scenarios are created to examine the effect of having a shared viewpoint in virtual reality by separating viewpoints from avatars.

- A user study is conducted to gather data by completing scenarios that are created in the collaborative virtual reality application.

- Data gathered from the user study is processed, and results are reported.

1.5 Thesis Overview

This thesis consists of six chapters. The rest of this thesis is organized as follows:

- Chapter 2 discusses related work that motivates this thesis. It presents topics about collaborative virtual reality applications, users' graphical viewpoints in collaborative virtual reality applications, and challenges in collaborative virtual reality applications.

- Chapter 3 presents the research methodology used in this thesis. It describes scenarios created and used by researchers to evaluate research questions, and the apparatus used for this thesis.

- Chapter 4 discuss the virtual reality application that is created for evaluating research questions in detail. It describes the technical tools and methods used to build the virtual reality application and the specifics of its implementation.

- Chapter 5 presents the results of the user study conducted to answer research questions. It describes participants' opinions in the study and provides qualitative and quantitative data to answer research questions.

- Chapter 6 concludes the thesis, presents limitations, and shows future directions for using a shared viewpoint without changing avatars' positions in collaborative virtual reality applications.

Chapter 2

Background and Related Work

The advantage of working in a group rather than individually to achieve better performance is shown in many articles [43]. Transferring knowledge and data between different persons using shared symbols and media is called communication [18]. During communication, different people interact with each other and interpret verbal and non-verbal messages [63]. With the outbreak of Covid, a new era of remote working and interactions began, and the need for remote communication feels more than ever [29, 42]. Moreover, different companies and organizations try to collaborate to gain better outcomes by sharing their knowledge and data [20]. Besides, many people moved from their friends and families due to different reasons such as studying in another city or country, and easy communication with their loved ones is an essential need for them [51, 72]. Due to these critical needs, technological progress, and having powerful computers, different computer tools were built to create efficient collaborations and communications [37].

In the following sections, we review studies done in a collaborative virtual environment. Then we investigate how viewpoint affects collaboration in virtual reality applications. Finally, we talk about evaluation metrics used to assess the usability of collaborative mixed reality applications.

2.1 Collaborative Virtual Environment

A virtual environment is a computer tool that tries to simulate a 3D environment for users to be able to interact with objects and creates a sense of being in the real-world. Having multiple users in a virtual environment interact with objects and each other creates a multi-user collaborative virtual environment [75]. Many researchers have proposed using a virtual environment to improve communication [9, 11]. Many industries specialized in different fields like aerospace, automative, construction, and agriculture use multi-user collaborative virtual environments to make their processes more efficient [6].

2.1.1 Collaborative Virtual Reality

Virtual Reality is a technology that helps users be in a 3D simulated world, interacting with 3D objects and representations, avatars, of each other, creating a more effective and efficient collaboration [41]. Many pieces of research are conducted to understand the benefits of collaborative Virtual Reality applications over two-dimensional video conferencing applications. The results show the benefits of collaborative virtual reality applications [1, 66]. Several benefits have been identified for collaborative virtual reality applications, including the enhancement of the sense of presence [61], the provision of immersion [3], the improvement of focus on conversations [57], the facilitation of communication [9], and the fostering of feelings of closeness to others [60].

Due to the improvement of technologies and feeling the need for effective and efficient collaborative technologies, many companies like Meta and Microsoft are investing in collaborative virtual reality applications. This causes research attention on new research questions related to communication and collaborative virtual reality to increase [77]. Some researchers investigated design guidelines and user experiences in these types of applications [82].

Although we mentioned many positive points about collaboration in a virtual reality application, there are some drawbacks mentioned in different articles for this kind of collab-

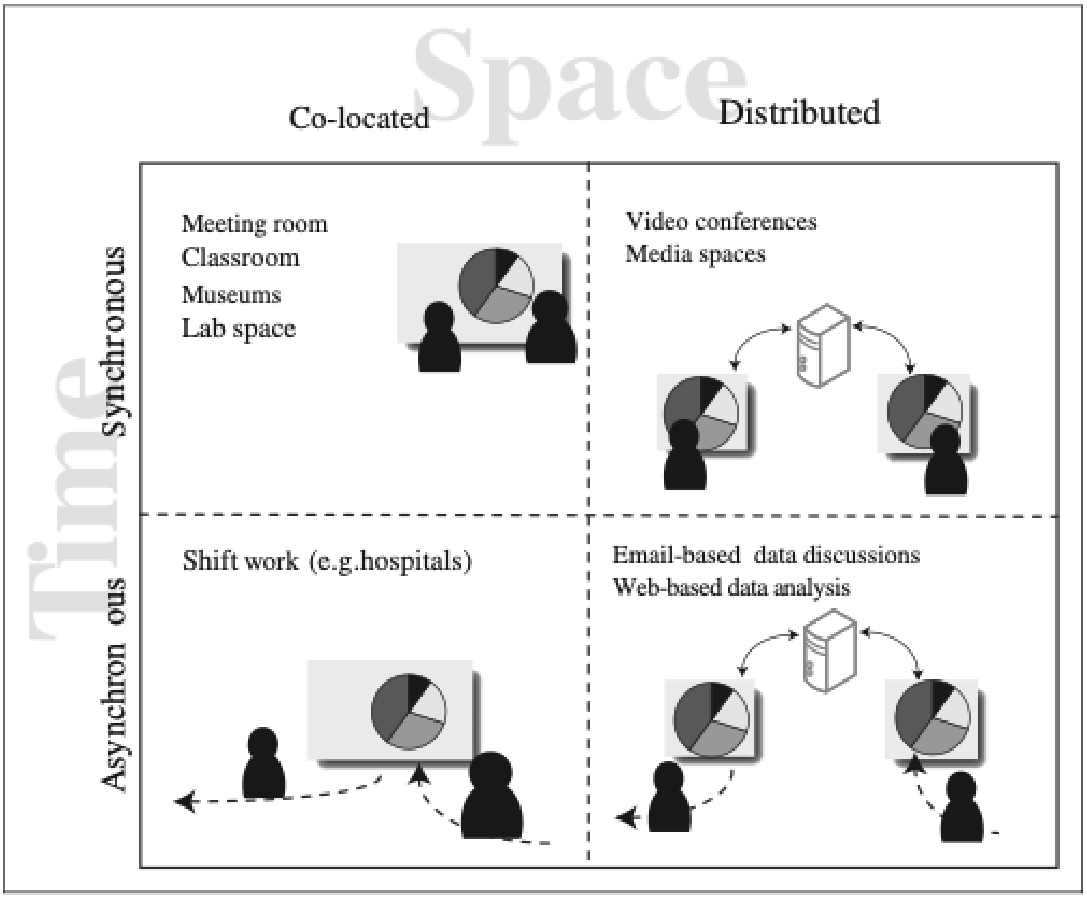

Figure 2.1: Different settings in collaboration [47].

oration. Many devices are available to enable users to work with Virtual Reality applications, such as the HTC Vive [34] and the Oculus Quest [27]. However, head-mounted displays may cause some problems for users, such as cybersickness [44, 21], and the need for improving them is sensed. Studies showed that users indicate that communication in Virtual Reality applications is not convenient due to the need to use Head Mounted Devices to start and enter the virtual world [3].

2.1.2 Collaboration Settings over Time and Space

In this section, we discuss different settings for collaboration. Collaboration can be divided into four groups based on the time and where they occur in space. As Figure 2.1 shows, we have four types of collaboration scenarios:

1. Collocated and Asyncronous
2. Remote and Asyncronous
3. Collocated and Syncronous
4. Remote and Syncronous

In collocated and asynchronous collaboration, individuals work together while physically located in the same place, but they do so at different times. Many articles show proper use cases for this kind of collaboration [70]. One example of such a collaboration system is a shared display that shows information to different users at different times but is placed in the same location [17]. For example, a shared display can show the information of a bus timetable to people [70]. An important note is that when considering different scenarios for collaboration, we have to come up with different interaction techniques useful for these scenarios because of their impact on the quality of collaboration [38].

Another setting for collaboration is Remote and Asynchronous. The benefit of this type of collaboration is that the participants can work on the task whenever they have time [71]. For example, email is a type of application that uses remote asynchronous type of collaboration.

The next setting for collaboration is collocated synchronous ones. In this type of collaboration, participants are placed in the same place, and they communicate and interact with each other and objects at the same time. As an example, the implementation of interactive tabletops for visual collaboration can establish a synchronous, and collocated collaboration [50]. To name some benefits of this setting, we can mention the sense of being together and seeing the task other collaborators are doing [78].

The last setting for collaboration is remote and synchronous. In a remote and synchronous collaboration, participants collaborate over a problem while they are located in

Figure 2.2: A remote synchronous virtual reality application that is a Social Virtual Reality experience where multiple users and computer-controlled characters exist in the same virtual environment, as perceived by an immersed participant's point of view [53].

different environments at the same time. For example, Latoschik et al, created a social virtual environment in which users can collaborate in a remote and synchronous setting [53] as Figure 2.2 shows. Several researchers have suggested utilizing avatars as a means of representing participants in this form of collaboration, with options ranging from abstract avatars [5] to more complex 3D models. In this type of collaboration, it would be helpful if collaborators could understand each others' perspectives. Many techniques help collaborators to understand that more efficiently. One of the essential approaches is to share views with others [67]. In the next section, we look at different articles that discuss the perspective of collaborators in a collaborative virtual reality application and approaches used to make this process easier and more effective during collaboration.

2.2 Viewpoints in Collaboration

In collaboration, there is a need to understand the situation and predict the future based on that to make a proper decision toward a goal. Moreover, being aware of other collaborators' states and activities helps participants to plan their activities [28]. Many articles show that sharing a mental model between different collaborators causes an increase in situational awareness and more efficient coordination between them [26]. Moreover, by increasing the situational awareness between collaborators, the need for verbal communication decreases, and collaboration continues with implicit coordination [30, 59].

Another important factor that affects collaboration's qualities and improves situational awareness in collaboration is the knowledge of users' visual attention. This knowledge can facilitate interactions during collaboration in VR applications [25]. Following participants' eye gaze in a collaboration benefits the collaboration in many ways, such as improving performance [35] and resolving ambiguity [39].

During collaboration, it is crucial for individuals to ensure that their messages are accurately understood by their partners [19]. This process is called grounding [19]. One strategy to facilitate the establishment of a shared understanding among collaborators is by having one collaborator share their viewpoint with others. [65]. Sharing a viewpoint or utilizing independent viewpoints during collaboration can offer numerous advantages depending on the specific task at hand [80]. When collaborators share their viewpoints with each other, it can help them to easily comprehend the environment, and enables communication with a shared understanding among collaborators [48]. However, if each collaborator only sees things from their own viewpoints, it can lead to left-right ambiguities, which have been demonstrated to negatively impact task performance [32]. Therefore, having a shared perspective, which is a solution to the left-right ambiguities problem, is mentioned as an effective approach in many articles [83].

In order to have a shared viewpoint in collaborative virtual reality applications, different approaches are investigated. One approach is by displaying the viewpoint of other participants on a small plane in the 3D space [23]. Freiwald et al. explored three different methods for displaying the viewpoints of participants to others in order to enhance collaboration effectiveness [33]. The three approaches employed by Freiwald et al. were: representation of the field of view of a user using a 3D cone, highlighting the object that the user is currently focusing on, and presenting a video feed of the user's perspective. They evaluate the task completion time, precision, and error rate to compare these approaches. The results show

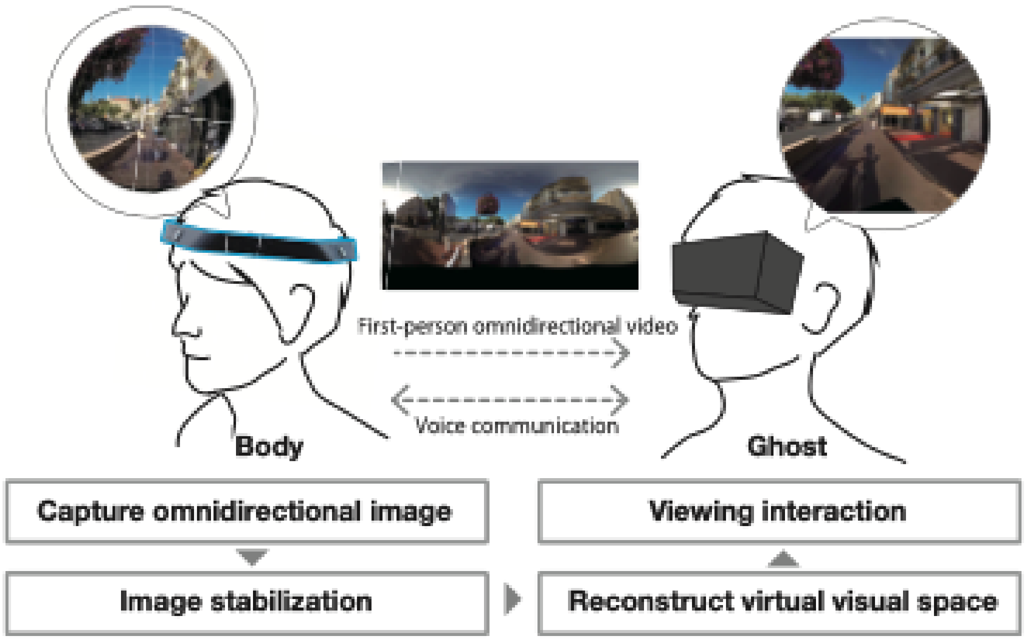

Figure 2.3: JackIn Head: Local user sends environment information using onmidirectional wearable camera to remote users. Remote users can view the environment independent of local user's head direction [49].

that these three approaches can be ranked from best to worst as follow, video mirroring, view cone, and highlighting in precision and error rate [33].

In another study, Kasahara et al. introduced JackIn Head, which is a system used for remote collaboration [49]. As Figure 2.3 shows, it is a telepresence technology in which one user sends visual information about the environment to remote collaborators that are in another place using an omnidirectional wearable camera on his head. This allows remote users to see the environment independent of the direction of the user who sends the visual information's head. The results show that sharing a first-person viewpoint using this approach is helpful for remote collaboration in telepresence [49].

Cai et al. developed a cross-reality application for remote collaboration, which allows the first user to be physically present in a shared environment, equipped with a mobile augmented reality device, while the second user remains in a separate location and experiences a virtual reality representation of the shared environment [16]. As Figures 2.4 and 2.5 show, the system aims to provide a unique form of collaboration called Shoulder-to-shoulder collaboration,

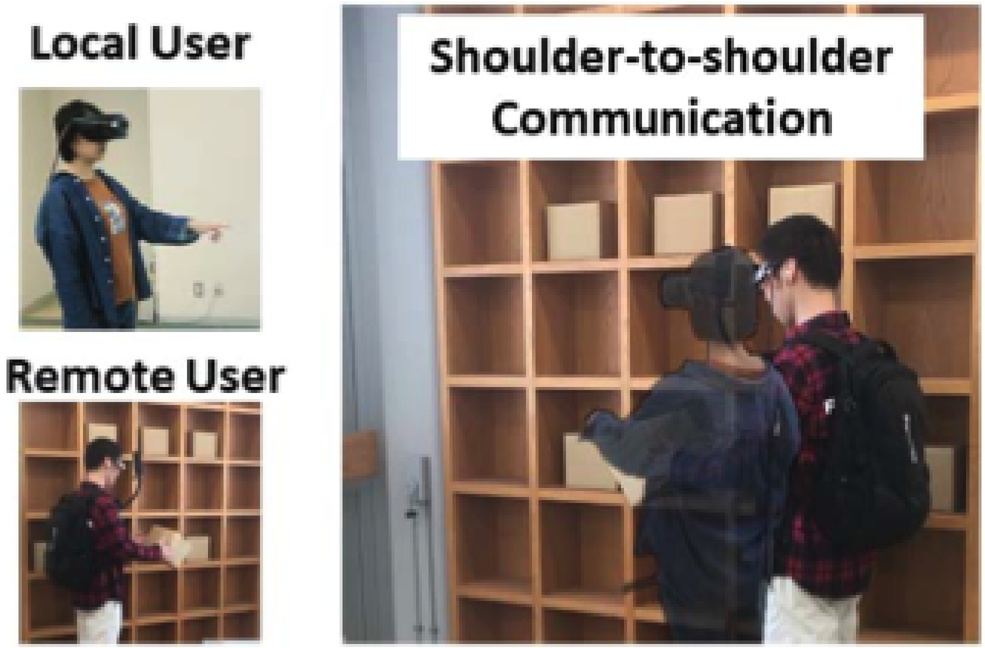

Figure 2.4: Two users collaborating showlder-to-showlder using VR and AR application [16].

which simulates the experience of walking side by side while allowing for independent viewing and bidirectional gesture communication. The results show that this shoulder-to-shoulder remote collaboration works effectively [16].

Chenechal et al. developed a cross-reality application for remote collaboration, which allows for one local user utilizing the augmented reality version of the application and one remote user utilizing the virtual reality version of the application to collaborate together [55]. As Figure 2.6 shows, the viewpoint of the local user is shared with the remote user. The main feature of the application is providing the local user with two virtual arms controlled by the remote user, which can be used as interactive guidance tools. The results show that the proposed approach may decrease cognitive load compared to traditional approaches [55].

H. Hoppe et al. created a collaborative virtual reality application and compared the effect of having a shared viewpoint and independent viewpoints [45]. As Figure 2.7 shows, in the application, all users are placed at the same location to ensure a shared perspective.

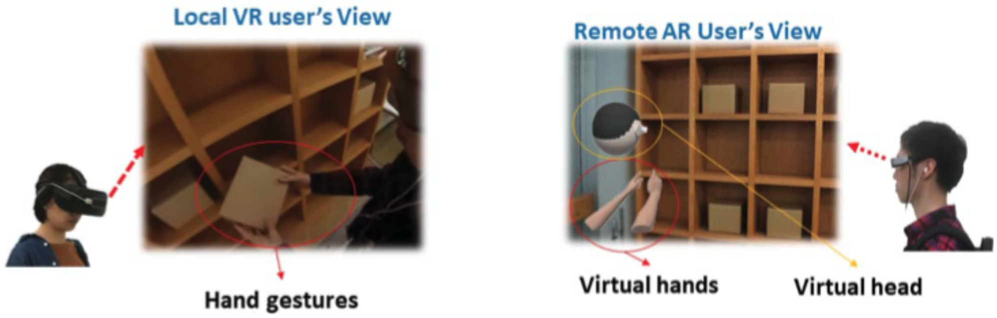

Figure 2.5: Showing the field of view of two users collaborating remotely using AR and VR applications. [16].

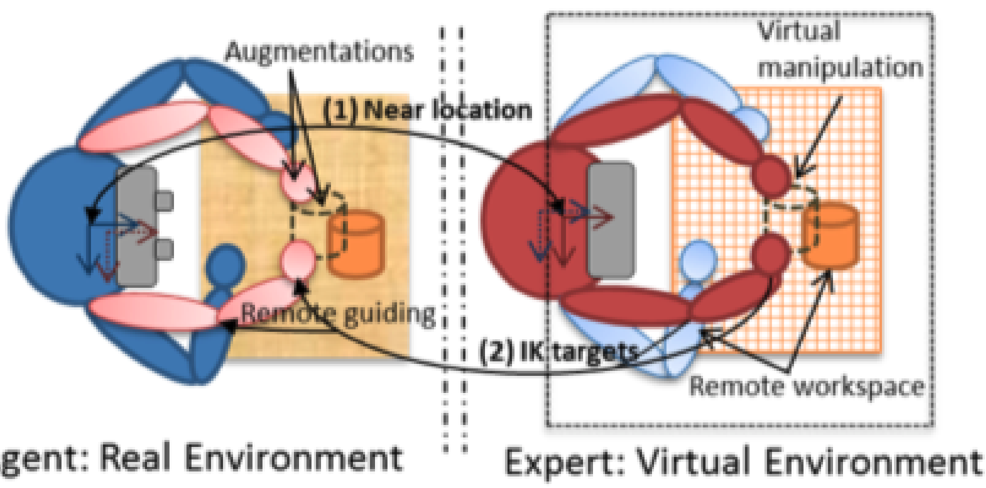

Figure 2.6: The local user uses an AR version of the application and the remote user uses a VR version of the application. The viewpoint of the local user is shared with the remote user. The local user see two virtual arms representing the arms of remote user [55].

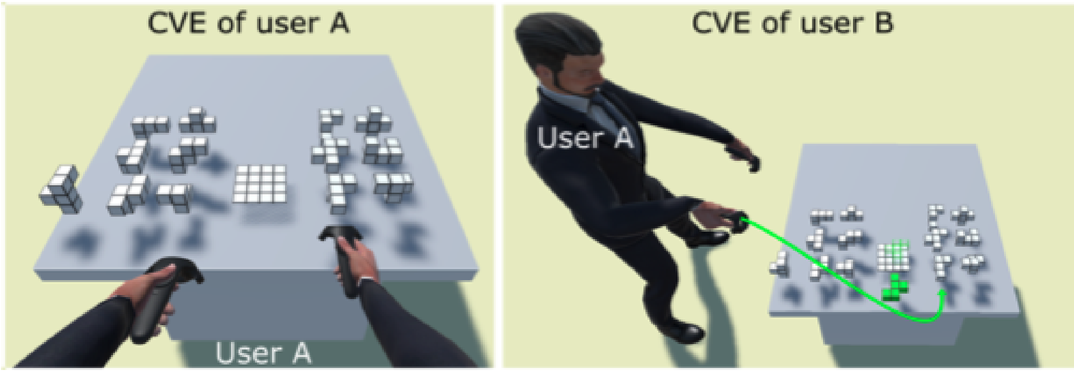

Figure 2.7: User B's viewpoint is shared with User A by separating viewpoints from avatars. Left: The viewpoint of User A. Right: The viewpoint of User B [45].

To prevent any overlap of body parts, the avatars of other connected users are moved to the side. The system then utilizes a redirected body pose modification to correct any inconsistencies that may arise. The system is compared to a baseline of two users standing in the same location and working with avatars that overlap with each other. They calculate task completion time for the task they defined for users to solve in the application, and for subjective measures, they asked for users' preference for the technique. The findings of a user study indicate that the proposed modifications make collaboration more efficient [45].

The difference between the study and ours is the final positions of avatars in the scene after decoupling viewpoints from them. In the "ShiSha: Enabling Shared Perspective With Face-to-Face Collaboration Using Redirected Avatars in Virtual Reality," avatars are teleported next to each other, and viewpoints are separated. Then, they put avatars in a position calculated following an algorithm defined in the approach. However, in our study, the final positions of avatars, after decoupling viewpoints from avatars, are the same as their initial positions.

2.3 Evaluation metrics

Different fields have distinct ways of evaluating usability. In Software Engineering, objective metrics such as system response time, task completion time, task precision, effectiveness, and efficiency are commonly used in studies [31]. Moreover, the usability of a system can be measured by calculating user performance, engagement, and acceptability [7].

Due to the rapidly evolving technology and human interaction challenges, there is a growing need for prompt assessment of systems that involve users distributed across different contexts, which led to an increased reliance on techniques such as questionnaires [73]. The advantage of questionnaires is that they provide insights into the users' perception of the system. However, the data collected through questionnaires may be inconsistent due to variations in individual's interpretation of the questions [79]. The main benefit of questionnaires is that it allows for easy collection of data from a large number of participants [73].

Another approach to gathering data is structured and semi-structured interviews. Although interviews tend to be more time-consuming for researchers than questionnaires, they can be a more appropriate method when identifying individuals in key positions with a thorough understanding of a situation [73]. In interviews, participants can offer important information and insights that may not be obtainable through questionnaires [73].

In this chapter, the various forms of collaboration in terms of space and time are discussed, as well as the advantages and disadvantages of each. Additionally, the literature on the topic of shared viewpoints during collaboration is also covered. To our knowledge, a previous study that is most similar to ours is conducted by H. Hoppe et al. in their paper "ShiSha: Enabling Shared Perspective With Face-to-Face Collaboration Using Redirected Avatars in Virtual Reality" [45]. The main difference between their study and ours is that they teleport two avatars to the same location and move one avatar to the side while we maintain the avatars' original positions and adjust the collaborators' viewpoints to be next to each other.

To assess the effectiveness of our system, we carried out a user study using various methods such as questionnaires, semi-structured interviews, and measuring the time users take to complete tasks. The next chapter will discuss the details of our research methodology and the user study design.

Chapter 3

Research Methodology

We want to evaluate the effect of sharing a viewpoint between collaborators by separating viewpoints from avatars in a collaborative virtual reality application. A user study is conducted with twenty-two participants to answer the research questions provided in Chapter 1[1]. This chapter discusses the user study's scenarios, apparatus, procedure, and participants. A virtual reality application was created and used in this user study to investigate the effect of sharing a viewpoint between collaborators by separating viewpoints from avatars in collaborative virtual reality applications. Chapter 4 discusses the virtual reality application in more detail.

Two types of data is collected from the user study:

1. Participants' opinions about having a shared viewpoint by separating viewpoints from avatars during a collaboration in the virtual reality application.

2. The amount of time that it takes to complete each scenario.

[1]The study was approved by CFREB. The ethics approval id is REB22-0712. See Appendix A for the ethics approval certification.

3.1 Collaborative virtual reality application

In order to find answers to our research questions, we had to create a tool to be able to have a shared viewpoint between collaborators and come up with scenarios to forcing participants to collaborate. The tool, tasks, and interaction techniques used in the application should be easy to learn and use, as many participants might be unfamiliar with using virtual reality applications and headsets. Moreover, participants should be able to understand and handle tasks easily because the thesis is concerned about the collaboration aspect of scenarios.

3.1.1 Overview

In order to force participants to collaborate, we show part of the information they need to complete scenarios to each of them. Communication allows them to share their missed information and access the data they need to finish each scenario.

The task we designed is matching shapes with colors. As Figure 3.1 shows, there are eight different shapes and a text field on a table and eight different colors organized around the table.

Our study focuses on the collaboration aspect of solving a task. Therefore, we created a simple task that is easy to solve for users. They do not need to have prior knowledge to be able to complete matching shapes and colors, except they should be able to communicate with each other and be able to differentiate between different colors and tasks. Designing a complicated task or a task that needs specific knowledge to be completed limits the number of participants who can participate in the user study. Moreover, if we design a task that needs knowledge that most people are not familiar with, we need to train them to understand the knowledge before starting the user study. This adds complexity to the user study that is not the focus of our research. However, to generalize the results for different domains, case studies need to be designed, specific tasks related to domains need to be defined, and users should be experts who are familiar with the knowledge needed to complete tasks.

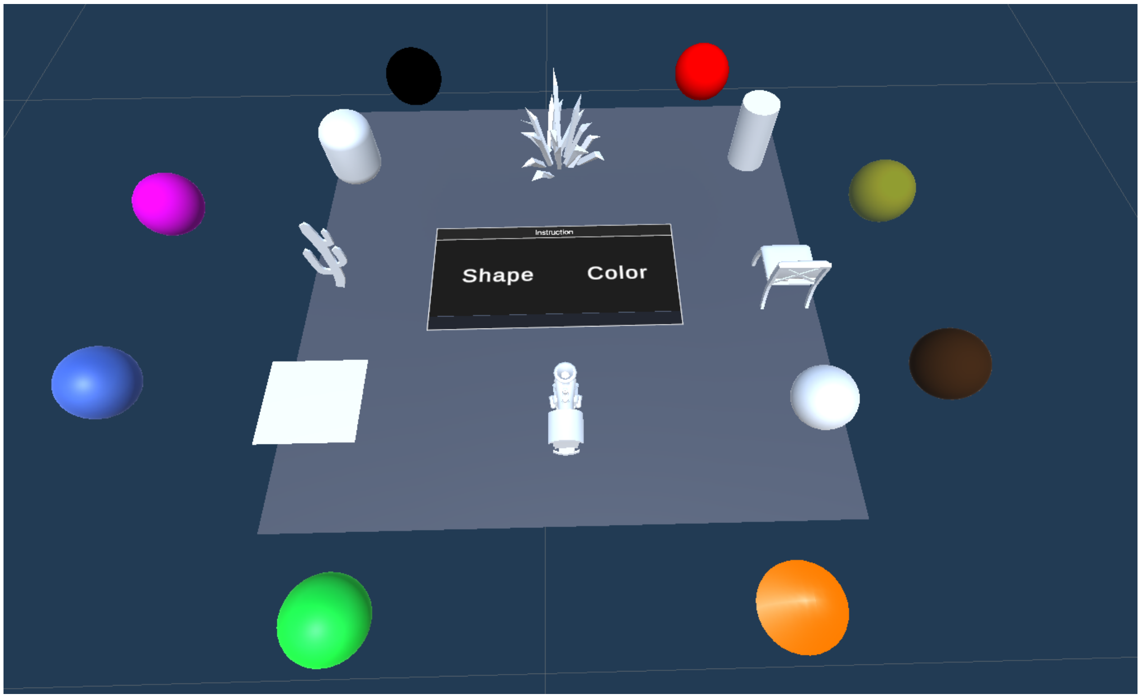

Figure 3.1: An image of the table used in the virtual reality application. Eight shapes are on the table, and eight colors are around it.

Two collaborators are needed to complete the scenarios. We defined two roles in the application:

1. Shape Collaborator: The participant who can see shapes. All colors are looked like Grey color to her; therefore, colors are not distinguishable for her
2. Color Collaborator: The participant who can see colors. All shapes are looked like Cube to her; hence, shapes are not distinguishable for her

The first collaborator, called Color Collaborator, is aware of the colors. She can see eight distinct colors around the table. All shapes look like cubes to her, and she cannot distinguish different shapes. Figure 3.2 shows how Color Collaborator sees a table. Furthermore, she can only see half of the text field, which shows the name of one color. Finally, she cannot interact with anything in the scene, and her only task is sharing her information with the other collaborator.

The next collaborator, called Shape Collaborator, is aware of the shapes. She can see

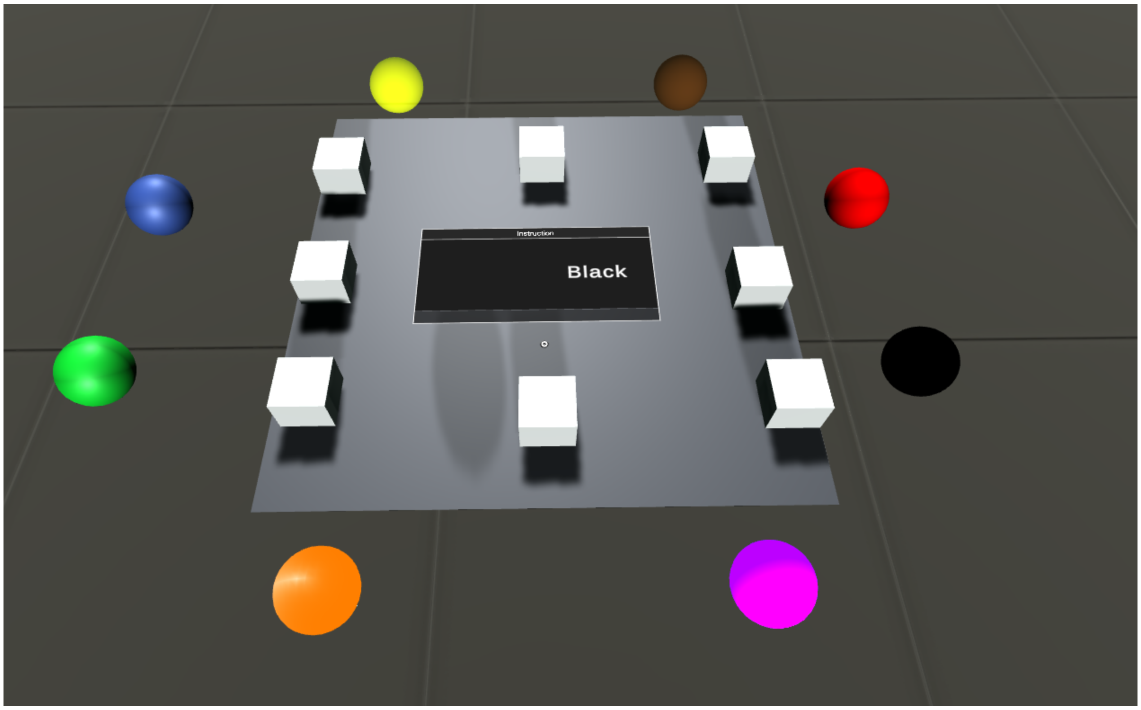

Figure 3.2: Color Collaborator can see eight distinct colors around a table. Shapes are like cubes to her, and she cannot distinguish different shapes. She sees part of a text field that shows the name of a color in the scene.

eight distinct shapes on the table. All colors look Grey to her; therefore, she cannot distinguish different colors. Figure 3.3 shows how Shape Collaborator sees a table. Like Color Collaborator, she can only see half of the text field, which shows the name of a shape on the table. Unlike Color Collaborator, Shape Collaborator can interact with shapes and colors. She is responsible for taking information from Color Collaborator and interacting with shapes and colors to match proper colors with shapes.

Color Collaborator and Shape Collaborator should communicate and share their information to match proper shapes with colors. Color Collaborator shares the place of the color that can see its name on the text field, and Shape Collaborator should place the color in the scene and match it with the shape that sees its name on the text field. When the color is matched with the correct shape, the shape will be colorful for Shape Collaborator for two and a half seconds, indicating the success of the matching, and the text field will be updated for both of them with the next color and shape names.

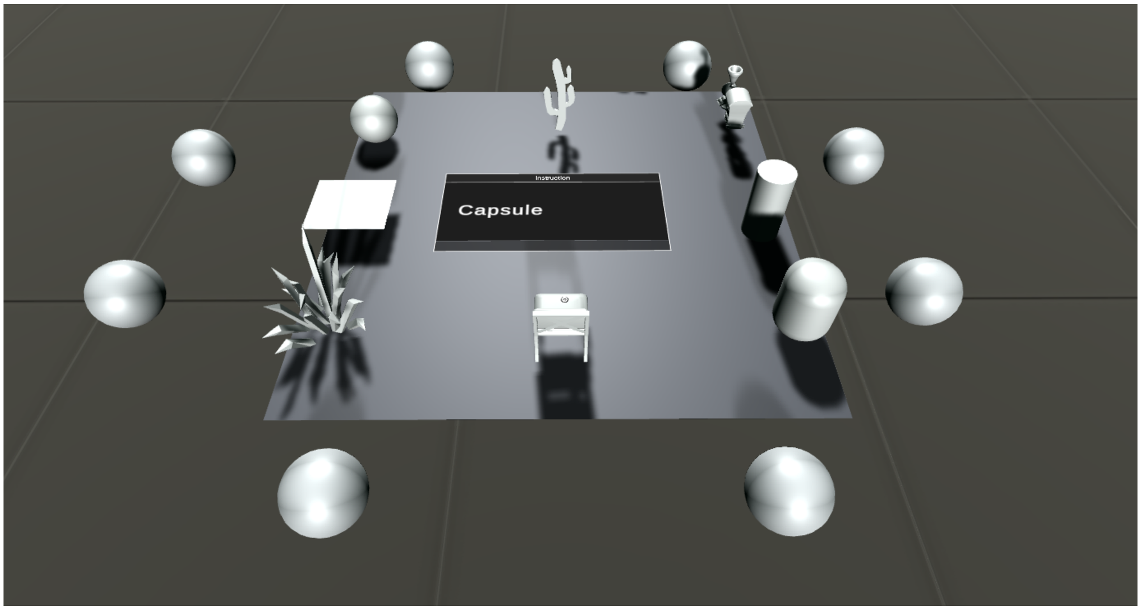

Figure 3.3: Shape Collaborator can see eight distinct shapes on the table. All colors look grey to her. She can see half of the text field that indicates the name of one shape on the table.

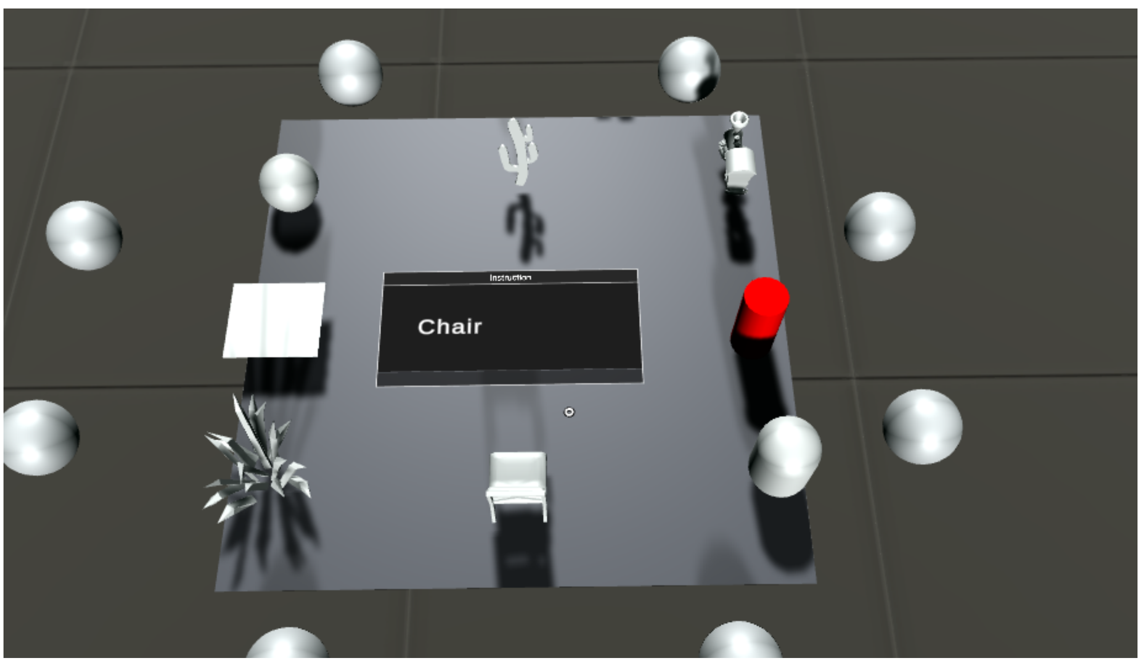

Figure 3.4: When a correct color is matched with a correct shape, the shape will be colorful for two and a half seconds, and the color will return to its original position.

Figure 3.5: An empty table will be shown to collaborators when they match all eight shapes and colors. The empty table indicates that the task is finished.

In order to complete each scenario, Shape Collaborator needs to match all eight colors with all eight shapes correctly. When the task is finished, the table with colors and shapes disappeares, and an empty table will be shown to them, indicating that the task is done. The order of shapes and colors is random and will be determined when a task is started.

Participants have infinite time to complete each task. We did not set any time limit for finishing tasks, and we let them think about the proper approach for collaboration, come up with their own strategy, and use that to complete scenarios.

3.1.2 Shared viewpoint vs. Independent viewpoint

In the collaborative virtual reality application created to answer research questions, we decoupled avatars and viewpoints from each other. This enables us to put users' viewpoints next to each other without the need to change their avatars' positions.

Given this feature, two modes for viewpoints are defined:

1. Independent viewpoint: Each user has their own viewpoint which is in the position that their avatar is.

2. Shared viewpoint: The viewpoint of one user is decoupled from her avatar and put next to the other user's viewpoint. Moreover, this user's avatar is hidden for herself in the scene. The viewpoint of the other user is where her avatar is.

3.2 Scenarios

Twelve scenarios are created to answer research questions provided in Chapter 1. We discuss those scenarios in this section in detail. The scenarios varied based on the following factors:

1. The positioning of the two avatars around a table

2. Whether the collaborators had a shared viewpoint or independent viewpoints

3. Which collaborator's viewpoint was shared with the other

If straight lines are drawn from avatars' eyes, the intersection of these two lines creates an angle. Using this angle, we established four different settings:

1. Setting 1- 180 degrees: In this scenario, collaborators stand in front of each other as Figure 3.8 shows. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 180-degree angle.

2. Setting 2- 135 degrees: In this scenario, collaborators stand around a table, as Figure 3.9 shows. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 135-degree angle.

3. Setting 3- 90 degrees: In this scenario, collaborators stand around a table, as Figure 3.10 shows. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 90-degree angle.

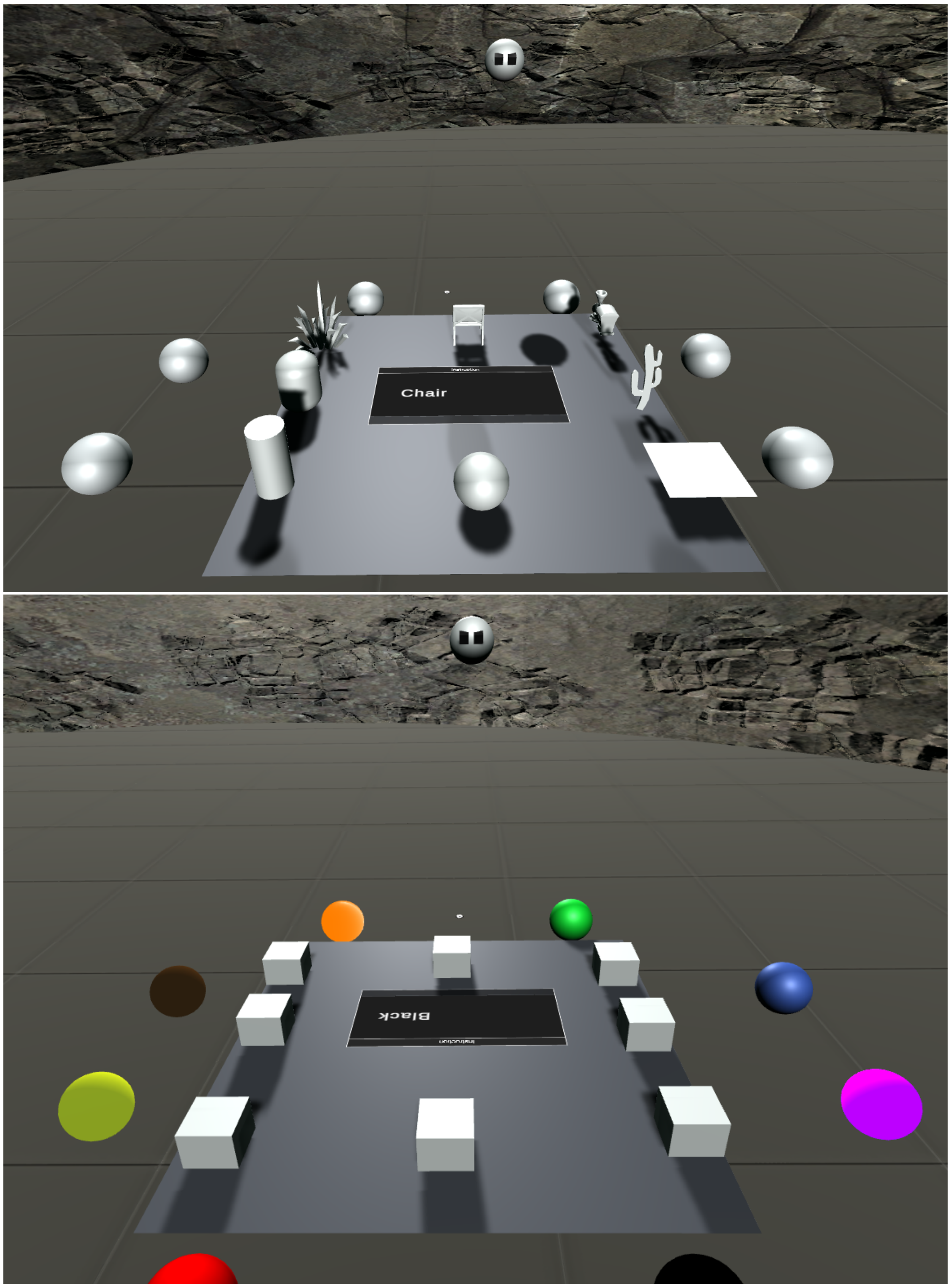

Figure 3.6: Independent viewpoints: Each collaborator has her own viewpoint independent of the other. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

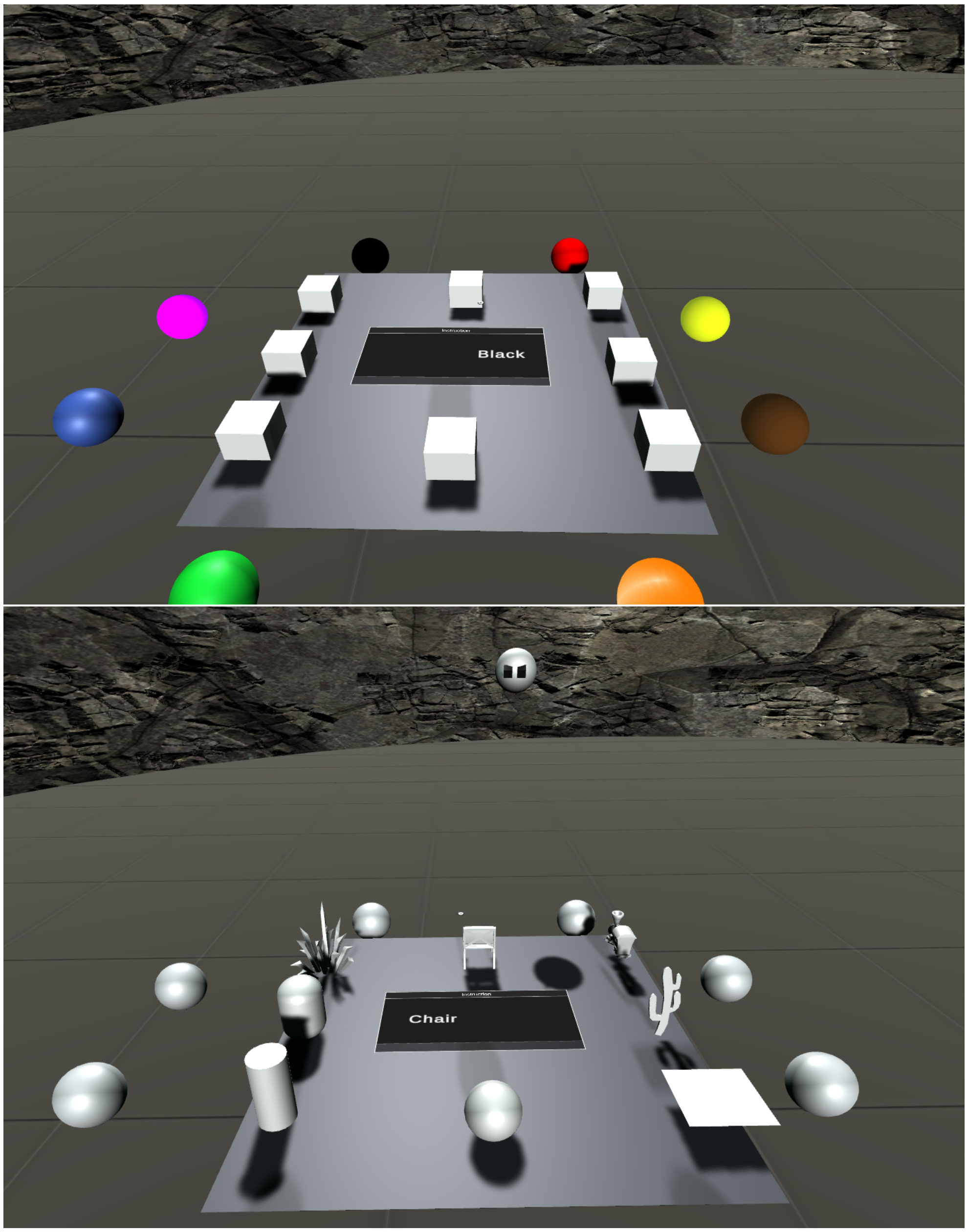

Figure 3.7: Shared viewpoint: The viewpoint of Color Collaborator is decoupled from her avatar and put next to the Shape Collaborator's viewpoint. The viewpoint of Shape Collaborator is where her avatar is.

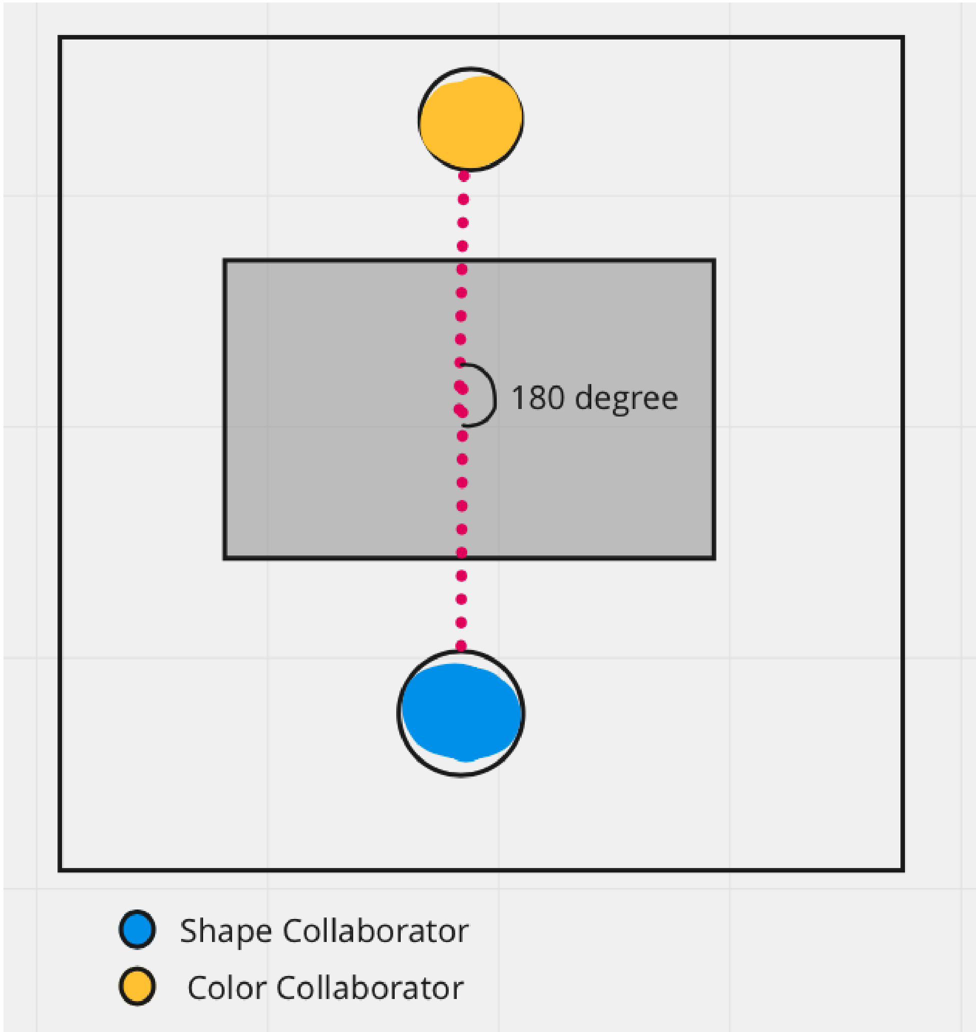

Figure 3.8: In setting 1, collaborators stand in front of each other behind the table. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 180-degree angle.

4. Setting 4- 45 degrees: In this scenario, collaborators stand around a table, as Figure 3.11 shows. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 45-degree angle.

Each setting consists of the following three scenarios:

1. Independent viewpoint: Collaborators have independent viewpoints. Shape Collaborator sees the text properly, and Color Collaborator sees the text tilted.

2. Shared viewpoint - Color Collaborator: Collaborators have a shared viewpoint by

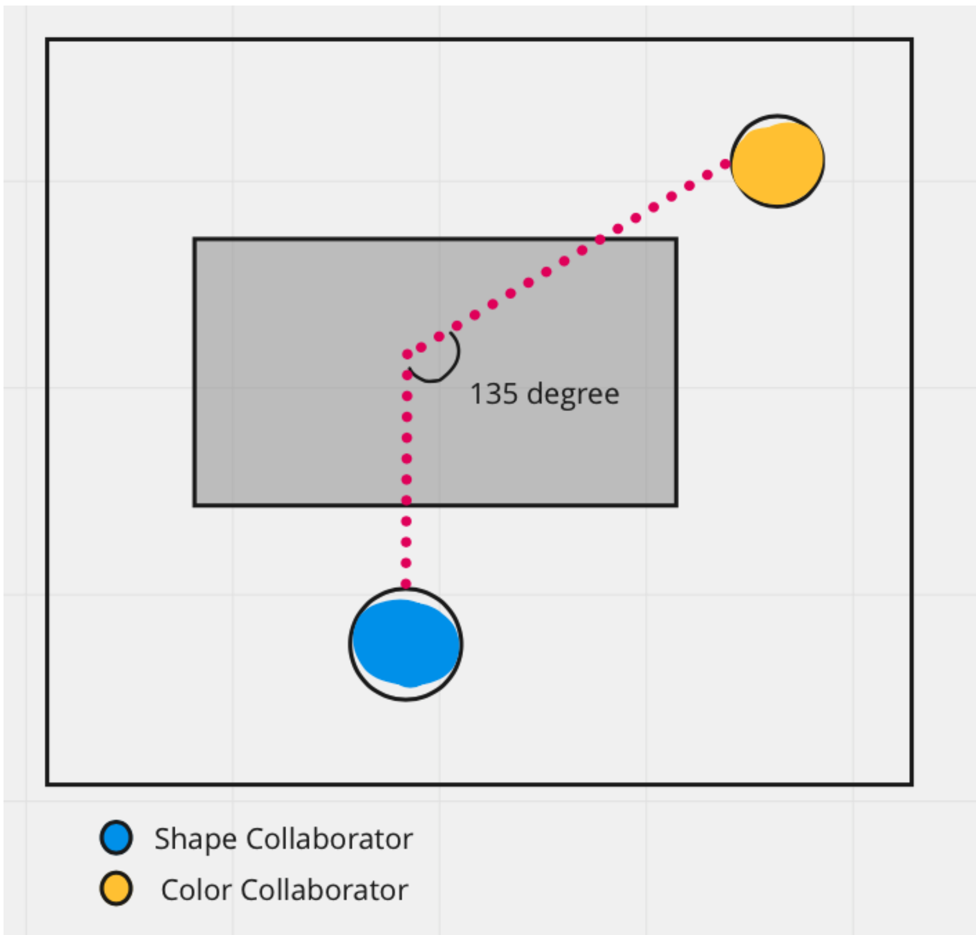

Figure 3.9: Setting 2: Collaborators stand behind a table. If straight lines are drawn from avatars' eyes, two line intersection point creates a 135-degree angle.

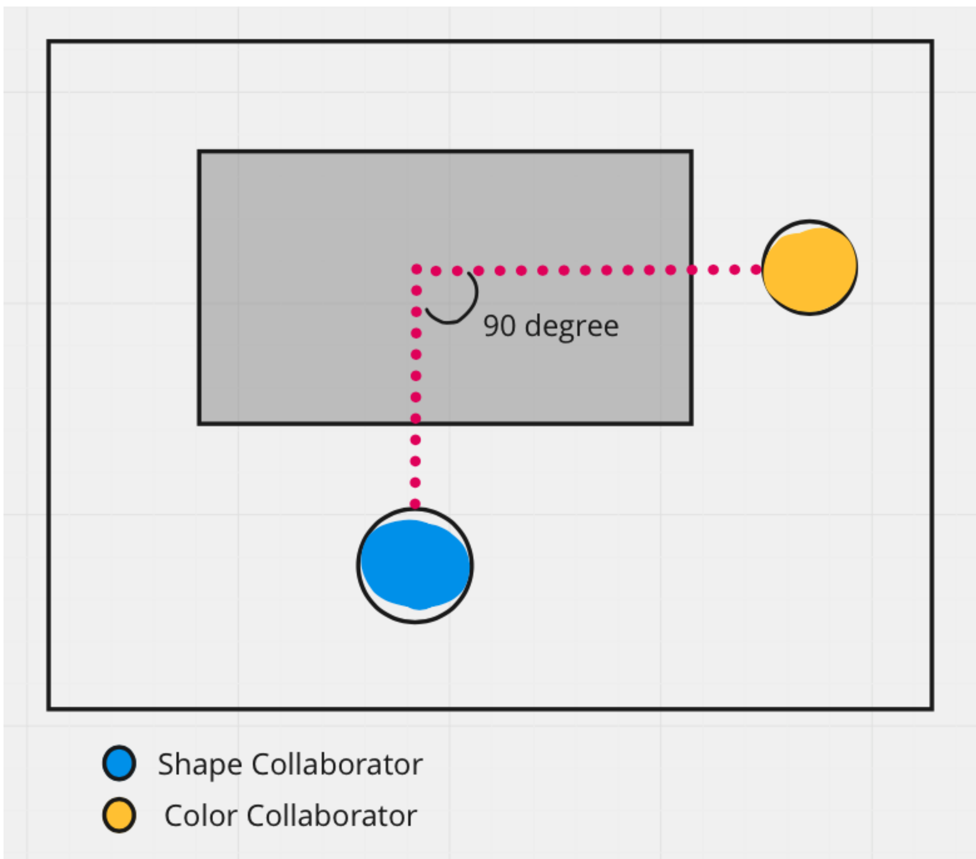

Figure 3.10: Setting 3: Collaborators stand behind a table. If straight lines are drawn from avatars' eyes, two line intersection point creates 90 degrees angle.

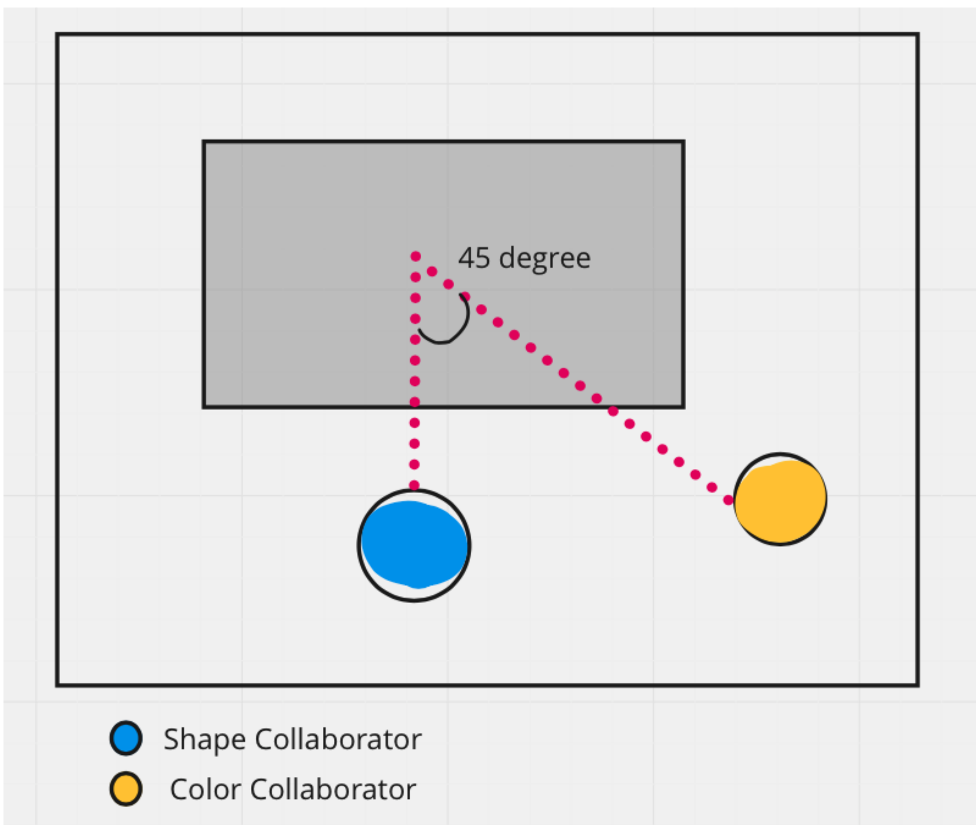

Figure 3.11: Setting 4: Collaborators stand behind a table. If straight lines are drawn from avatars' eyes, two line intersection point creates 45 degrees angle.

separating Shape Collaborator's viewpoint from her avatar and moving it next to Color Collaborator's viewpoint.

3. Shared viewpoint - Shape Collaborator: Collaborators have a shared viewpoint by separating Color Collaborator's viewpoint from her avatar and moving it next to Shape Collaborator's viewpoint.

3.2.1 Order of scenarios

Table 3.1 shows the order of scenarios that participants completed during the user study.

Setting	Viewpoint mode
90 degree	Independent
180 degree	Shared : Shape Collaborator
90 degree	Shared : Color Collaborator
180 degree	Shared : Color Collaborator
90 degree	Shared : Shape collaborator
180 degree	Independent
135 degree	Shared : Color Collaborator
45 degree	Shared : Shape collaborator
135 degree	Independent
45 degree	Independent
135 degree	Shared : Shape collaborator
45 degree	Shared : Color Collaborator

Table 3.1: The order of scenarios used in the user study

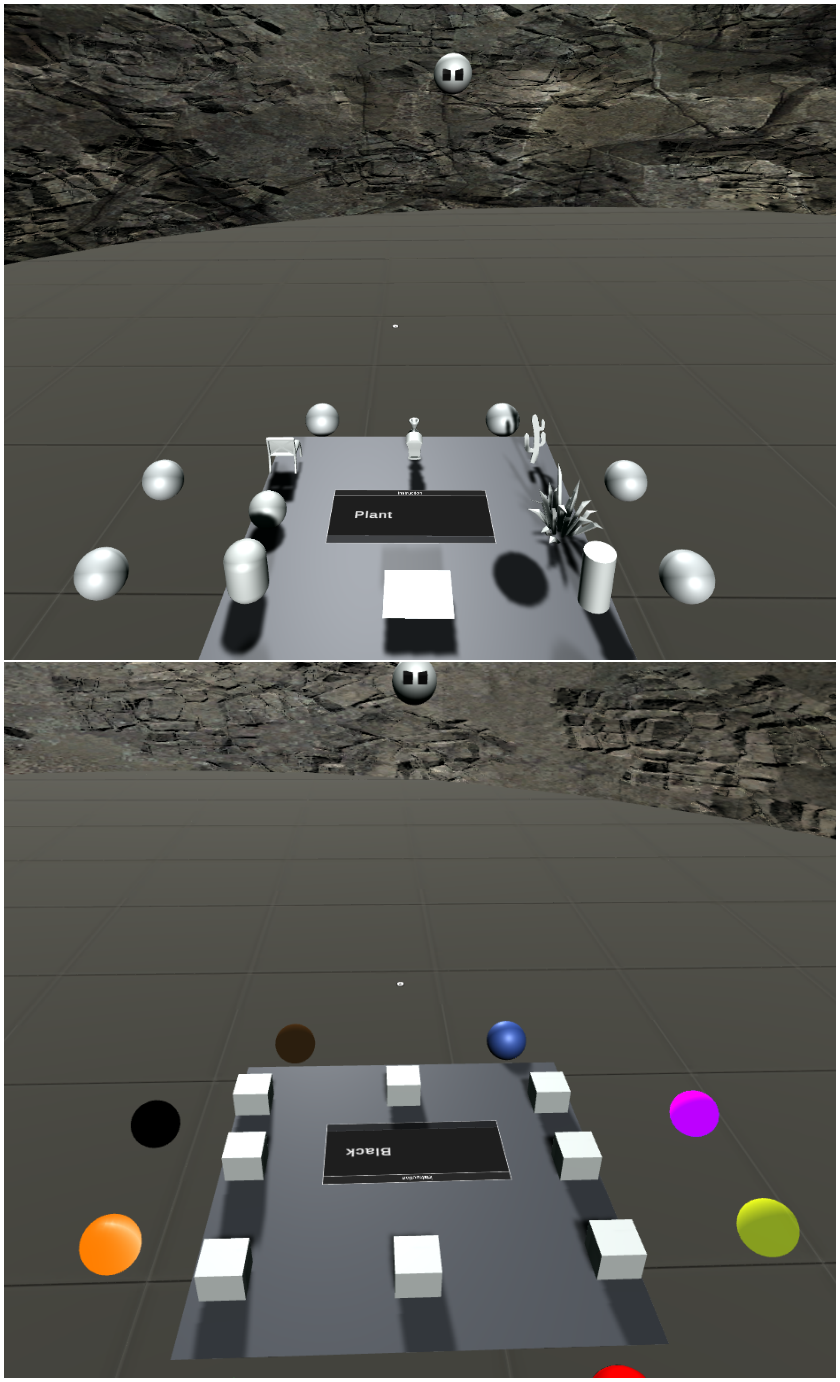

Figure 3.12: Setting 1 - Independent viewpoint scenario: Collaborators stand in front of each other behind the table and have independent viewpoints. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 180-degree angle. These figures show the view of each collaborator when they have independent viewpoints. Top: View of Shape Collaborator. Bottom: View of Color Collaborator.

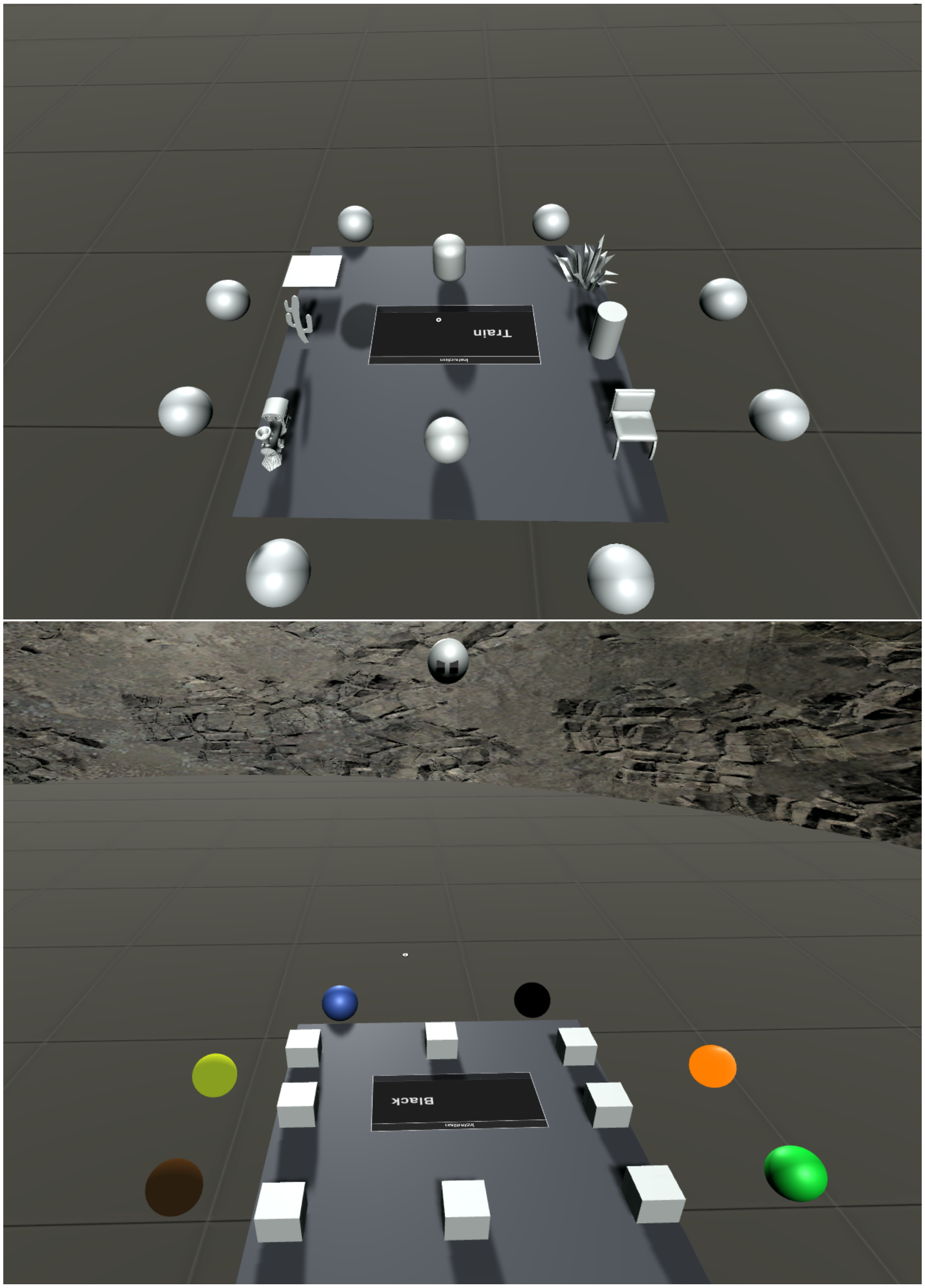

Figure 3.13: Setting 1 - Shared viewpoint, Color Collaborator: Collaborators stand in front of each other. Color Collaborator's viewpoint is shared with Shape Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

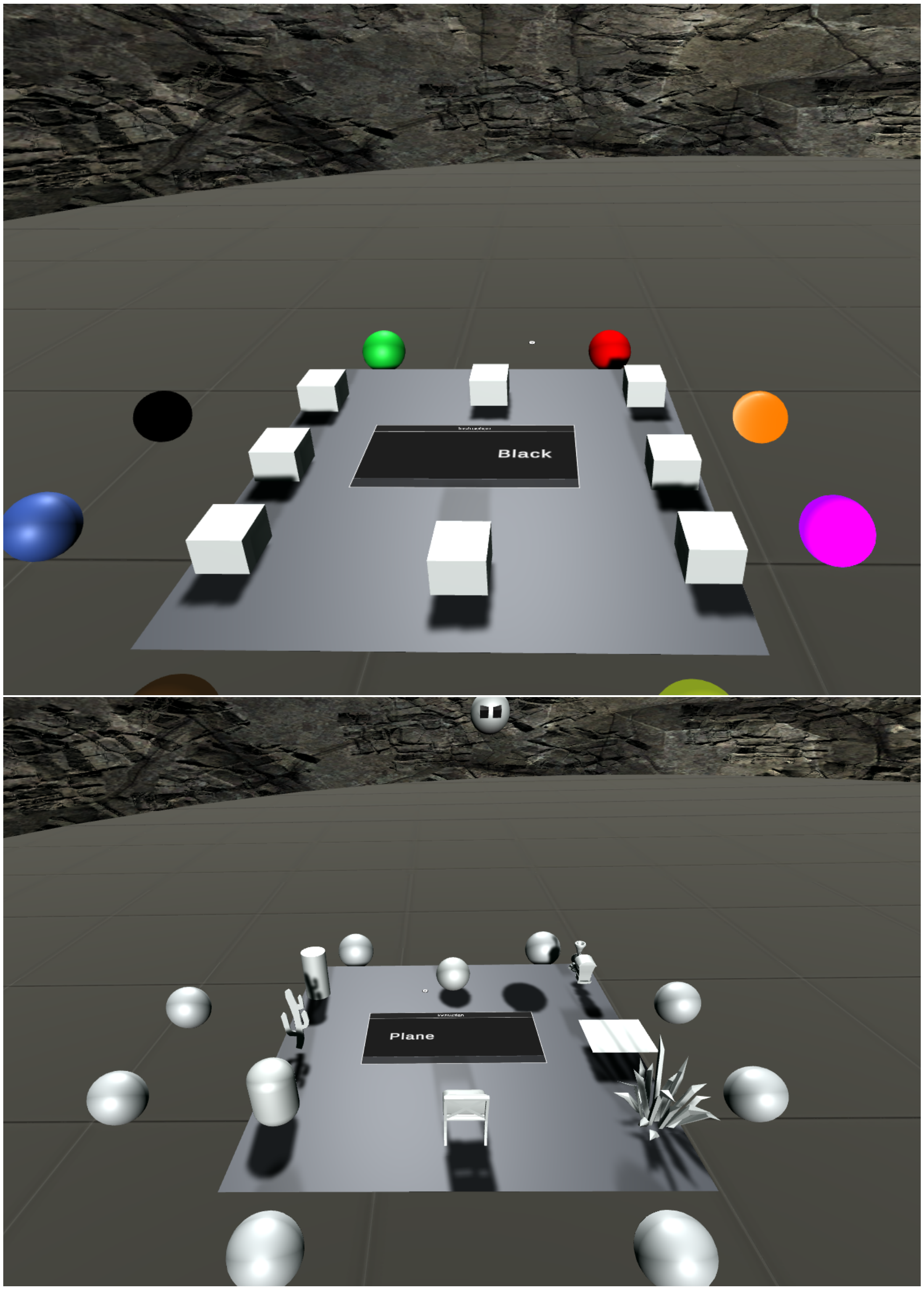

Figure 3.14: Setting 1 - Shared viewpoint, Shape Collaborator: Collaborators stand in front of each other. Shape Collaborator's viewpoint is shared with Color Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

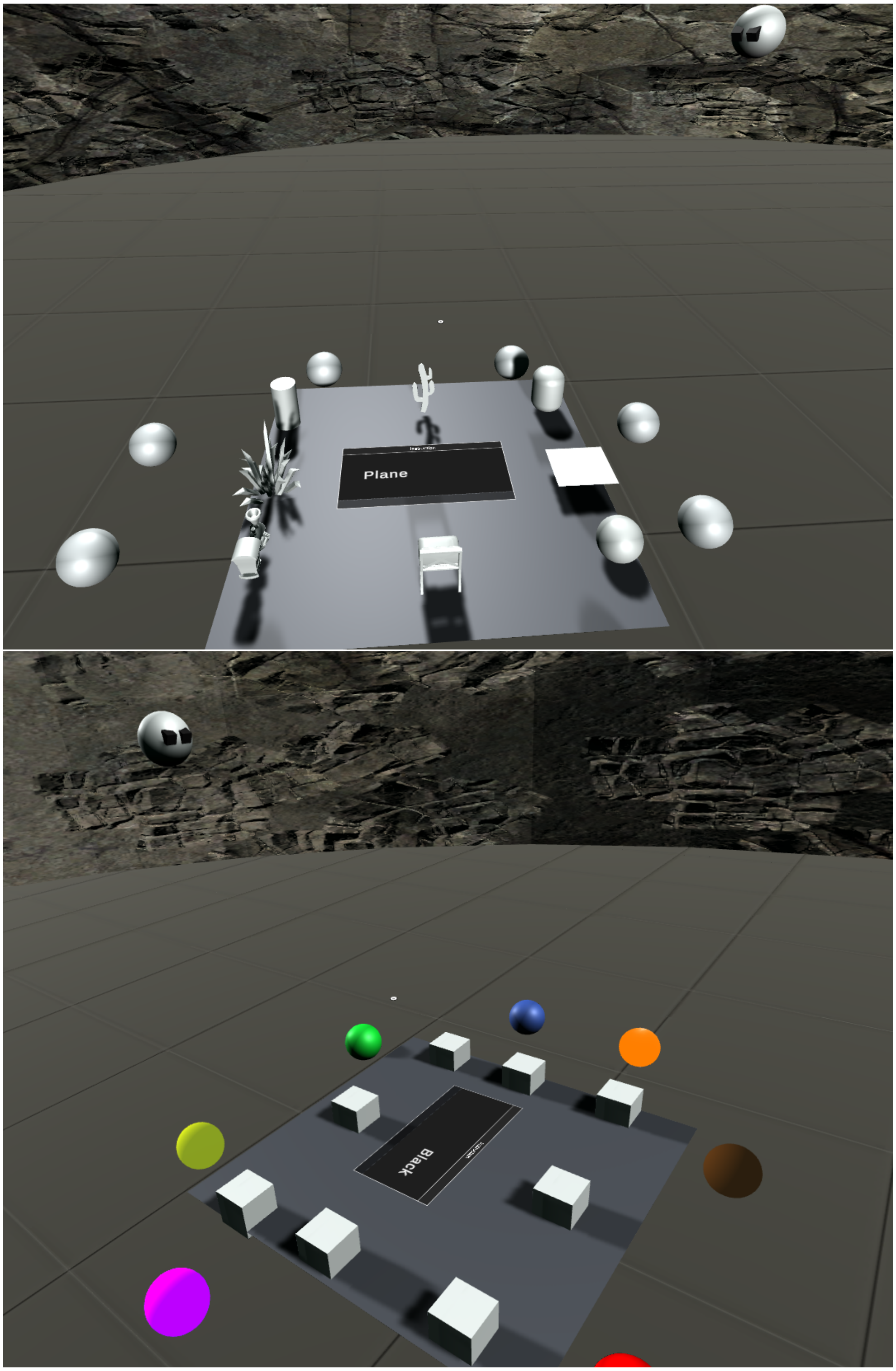

Figure 3.15: Setting 2- Independent viewpoint: Collaborators stand behind a table and have independent viewpoints. If straight lines are drawn from avatars' eyes, two line intersection point creates 135 degrees angle. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

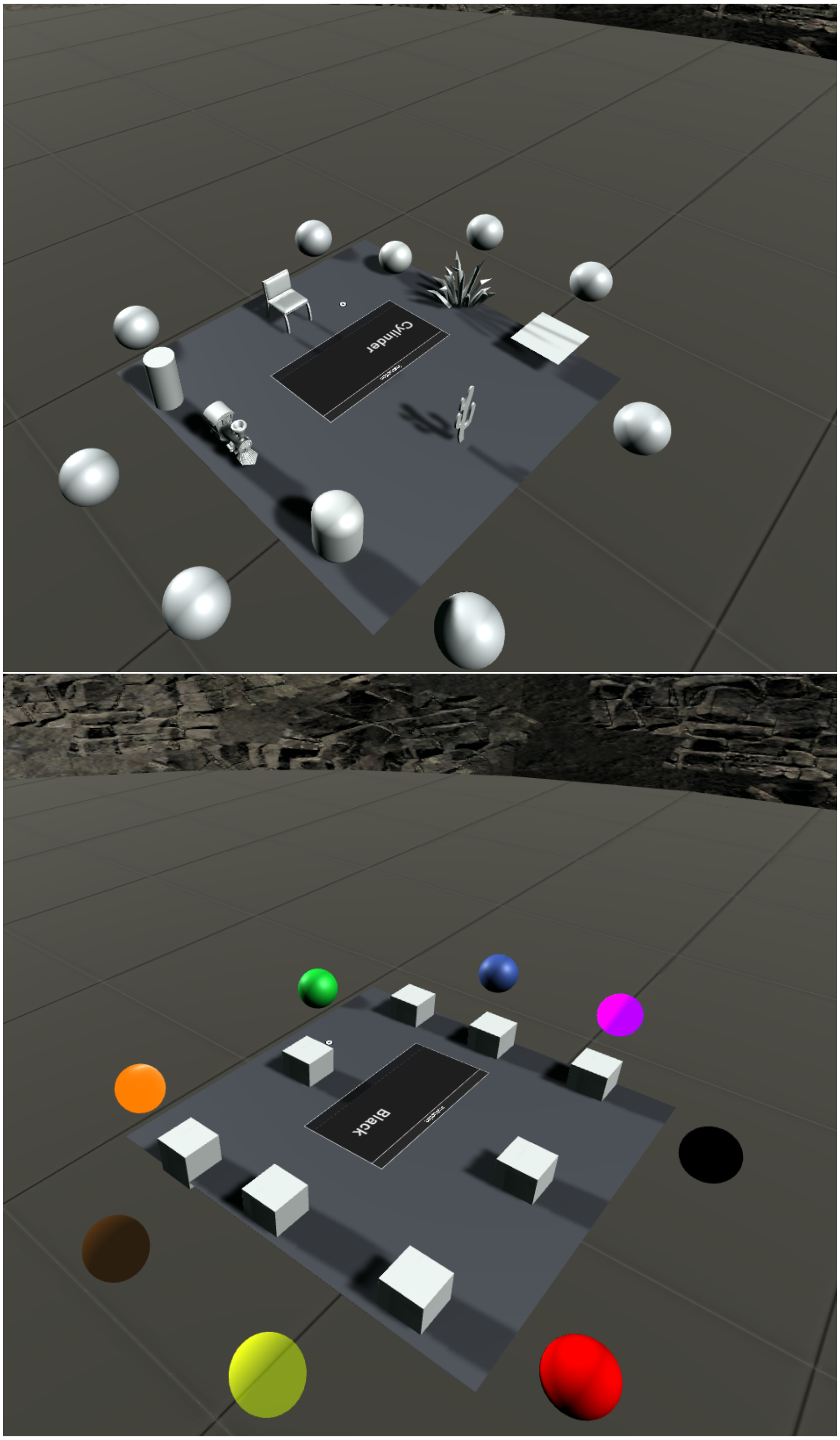

Figure 3.16: Setting 2 - Shared viewpoint, Color Collaborator: Color Collaborator's viewpoint is shared with Shape Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

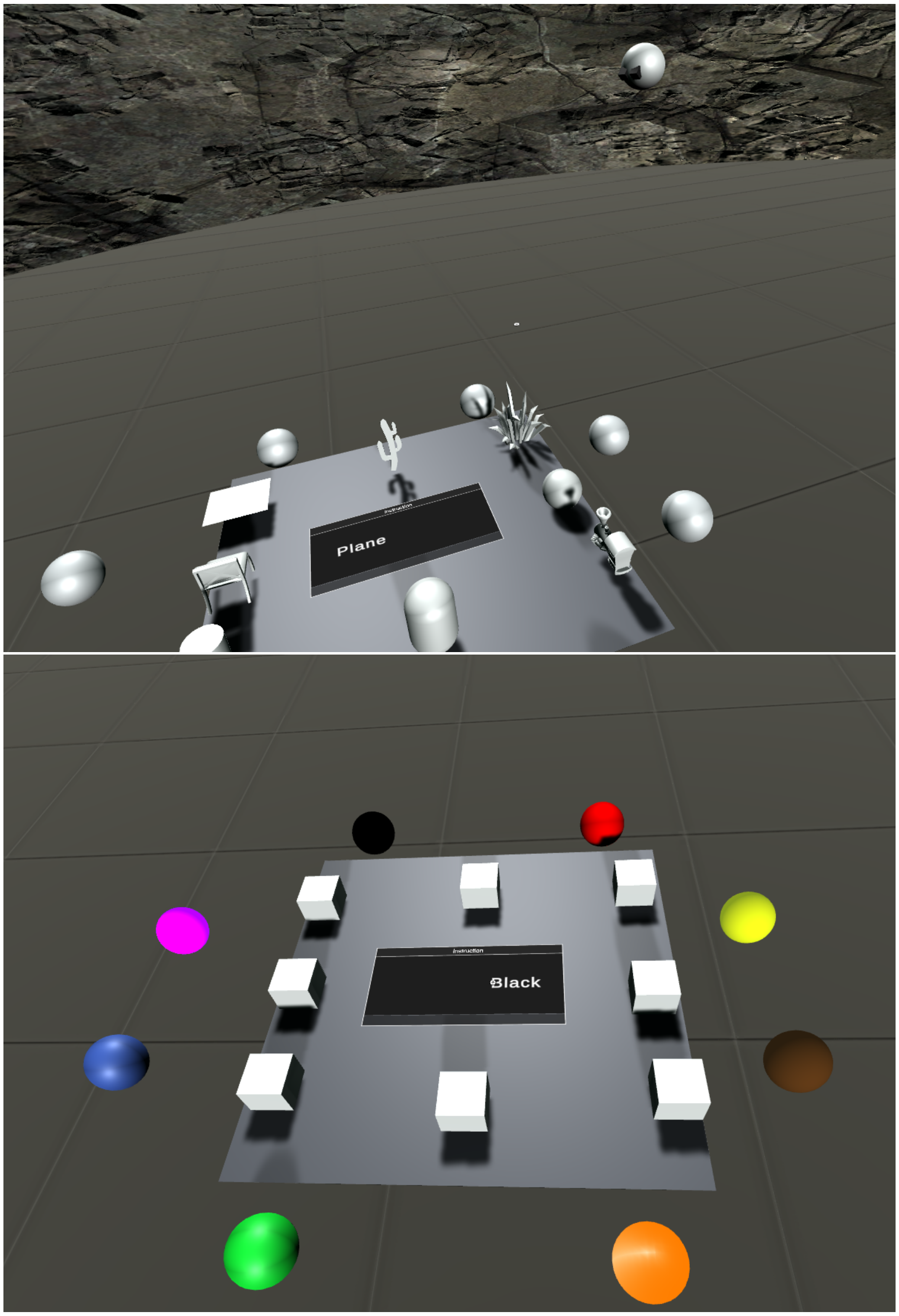

Figure 3.17: Setting 2- Shared viewpoint, Shape Collaborator: Shape Collaborator's viewpoint is shared with Color Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

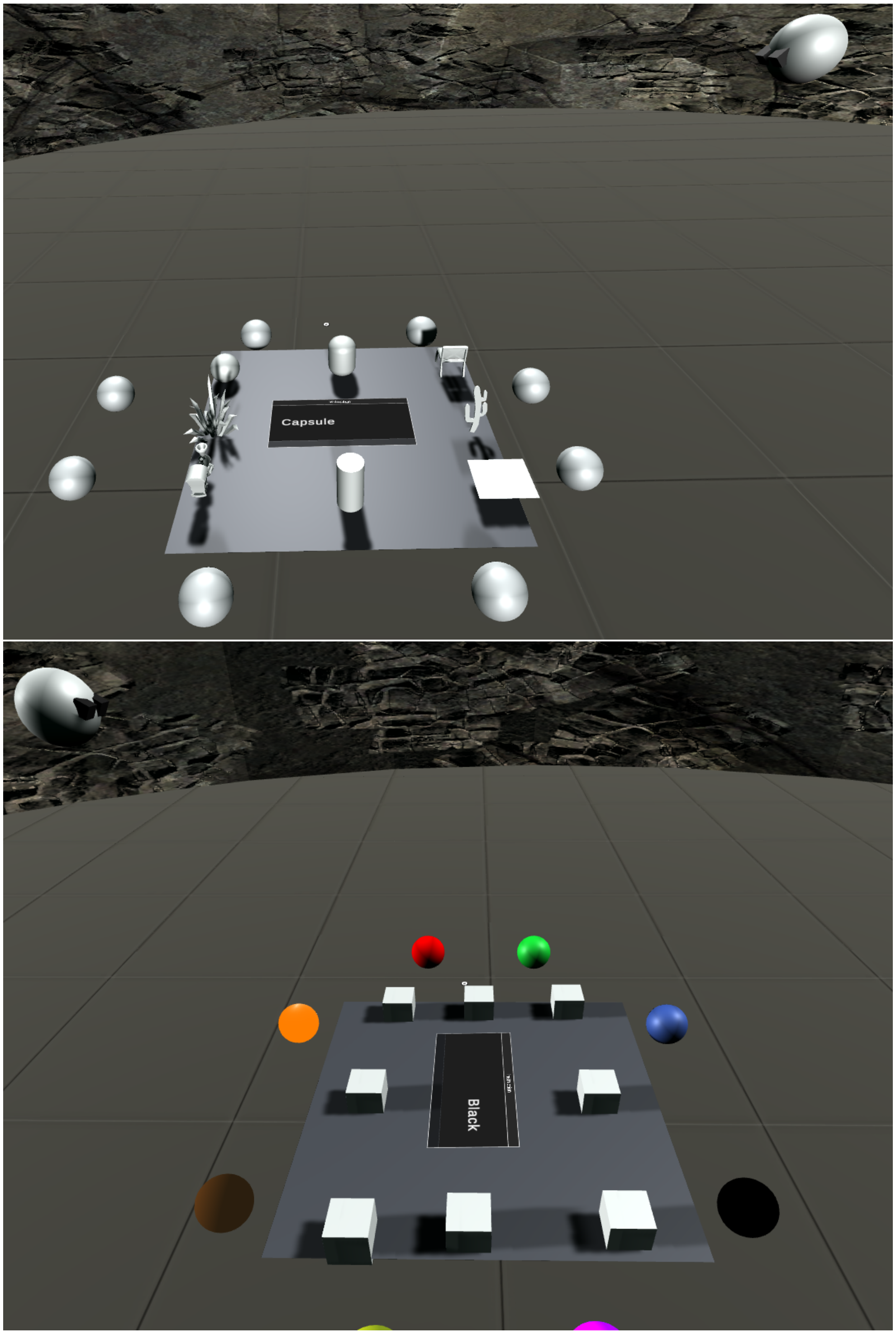

Figure 3.18: Setting 3- Independent viewpoint: Collaborators stand behind a table and have independent viewpoints. If straight lines are drawn from avatars' eyes, two line intersection point creates 90 degrees angle. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

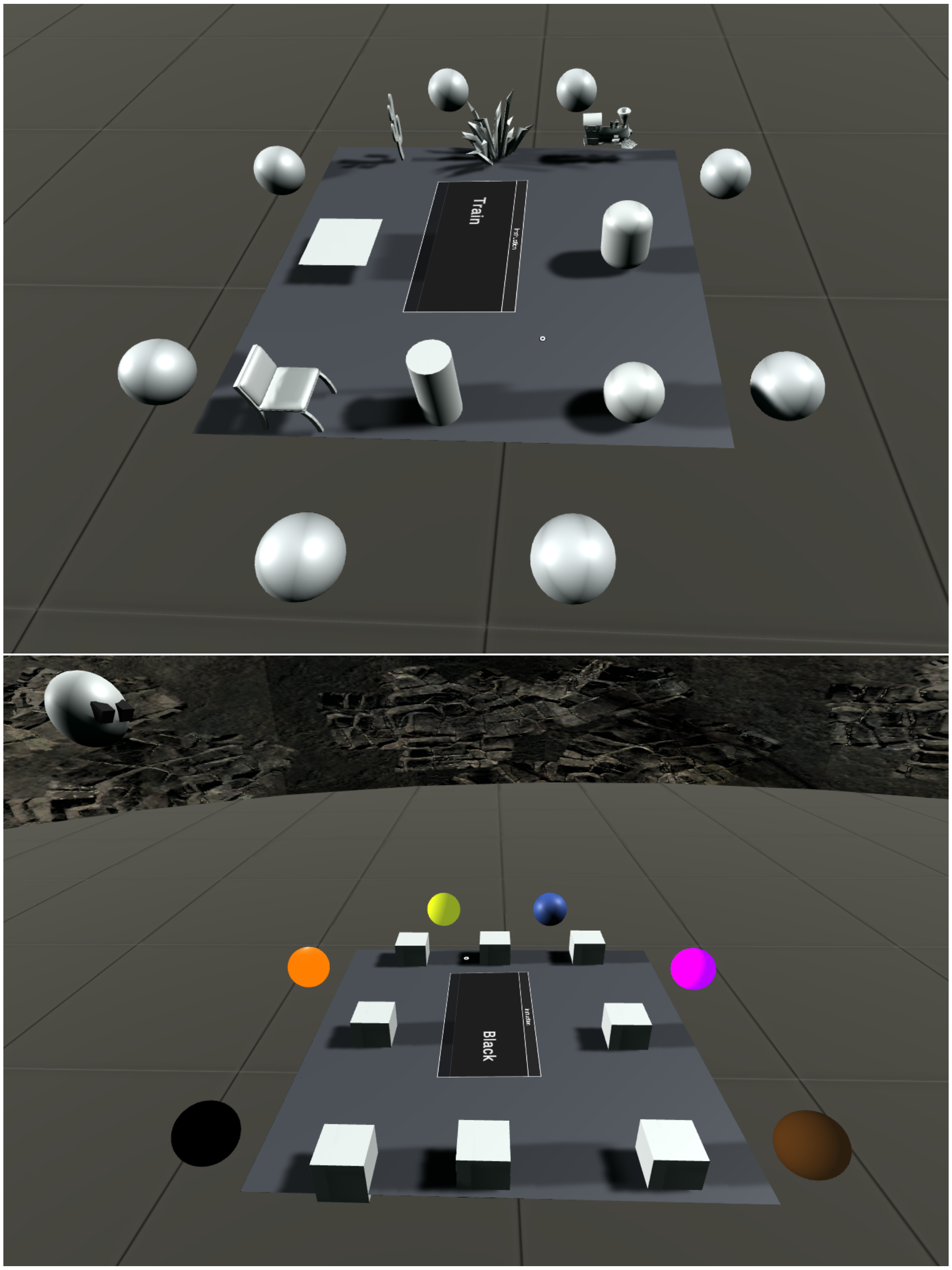

Figure 3.19: Setting 3- Shared viewpoint, Color Collaborator: Color Collaborator's viewpoint is shared with Shape Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

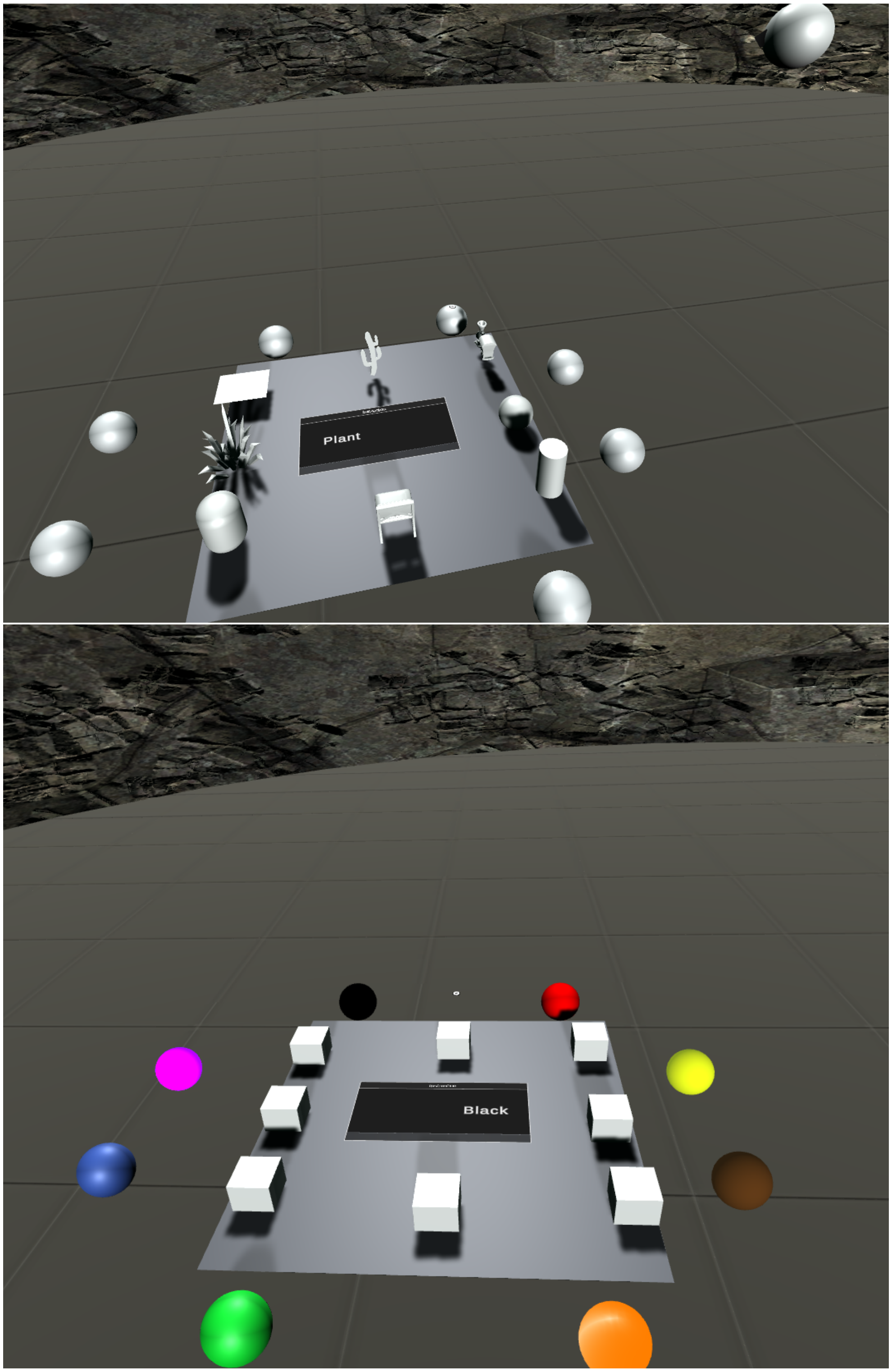

Figure 3.20: Setting 3- Shared viewpoint, Shape Collaborator: Shape Collaborator's viewpoint is shared with Color Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

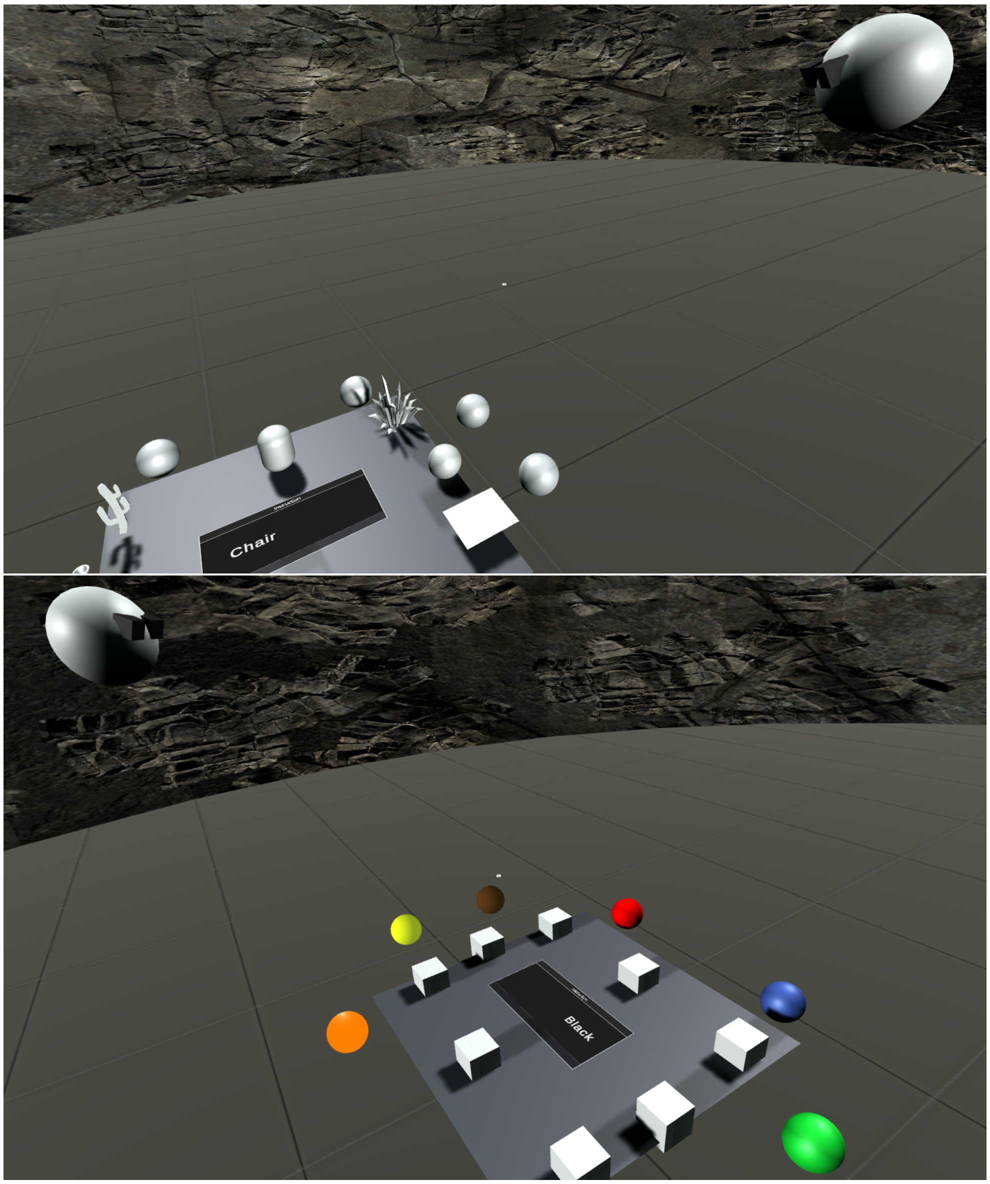

Figure 3.21: Setting 4- Independent viewpoint: Collaborators stand behind a table and have independent viewpoints. If straight lines are drawn from avatars' eyes, two line intersection point creates 90 degrees angle. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

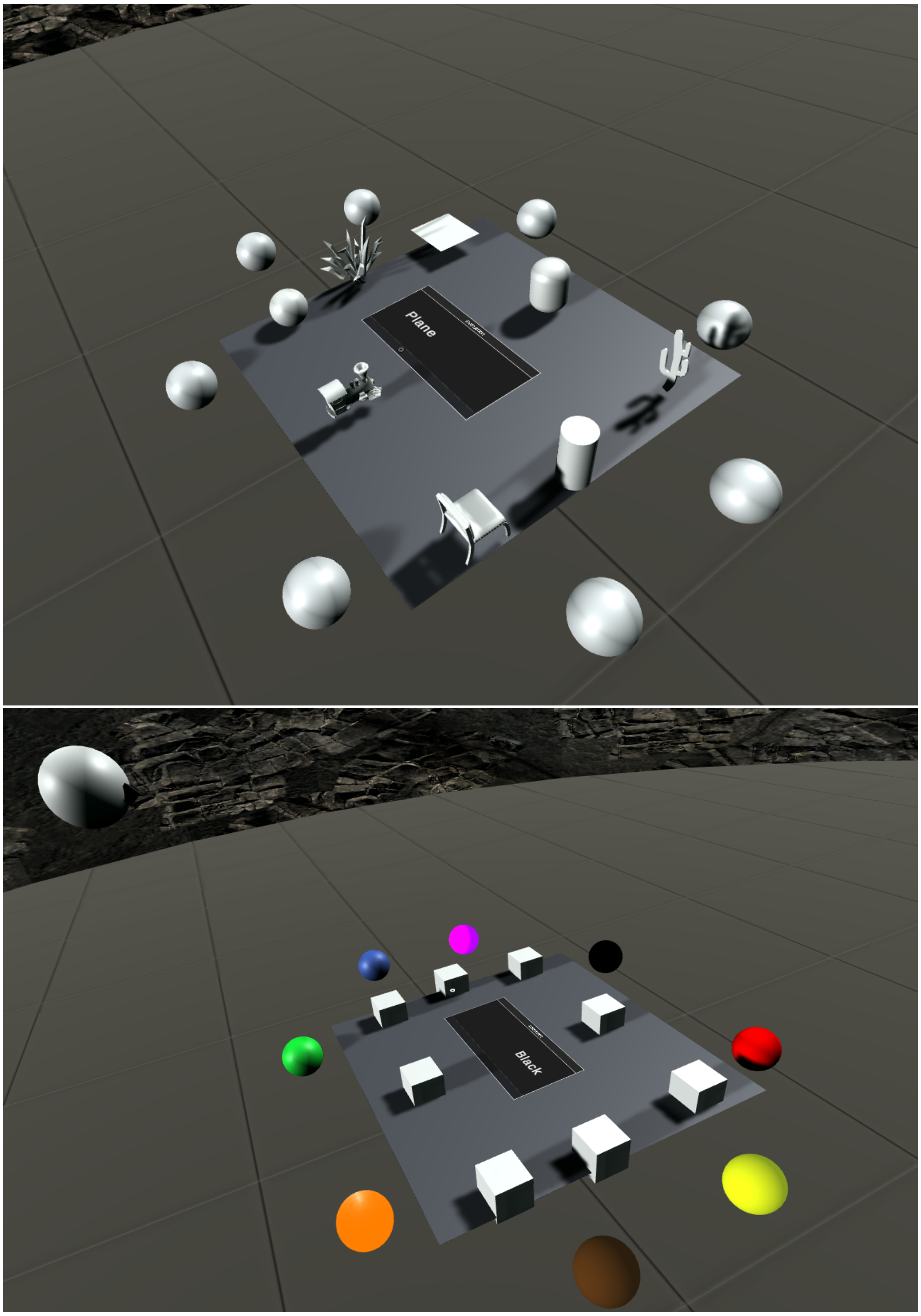

Figure 3.22: Setting 4- Shared viewpoint, Color Collaborator: Color Collaborator's viewpoint is shared with Shape Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

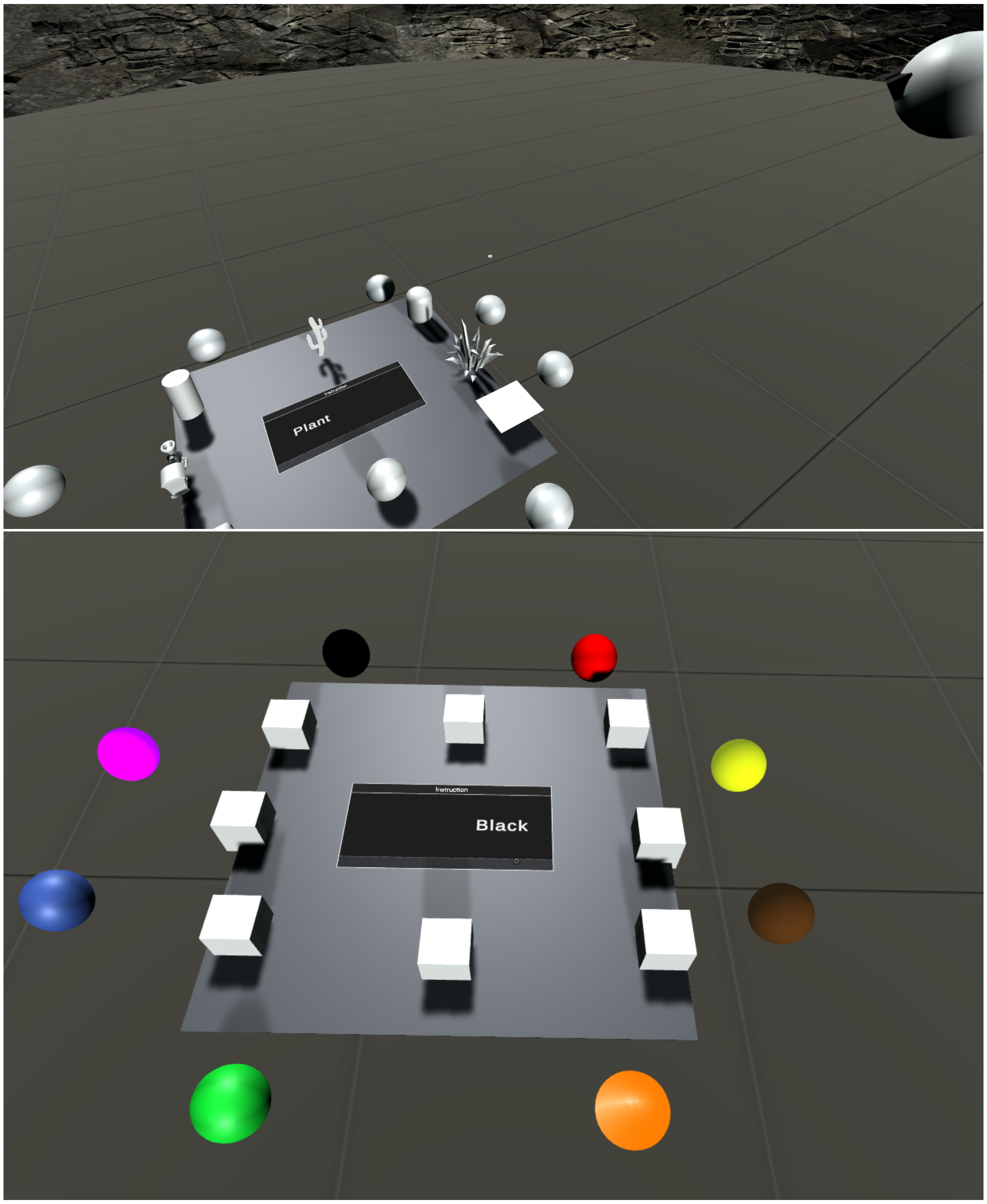

Figure 3.23: Setting 4- Shared viewpoint, Shape Collaborator: Shape Collaborator's viewpoint is shared with Color Collaborator. The top picture shows Shape Collaborator's viewpoint, and the bottom shows Color Collaborator's viewpoint.

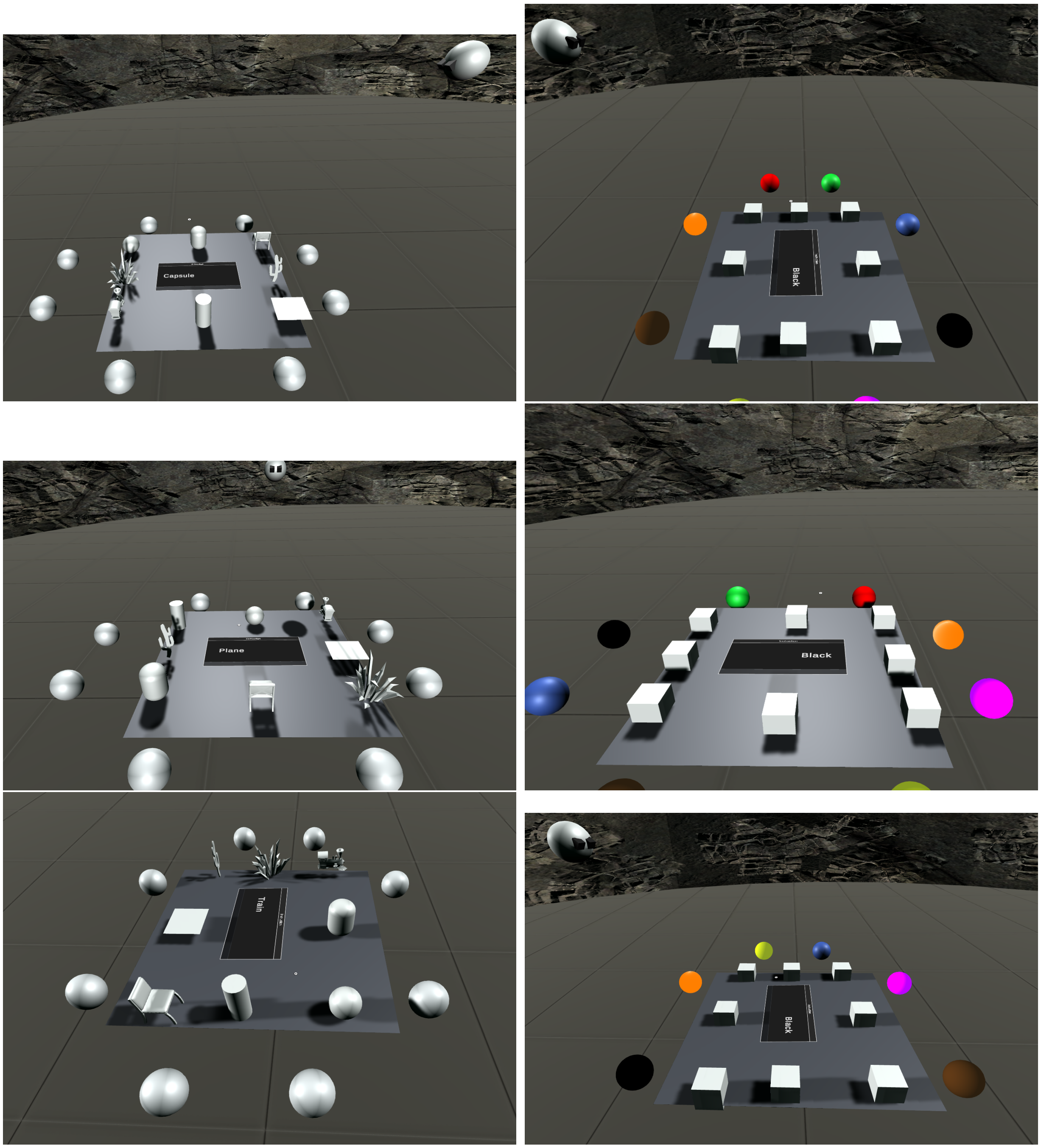

Figure 3.24: Scenarios 1-3 used in user studies are shown in this figure. The order is from top to bottom.

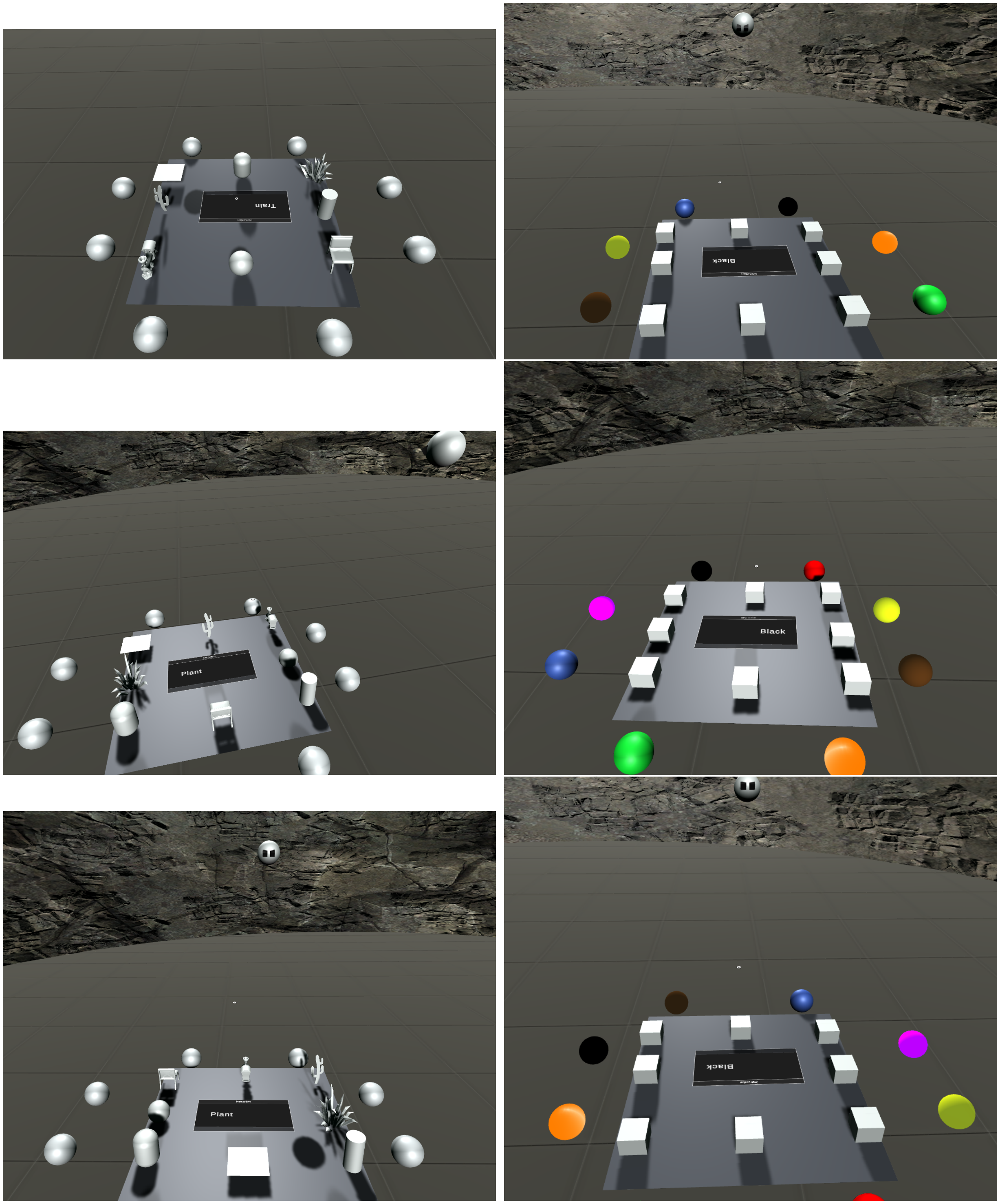

Figure 3.25: Scenarios 4-6 used in user studies are shown in this figure. The order is from top to bottom.

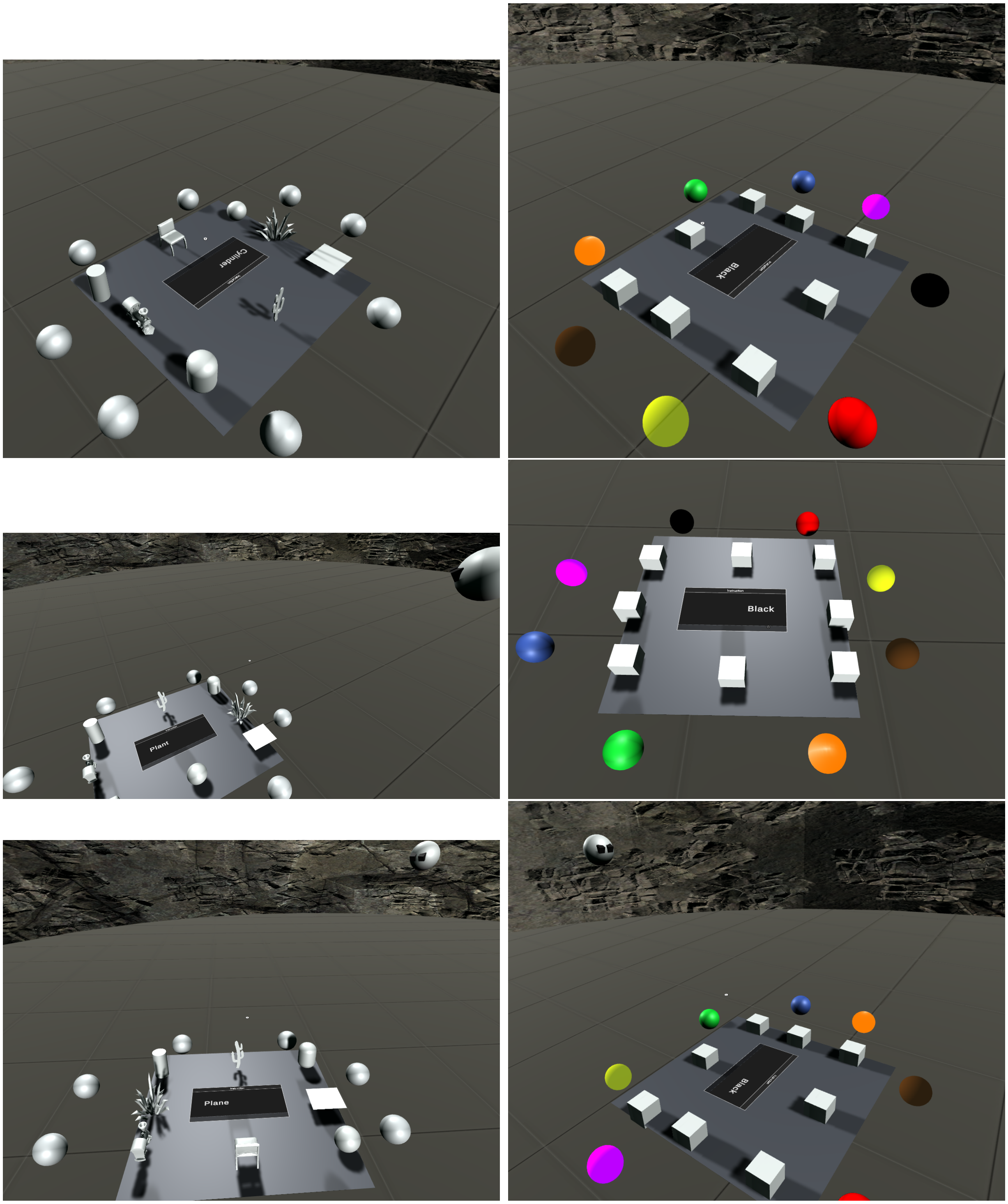

Figure 3.26: Scenarios 7-9 used in user studies are shown in this figure. The order is from top to bottom.

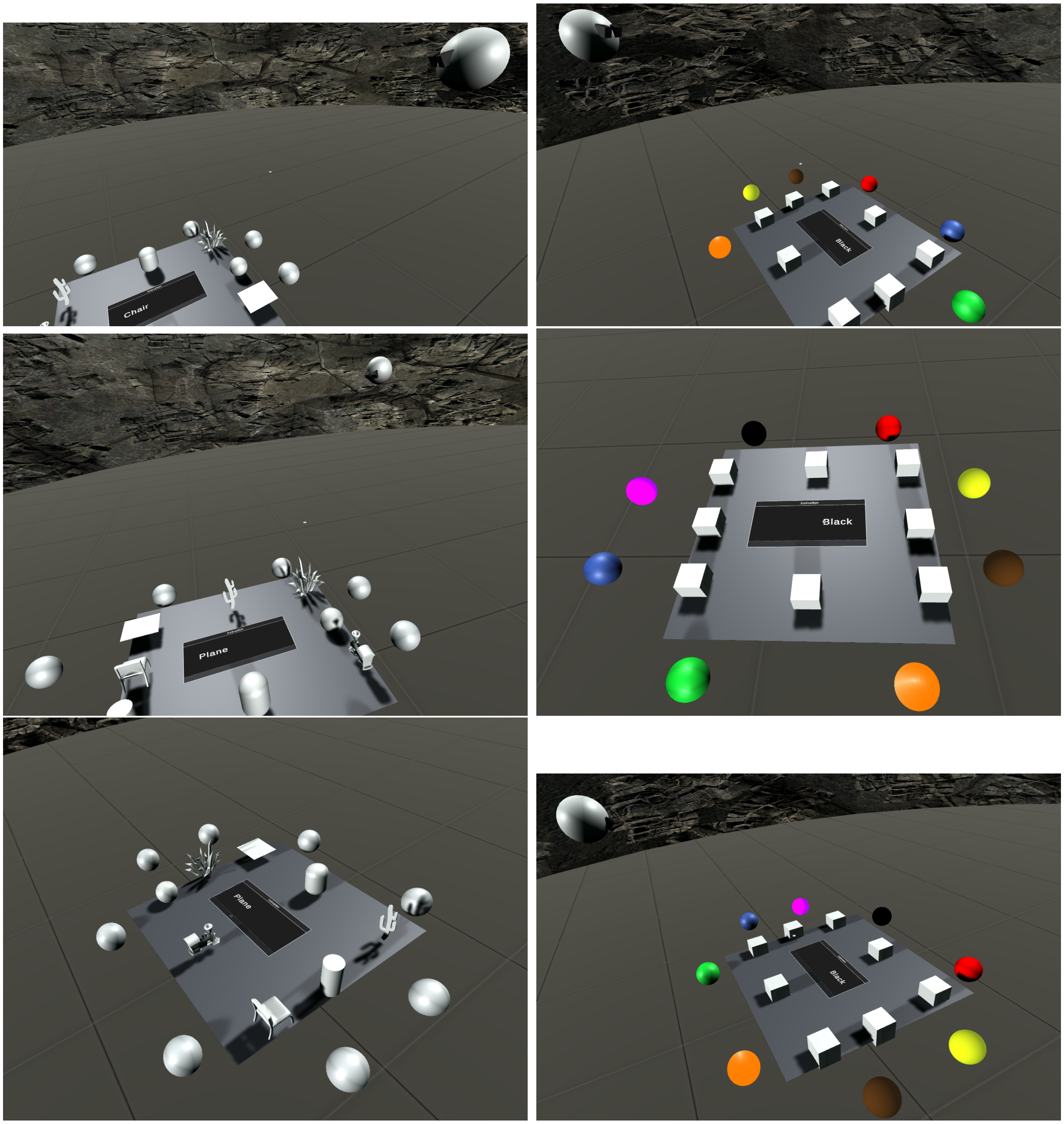

Figure 3.27: Scenarios 10-12 used in user studies are shown in this figure. The order is from top to bottom.

3.3 Apparatus

The main devices used in studies are Meta Quest 2, a virtual reality headset created by Meta.

Each Meta Quest 2 was connected to a computer via a cable, and the application was run on the Meta Quest 2 using Unity. The researcher could monitor the state of each participant during studies using the computer monitor. Moreover, each scenario was mapped to a component in Unity, and the researcher could start the scenario and study by clicking on the component.

In order to enable participants to communicate with each other while performing tasks, they called each other by cell phones and put them on speaker. The quality of sounds was tested before doing each task. Voices were easy to understand and no problems were reported by participants.

3.4 Procedure

First, each group that consisted of two participants came into one room. The overall study procedure, each step they had to do, and the purpose of the study was explained to them. Tasks they had to complete, and the terms (i.e., Independent viewpoint, Shared viewpoint, Shape Collaborator, and Color Collaborator) were explained to them by showing them tutorial videos created by the researcher. The videos show a simulation of performing scenarios via two people. Then, each read and filled out a consent form to gather and analyze data for this study. They also filled out a separate form related to their experience using Virtual Reality devices, age, and gender.

After filling out the above forms, participants called each other using cell phones, and one of the group members was moved to another room to simulate remote collaboration. Group members could not see each other until the end of the study. Participants could hear each other using cell phones. The cell phones were on speaker and put on a desk near participants where they could hear each other appropriately. Before performing each scenario, the quality of the sound was checked. Then, participants sat on a chair, Meta Quest 2 headsets were put on participants' heads, and the application was started.

In order to be familiar with the virtual reality environment and the application, four training scenarios are created. Two use independent viewpoint mode, and the others use shared viewpoint mode. Table 3.2 shows the order and type of training scenarios. Participants completed these four training scenarios and made themselves familiar with the environment.

Setting	Viewpoint mode
135 degree	Independent
180 degree	Shared - Shape Collaborator's viewpoint
90 degree	Shared - Color Collaborator's viewpoint
45 degree	Independent

Table 3.2: The order of training scenarios performed by participants to make themselves familiar with the environment.

After finishing the training scenarios, participants started doing the main ones one by one. Before starting each scenario, the researcher explained which viewpoint mode would be used in the following scenario and the role of each participant. On each turn, their role would be changed. For example, if participant A were Shape Collaborator in the previous scenario, she would be Color Collaborator for the next scenario. After confirming they were ready, the researcher started tasks using the computers connected with Meta Quest 2.

After finishing all twelve scenarios mentioned in section 3.2, each group member participated in a semi-structured interview designed to gather their opinion about having a shared viewpoint by separating viewpoints from avatars and its effects on collaboration separately in the absence of their group members. Finally, they filled out one form to measure how difficult they found completing tasks while having a shared viewpoint in the collaborative virtual reality application.

3.5 Pilot Studies

Three pilot studies were conducted to improve and finalize the format of the user study. Four participants took part in pilot studies. Pilot studies' participants were recruited by sending a message on Team's application. Participants were in a professional relationship with the researcher.

In the first pilot study, participants mentioned that the original interaction techniques were not intuitive to use. The first interaction technique used to match colors and shapes was by dragging color objects and colliding them with shape objects. They mentioned that some colors and shapes are not distinguishable from each other. Moreover, participants could hear each other directly from where they were placed without using phones.

After the first pilot study, the interaction technique, colors, and shapes were modified. In the second pilot study, positive feedback was received from participants about the procedure and application. Although we changed the participants' rooms to prevent them from hearing each other without using phones, we found out the new setup did not work either, and still, they could hear each other.

In the last pilot study, we tried two new rooms. After finishing the pilot study, the feedback was positive.

Pilot studies helped us develop proper settings and scripts and improve the virtual reality application designed for the study, and finalize details.

3.6 Participants

Twenty-two participants participated in the study. They formed groups of 2 people; hence, 11 groups were created. Eleven participants were male, and eleven were female. Six participants were in the age range of 21 to 25. Fifteen participants were in the age range of 26 to 30, and

Participants' experiences using VR devices

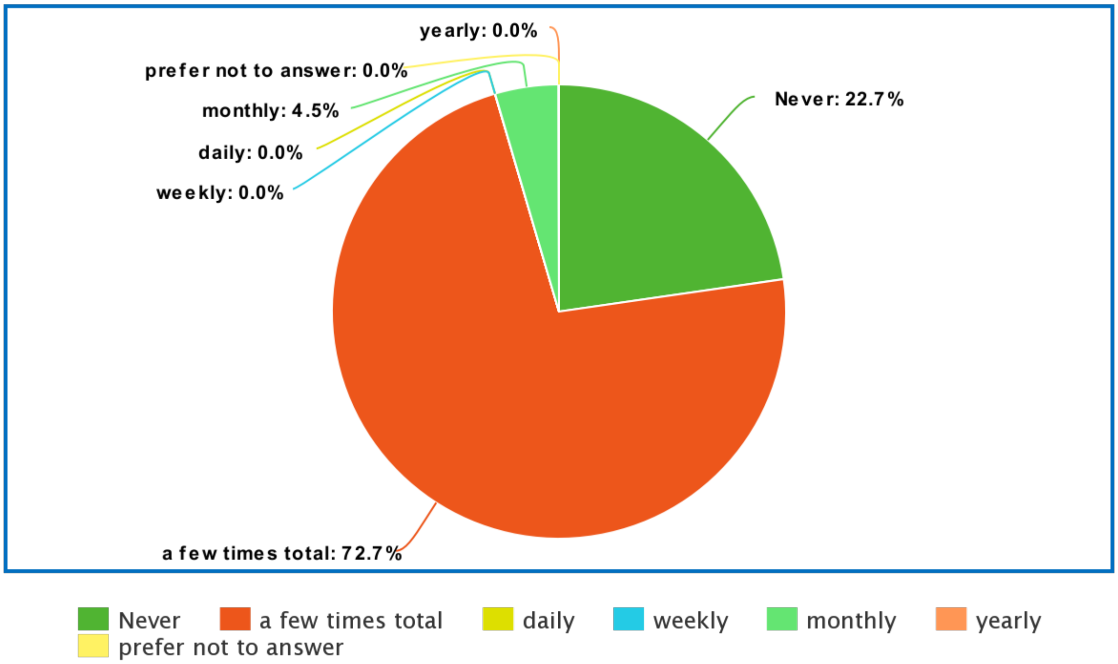

Figure 3.28: 1 participant used VR devices monthly. 16 participants used VR devices a few times total. 5 participants have never used VR devices.

one was in the age range of 31 to 35. One participant mentioned that she used virtual reality devices monthly. Sixteen participants mentioned they had used virtual reality devices a few times, and five mentioned they had never used them.

Three approaches were used to recruit potential participants: email, Social media (Telegram), and the snowball sampling technique. The recruitment Notice was sent to the email list of people whom researchers were familiar with or in a professional relationship with. Also, the recruitment Notice was sent to virtual groups on Telegram social media. We also asked existing participants to send recruitment information to other potential subjects.

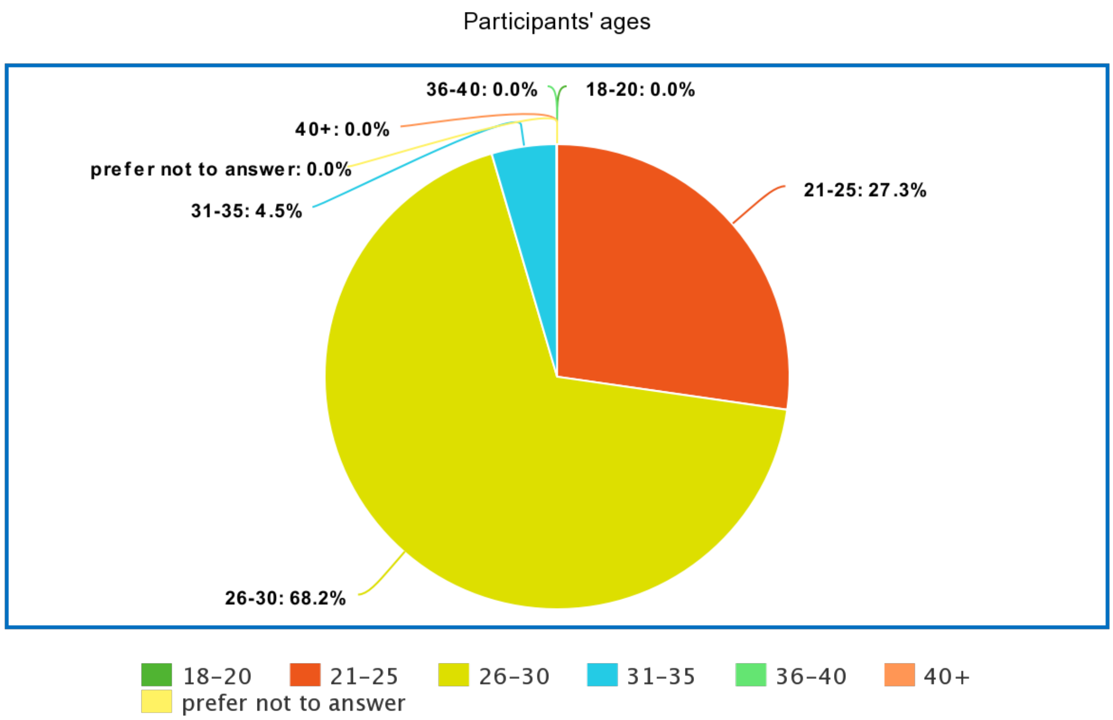

Figure 3.29: 6 participants were in the age range of 21-25. 15 participants were in the age range of 26-30. 1 participant was in the age range of 31-35.

Chapter 4

System Design and Implementation

This chapter discusses the collaborative virtual reality application and interaction techniques created and used in the user study to answer research questions provided in Chapter 1. The collaborative virtual reality application is designed to enable users to have a remote and synchronous collaboration while they have a shared viewpoint without moving avatars' positions.

4.1 Overview

The application is built using Unity 3D. In order to develop the application, we used Microsoft Reality Toolkit, built by Microsoft for developing extended-reality Applications. MRTK is a well-known SDK because of its rich documentation and community. It is easy to use and has many valuable features that help develop applications and prototypes quickly.

We needed to add networking to the application to create a remote and synchronous collaboration environment. In order to handle networking, we used the PhotonPun unity asset. Among many alternative assets for handling networking in Unity 3D, such as MLAPI, DarkRIFT 2, Photon Quantum 2.0, Mirror, and Photon Bolt, we found PhotonPun the most suitable for our study and task. PhotonPun is a Unity networking solution that is easy to learn and use. Furthermore, it has rich documentation and community.

Scenarios that are defined for collaboration in the virtual reality application consist of a table, eight shapes, and eight colors. Avatars are utilized to depict the positioning of collaborators around the table in the virtual reality world and the direction in which they are looking. The following sections discuss details of implementations of the virtual reality application.

4.2 Colors, Shapes and Avatars

Eight distinguishable shapes and colors are used for each task. Unity game objects are used to implement these shapes and colors. Shapes are Cactus, Plant, Chair, Train, Plane, Sphere, Cylinder, and Capsule. Colors are Red, Pink, Green, Brown, Yellow, Black, Orange, and Blue. By not synchronizing the materials of shape and color objects across the network between users, we were able to simulate an environment where all colors appear as gray to the Shape Collaborator and all shapes appear as cubes to the Color Collaborator.

In order to represent participants' location and where they are looking at, we needed to use an avatar. Looking at avatars' eye gaze during collaboration conveys information about collaborators' goals and focus and affects collaboration quality [14]. We created an avatar made of a sphere and two cubes representing the eyes, which is enough for users to infer where collaborators are focusing during collaboration. Avatars' positions and rotations are synchronized over the network for all users.

4.3 Interactions

The Shape Collaborator must point their hand towards the desired color or shape object and click any button on the controller to make a selection. When a color is selected, it will rise above its original position. The positions of color and shape objects are synchronized across the network among all users. When the Shape Collaborator chooses a color object, and it rises, the same color object will also rise for the other collaborator due to the synchronous.

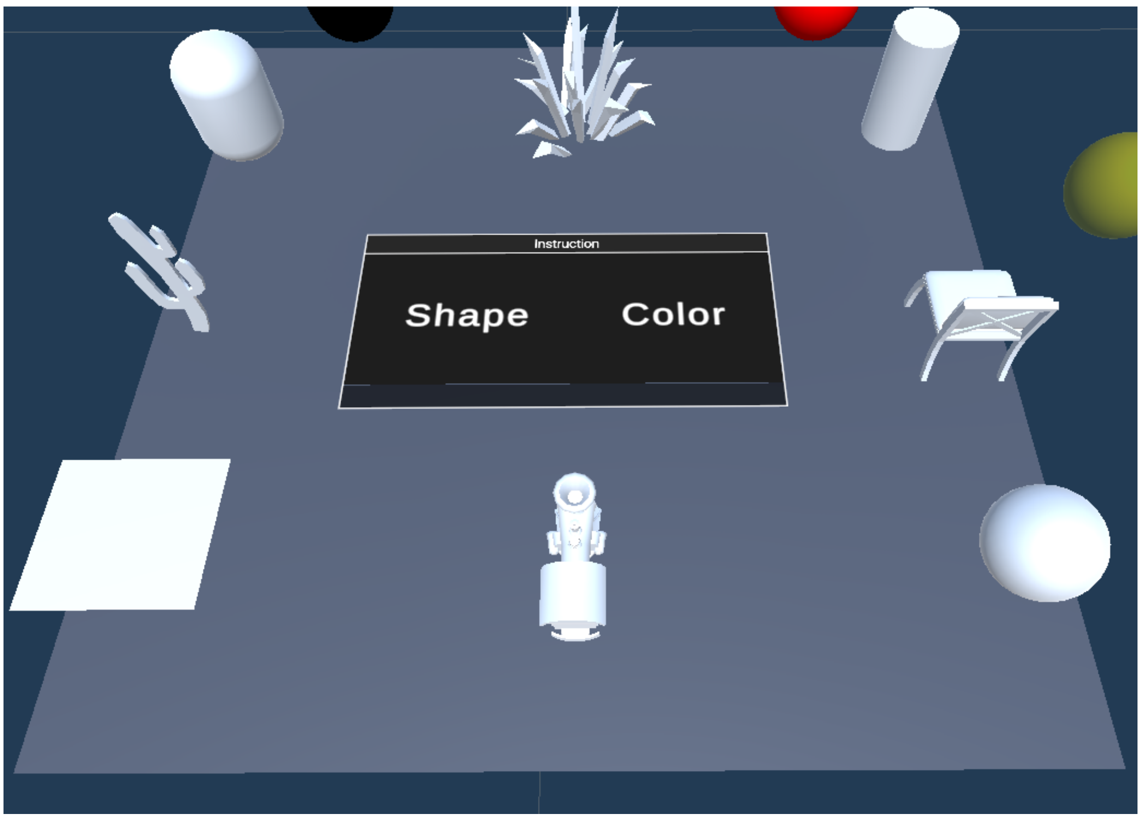

Figure 4.1: There are eight shapes on the table: Cactus, Plant, Chair, Train, Plane, Sphere, Cylinder, and Capsule.

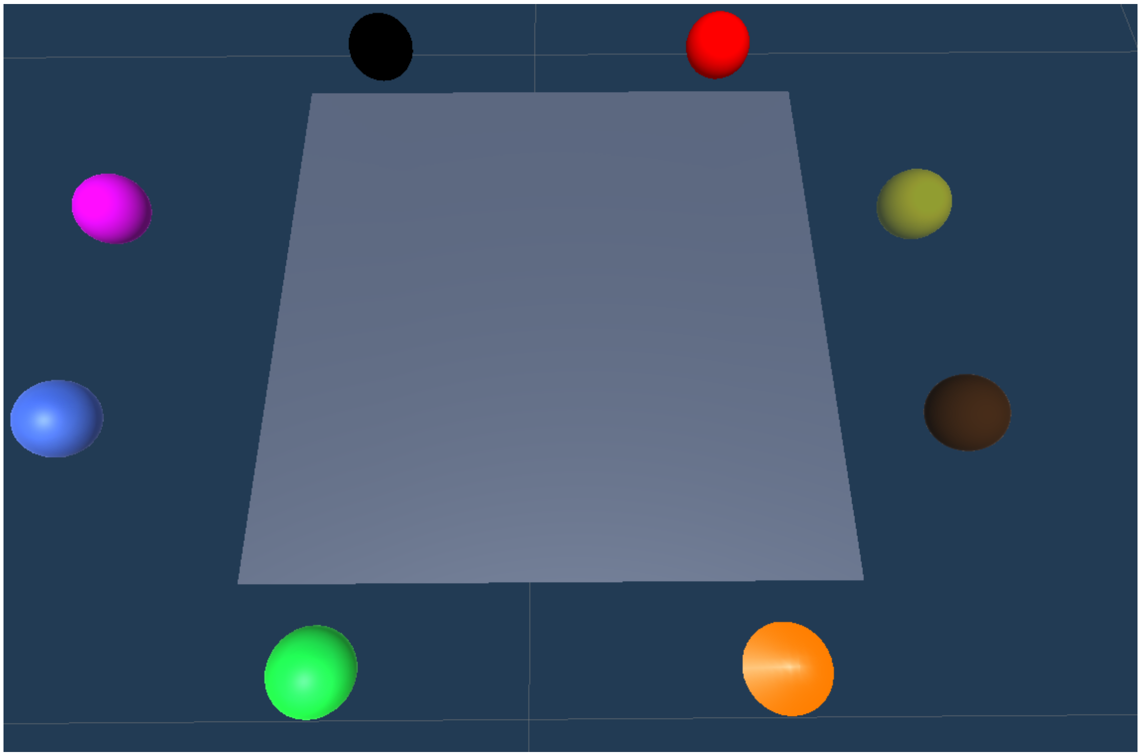

Figure 4.2: There are eight colors around the table: Red, Pink, Green, Brown, Yellow, Black, Orange, and Blue.

Shape Collaborator resolves a task by selecting the shape she sees its name on the text field and the color that Color Collaborator sees its name on the text field. If the shape and color selection is correct, the shape will appear in color for the Shape Collaborator for 2.5 seconds. Moreover, the text field updates with the next color and shape names for both collaborators. However, when a wrong shape and color object got matched, the color object returns to its original position, and Shape Collaborator can try again. If the Shape Collaborator chooses the wrong color and wants to change it before matching it with any shape, they can click on another color object. This makes the previous color returns to its original position, and the new color rises.

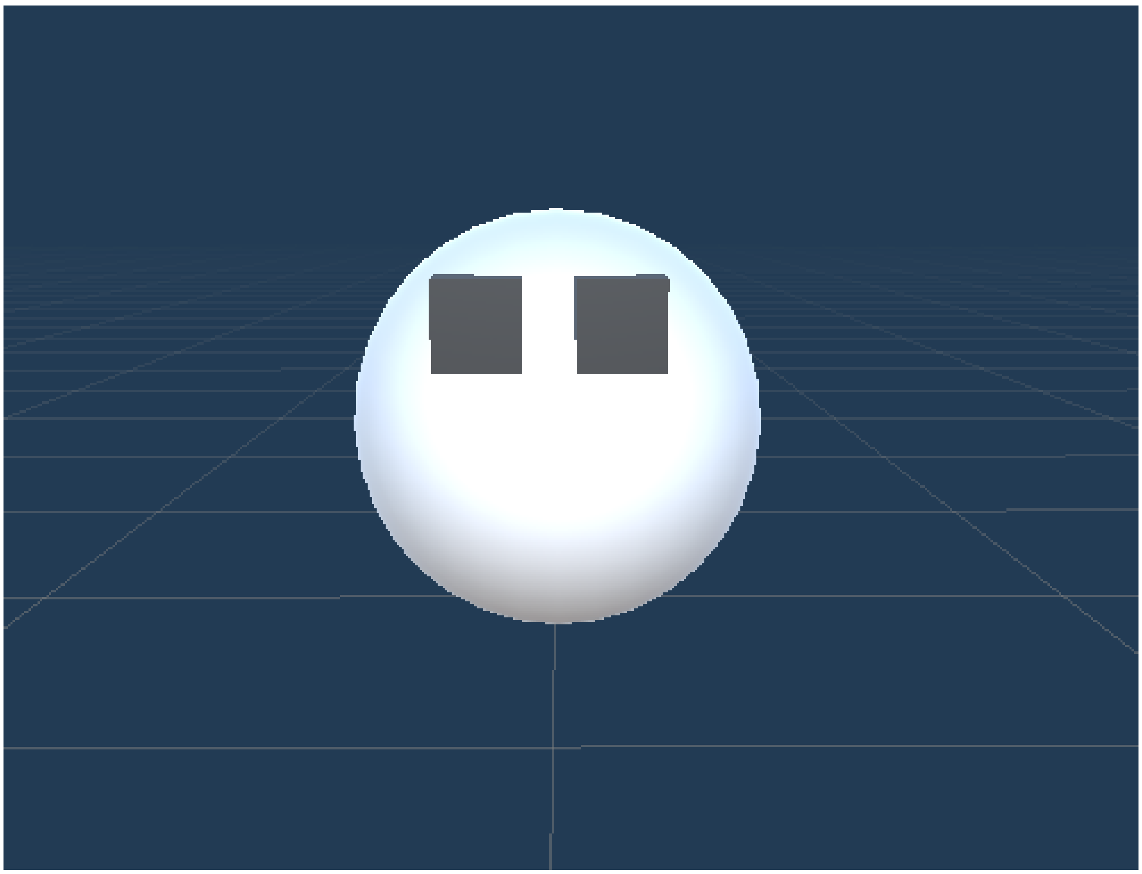

Figure 4.3: Avatars are indicators of the positions of collaborators and where they are looking.

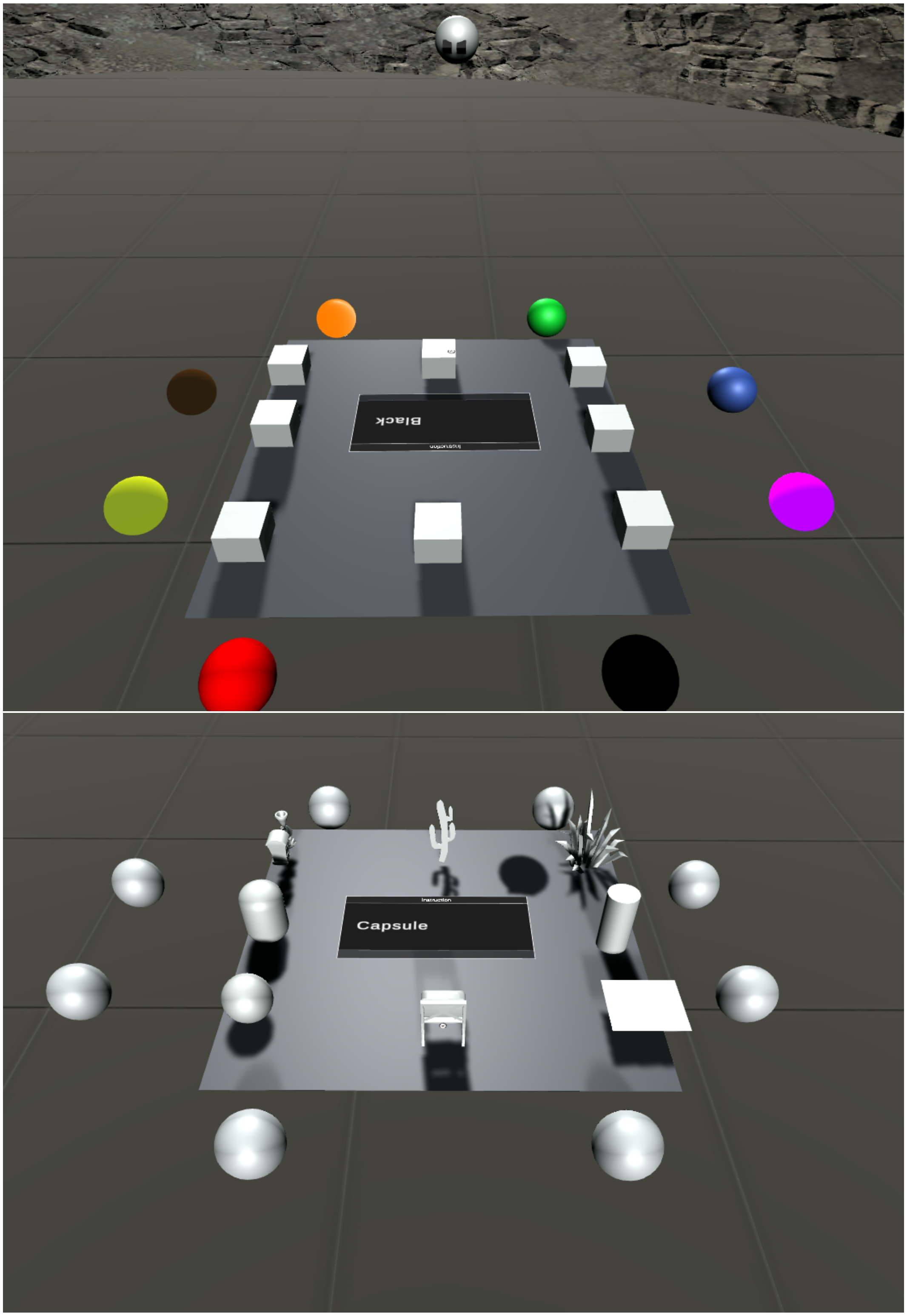

Figure 4.4: The eyes of avatars are indicators of where the participants are looking at. The top picture is the Color Collaborator's perspective, and the bottom is the Shape Collaborator's perspective.

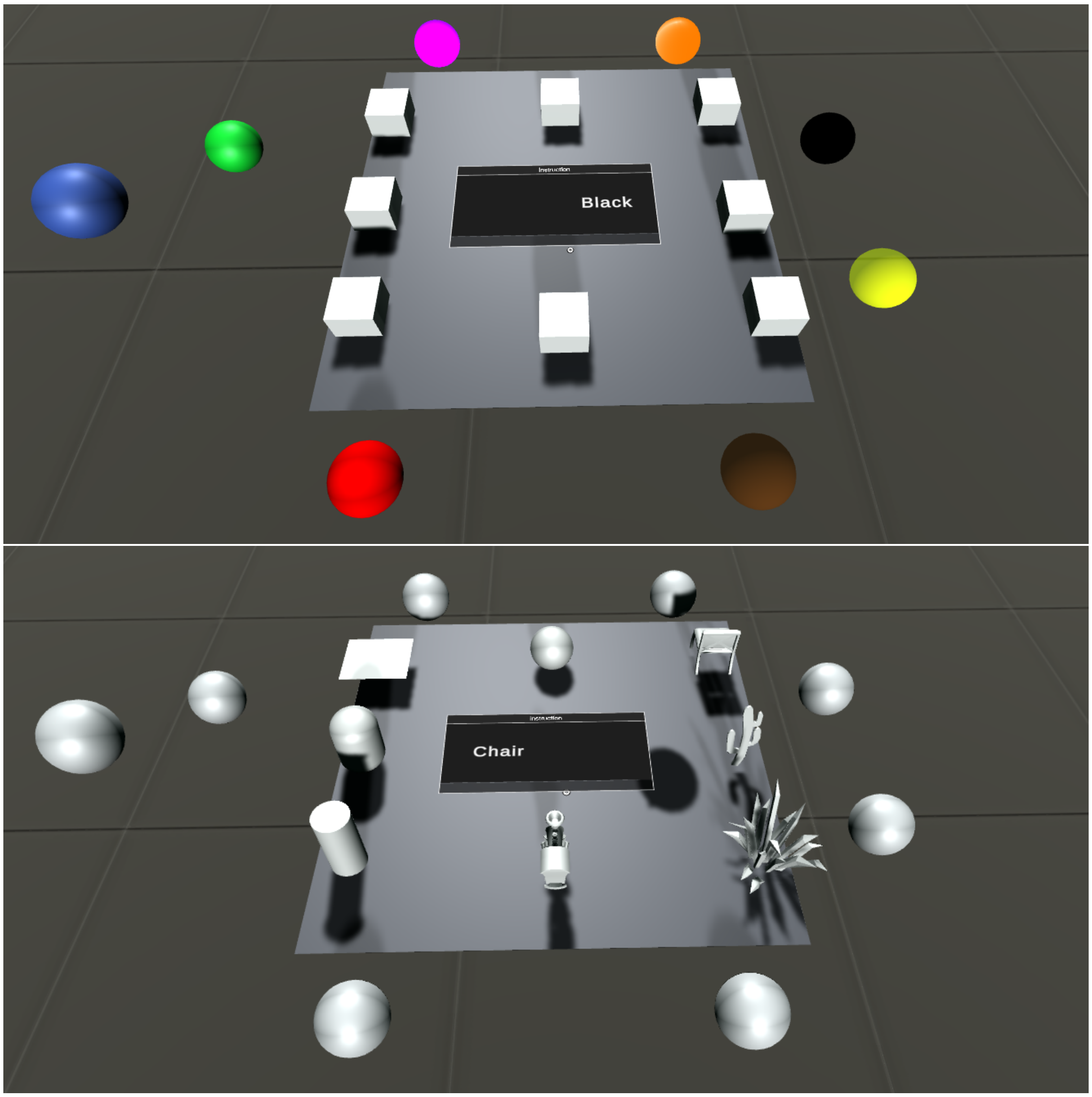

Figure 4.5: When a color is chosen, it rises above its original position, indicating that it is chosen successfully. The top picture is the Color Collaborator's perspective, and the bottom is the Shape Collaborator's perspective.

4.4 Shared viewpoint and Independent viewpoints

Each user has their own Camera object through which they see the virtual world. Typically, the position of the Camera object is set close to the user's avatar and is synchronized with the avatar's position. When a user moves in the real world, their avatar also moves in the virtual world, and as a result of the synchronization between the Camera object's position and the avatar's position, the Camera object moves as well.

The camera object's position can be decoupled from the avatar's position. We createZ a shared viewpoint between users by decoupling the Camera object's position from the avatar's position. In Independent viewpoint scenarios, collaborators' Camera objects are near their avatars. However, in Shared viewpoint scenarios, a collaborator's Camera object, depending on whose viewpoint is shared, is decoupled from their avatar and placed next to the other collaborator's Camera object. This causes both users to have a shared viewpoint without changing the avatars' positions. Furthermore, we hide the collaborator's avatar, whose Camera object is moved and placed next to the other collaborator for her.

Figure 4.6 shows an example of having a shared viewpoint in the application. Although avatars are standing in front of each other, due to moving Color Collaborator's Camera object next to the Shape Collaborator, they see the virtual world like they are standing next to each other.

In the application, the avatars' eyes indicate where the collaborators are directing their gaze. Although cameras are separated from avatars, avatars' eyes are aligned with where collaborators are looking. Therefore, by observing the avatar's eyes, collaborators can infer where the other collaborator is directing their attention within the virtual environment.

In the following chapter, the results of the user study will be discussed.

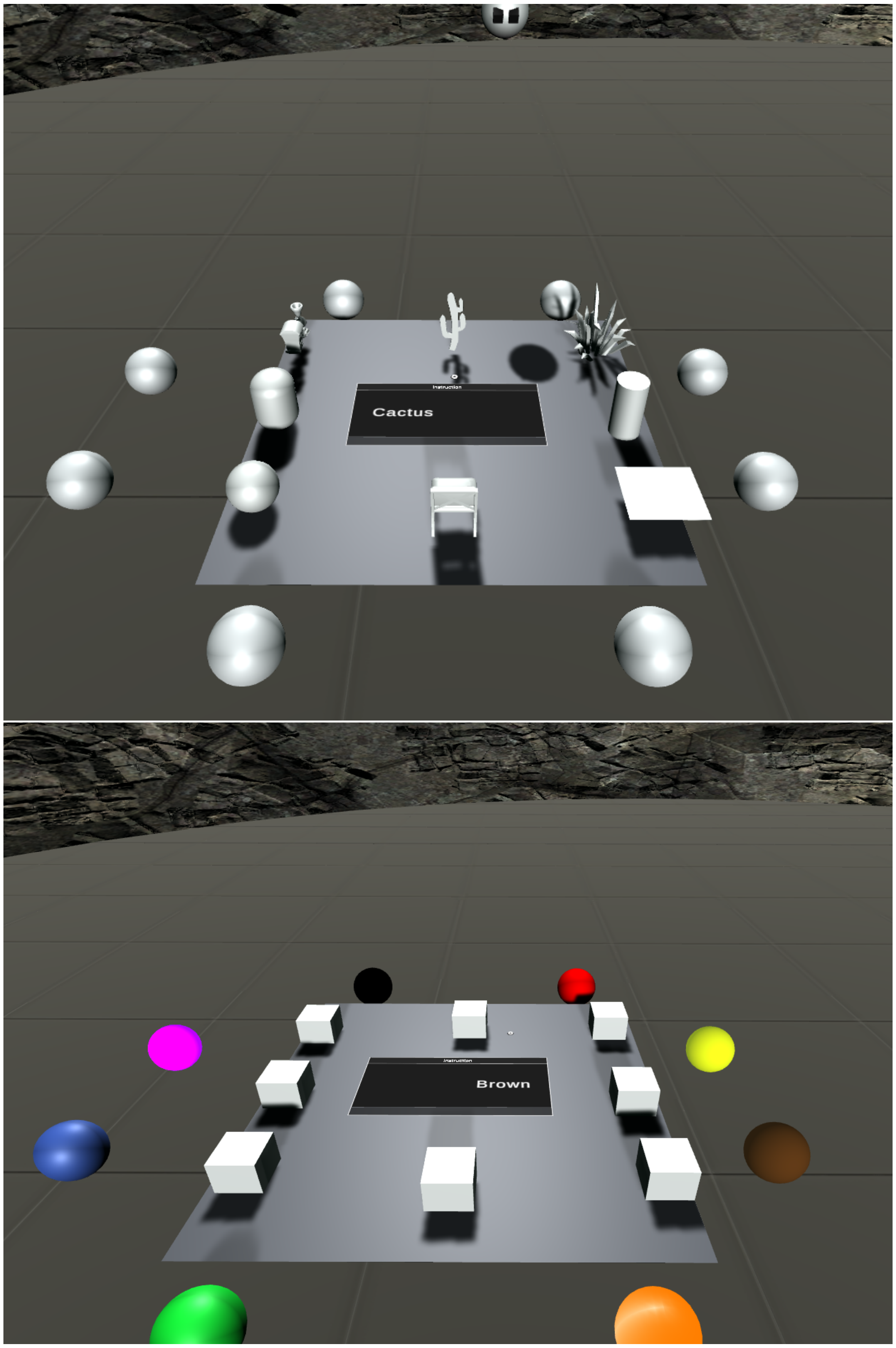

Figure 4.6: Although avatars are located in front of each other, they have similar viewpoints. The top picture is the Shape Collaborator's viewpoint, and the bottom is the Color Collaborator's viewpoint.

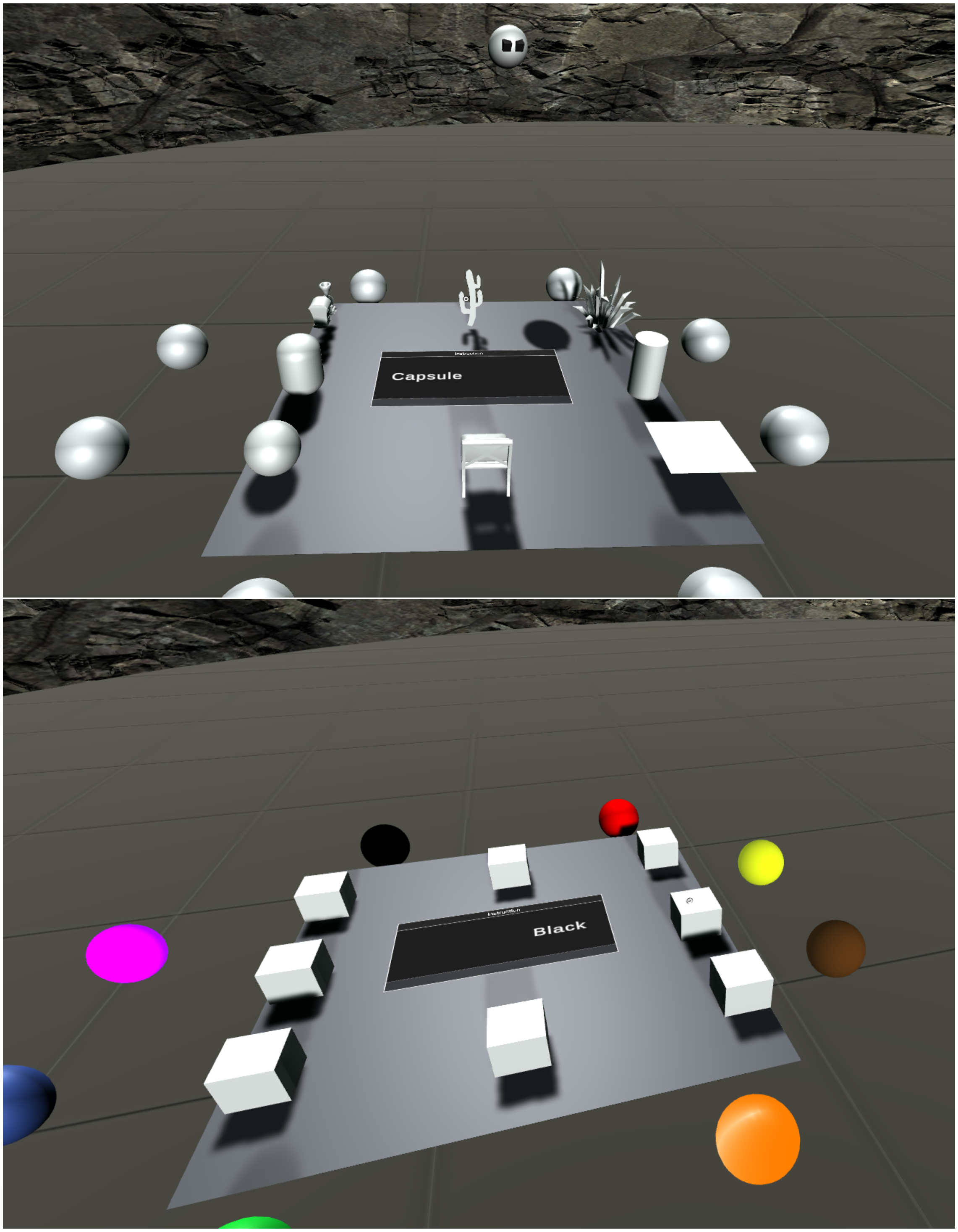

Figure 4.7: Although a Camera object is separated from an avatar, the eyes of avatars point to the place collaborators are looking at. The top picture is the Shape Collaborator's perspective, and the bottom is the Color Collaborator's perspective.

Chapter 5

Results and Discussion

This chapter discusses data gathered from the user study to answer research questions. First, users' preferences between having a shared viewpoint by separating viewpoints from avatars and independent viewpoints are shown. Then, data about scenario completion times is presented. Finally, answers to research questions are discussed.

5.1 Data Size

Twenty-two participants volunteered to participate in the user study. As discussed in Chapter 3, they were grouped in teams of two people. Overall, 132 scenarios were completed by these participants. In 88 scenarios, one user's viewpoint was shared with the other by separating viewpoints from avatars, and in the remaining 44 scenarios, each participant had their own viewpoint independent of the other. The scenario completion times are calculated. Moreover, a semi-structured interview was conducted with each participant to understand their preferences between having a shared viewpoint by separating viewpoints from avatars and independent viewpoints during collaboration in the collaborative virtual reality application.

Participants	Groups	Scenarios	Semi-Structured Interviews
22	11	132	22

Table 5.1: Overall, 22 volunteers participate in the user study. 11 groups were formed. 132 scenarios were completed, and 22 semi-structured interviews were conducted.

5.2 Viewpoint Preference

After each user study session, a semi-structured interview was conducted with each participant in the absence of their group member. They were asked about their preference for having a shared viewpoint by separating viewpoints from avatars or independent viewpoints during a collaboration in the virtual reality application. Moreover, the reasons why they have the preference were asked. These semi-structured interviews were voice recorded and transcribed.

Out of twenty-two participants, eighteen mentioned they prefer the proposed approach for having a shared viewpoint to complete scenarios in the virtual reality application, and four mentioned they prefer independent viewpoints.

In semi-structured interviews, we asked participants how easy it was to get used to and collaborate when having a shared viewpoint with another collaborator. All of them mentioned that it was easy to get used to having a shared viewpoint while the avatars' positions are fixed and are not an indicator of viewpoints.

After semi-structured interviews, participants scored how difficult they find completing tasks when they have a shared viewpoint. On a scale of zero to five, with zero being very easy and five being very hard, thirteen participants chose 0, seven participants chose 1, one participant chose 2, and one participant chose 3 as Figure 5.2 shows.

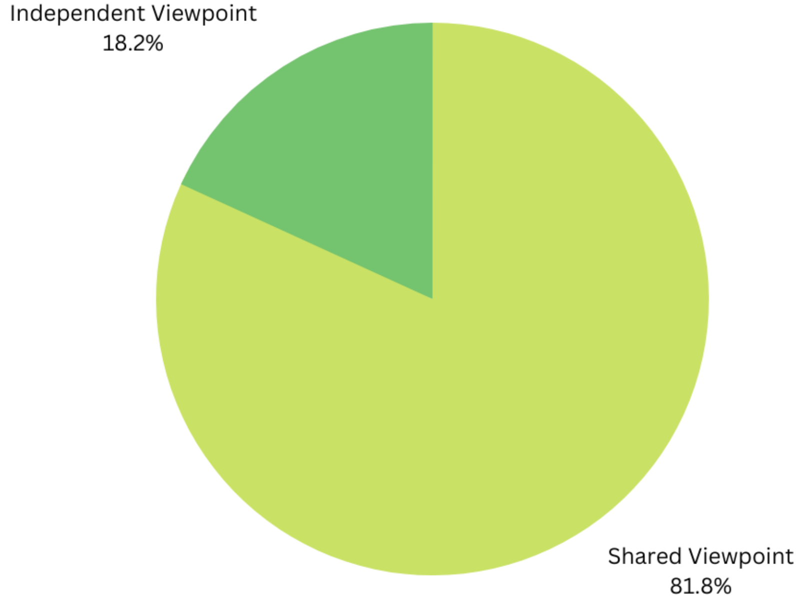

Figure 5.1: Eighteen participants mentioned they prefer a shared viewpoint with the other collaborator, and four mentioned an independent viewpoint.

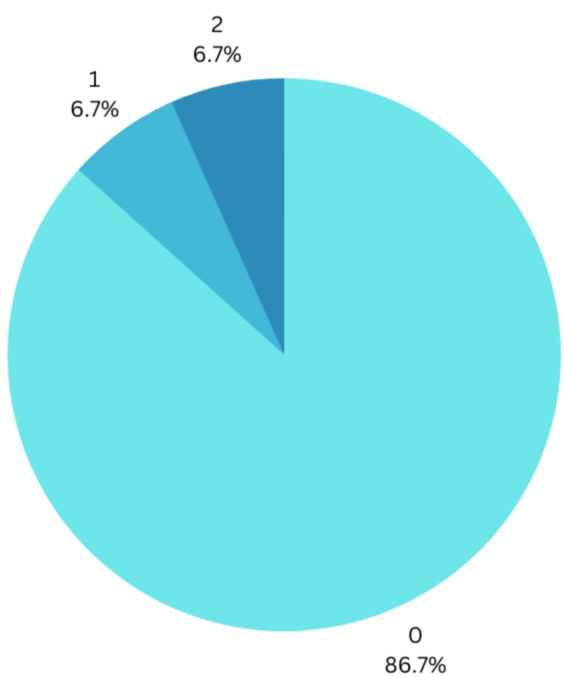

Figure 5.2: On a scale of zero to five, participants ranked how difficult they find completing tasks when they have a shared viewpoint with the other collaborator.

5.2.1 An Aggregated View of Reasons

Participants were asked why they preferred to have shared or independent viewpoints. Listing all responses would make the thesis verbose, so we categorized participants' reasons into six categories based on statements participants made during semi-structured interviews.

These are four reasons that participants believe having a shared viewpoint during collaboration is helpful. We used participants' wordings in the categories' titles.

1. Improving communication quality
2. Ignoring other collaborator's avatar and focusing on tasks
3. Easy to resolve left-right ambiguity
4. Improving the grounding process

These are two reasons participants mentioned why they prefer to have an independent viewpoint when they are collaborating in the virtual reality application:

1. Having a shared viewpoint is not natural
2. Having an avatar in the scene while its viewpoint is separated is distracting

Improving communication quality

In total, 10 participants mentioned that having a shared viewpoint helped them communicate better and guide each other more easily during collaboration.

Here are some quotes by participants who preferred having a shared viewpoint during collaboration: "We had better communication", "It is easier to navigate my partner", "Communication is easier", "Telling orientation was easier for me", "It was easier to say where are the shapes and colors", and "We could communicate better when we had same perspective".

Ignoring other collaborator's avatar and focusing on tasks

In total, 9 participants mentioned that having a shared viewpoint helped them ignore the other collaborator's avatar and stay focused on the task itself. In other words, they could ignore the other collaborator's viewpoint and did not need to consider the other avatar's position to share information needed to complete scenarios.

Here are some quotes from participants: "I could only concentrate on the task and ignore the other person's avatar position", "We needed to just do the task and ignore each others' avatars", "I ignored avatars' positions", "I didn't need to convert perspective to guide [her/him]", "I had no worry about [her/his] place", "I just explained what I see and ignored other things", "We didn't have to consider each other's viewpoint", "I didn't have to Evaluate other person's view", "There was no need to locate my partner's avatar", and "I didn't have to convert what my partner sees".

Easy to resolve left-right ambiguity

In total, 3 participants mentioned that having a shared viewpoint helped them to resolve left-right ambiguity in collaboration.

Here are some quotes from participants: "I could recognize left and right easier", "It was easier to say left and right to my partner", "I always tell myself, it is like the same point of view and I could comfortably choose right or left in this case", and "I could easily understand which side is her left or right".

Improving the grounding process

In total, 5 participants mentioned that having a shared viewpoint helped them understand each other faster and easier. As we mentioned in Chapter 2, collaborators come up with some terminologies during the collaboration that helps them to understand each other more efficiently. This process is called grounding [19]. Participants mentioned that having a shared viewpoint helped them to do this process easily.

Here are some quotes from participants: "Having same perspective helped us in talking and coming up with small directional codes", "It helped us to be on a same page and communicate easily", "we could conduct rules easier", "developing a common language is more efficient", and "It is good for finding best way to communicate".

Having a shared viewpoint is not natural

In total, 3 participants mentioned that having a shared viewpoint by separating viewpoints from avatars did not seem natural and confused them.

Here are some quotes from participants: "I need clarification for the new rule", "I need time to calibrate with shared viewpoint", and "Independent viewpoint seems more natural to me".

Having an avatar in the scene while its viewpoint is separated is distracting

In total, 2 participants mentioned that seeing an avatar in the scene whose viewpoint is independent of its position is distracting.

Here are some quotes from participants: "Looking at my partner's avatar was distracting", and "Looking at the avatar made me confused".

5.3 Task Completion Times

In total, participants completed 132 scenarios. This section discusses the scenarios' completion times.

As we discussed before, four settings are defined based on avatars' positions around a table, each consisting of the following three scenarios:

1. Independent viewpoint: Avatars have independent viewpoints based on their positions. Shape Collaborator sees the text properly, and Color Collaborator sees the text tilted.

2. Shared Viewpoint - Color Collaborator's viewpoint: Color Collaborator's viewpoint is shared with Shape Collaborator.

3. Shared viewpoint - Shape Collaborator's viewpoint: Shape Collaborator's viewpoint is shared with Color Collaborator.

Therefore, in total, each group of participants completed twelve scenarios. In the following sections, we show results based on these settings. The results are reported as mean values with standard deviation.

5.3.1 Setting 1: 180 degree

In this setting, avatars stand in front of each other. With Independent viewpoint, Shape Collaborator sees the text properly, and Color Collaborator sees the text upside down.

Table 5.2 shows the completion time for each scenario for different groups. [1]

[1] In Section 5.3.5 we analyzed data using linear mixed-effect model.

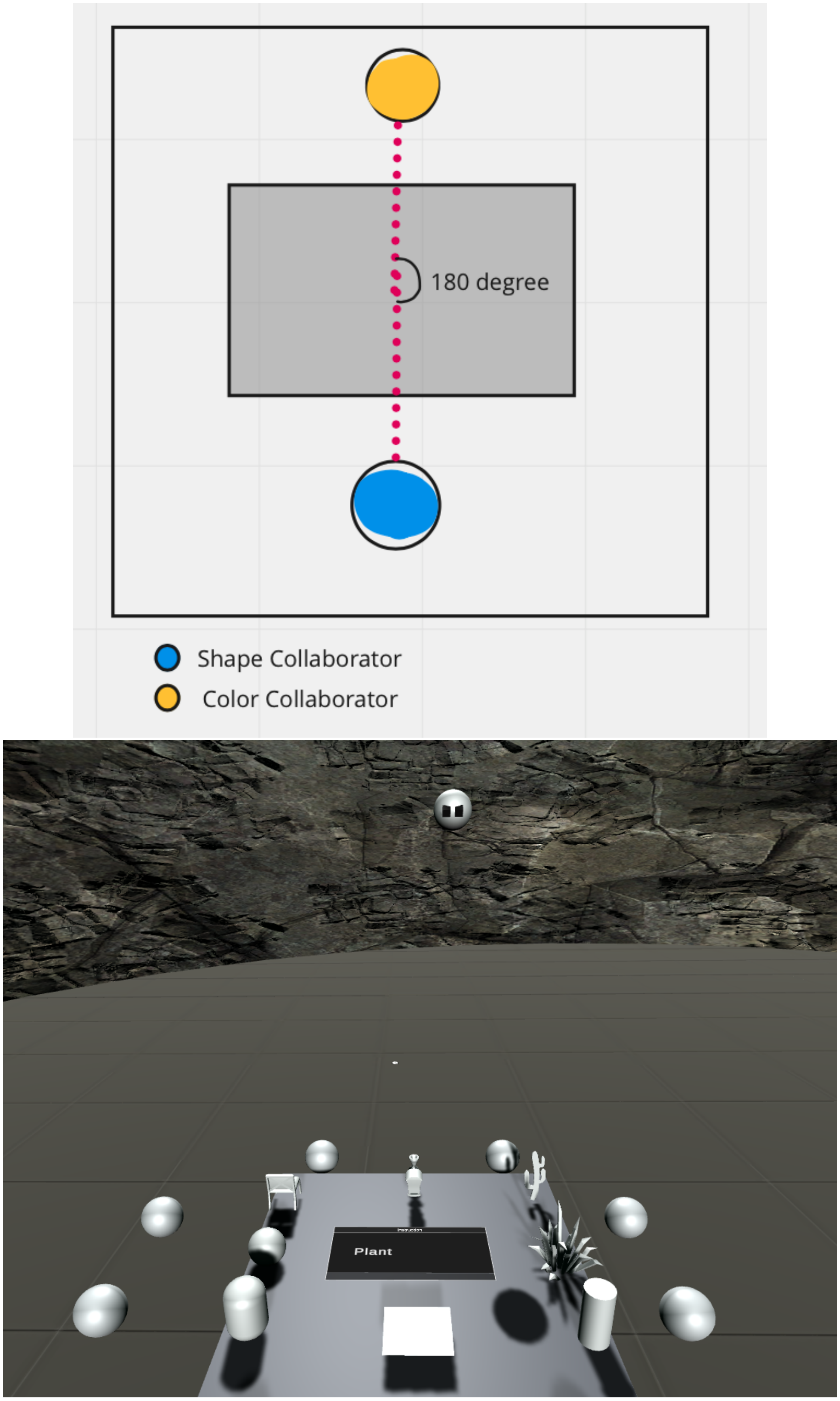

Figure 5.3: Setting 1: The top image shows the abstract of two avatars standing in front of each other behind the table. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 180-degree angle. The bottom image shows how Shape Collaborator sees the environment.

Group#	Independent Viewpoint	Shared Viewpoint: Shape Collaborator's view	Shared Viewpoint: Color Collaborator's view
1	60.24	69.58	73.6
2	62.75	63.48	70.92
3	65.59	61.84	62.48
4	77.01	71.45	80.85
5	57.97	62.62	54.48
6	63.65	61.47	64.53
7	70.84	81.27	87.36
8	52.14	54.46	52.53
9	83.19	74.92	85.43
10	57.28	80.66	84.12
11	74.17	60.78	72.1
Mean	65.83	67.50	71.67

Table 5.2: Setting 1: Completion time for scenarios when two avatars stand in front of each other.

As Figure 5.4 shows, the mean time to complete scenarios was 65.83 (SD=9.42) seconds when participants had an independent viewpoint. When the Shape Collaborator's viewpoint was shared, the mean time was 67.50 (SD=8.72) seconds. When the Color Collaborator's viewpoint was shared, the mean time was 71.67 (SD=12.15) seconds.

5.3.2 Setting 2: 135 degree

In this setting, avatars stand around a table in a way that if straight lines are drawn from their eyes, two line intersection point creates 135 degrees angle. With Independent viewpoint, Shape Collaborator sees the text properly, and Color Collaborator sees the text upside down.

Table 5.3 shows the completion time for each scenario for different groups.

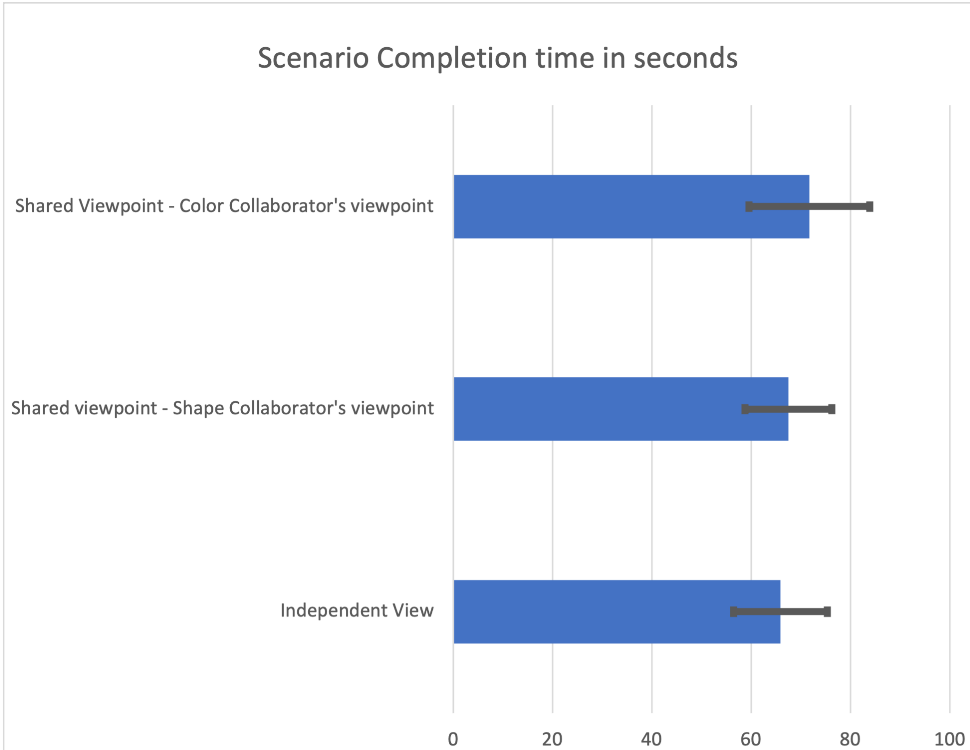

Figure 5.4: Mean and standard deviation of scenarios completion times for each scenario when collaborators stand in front of each other.

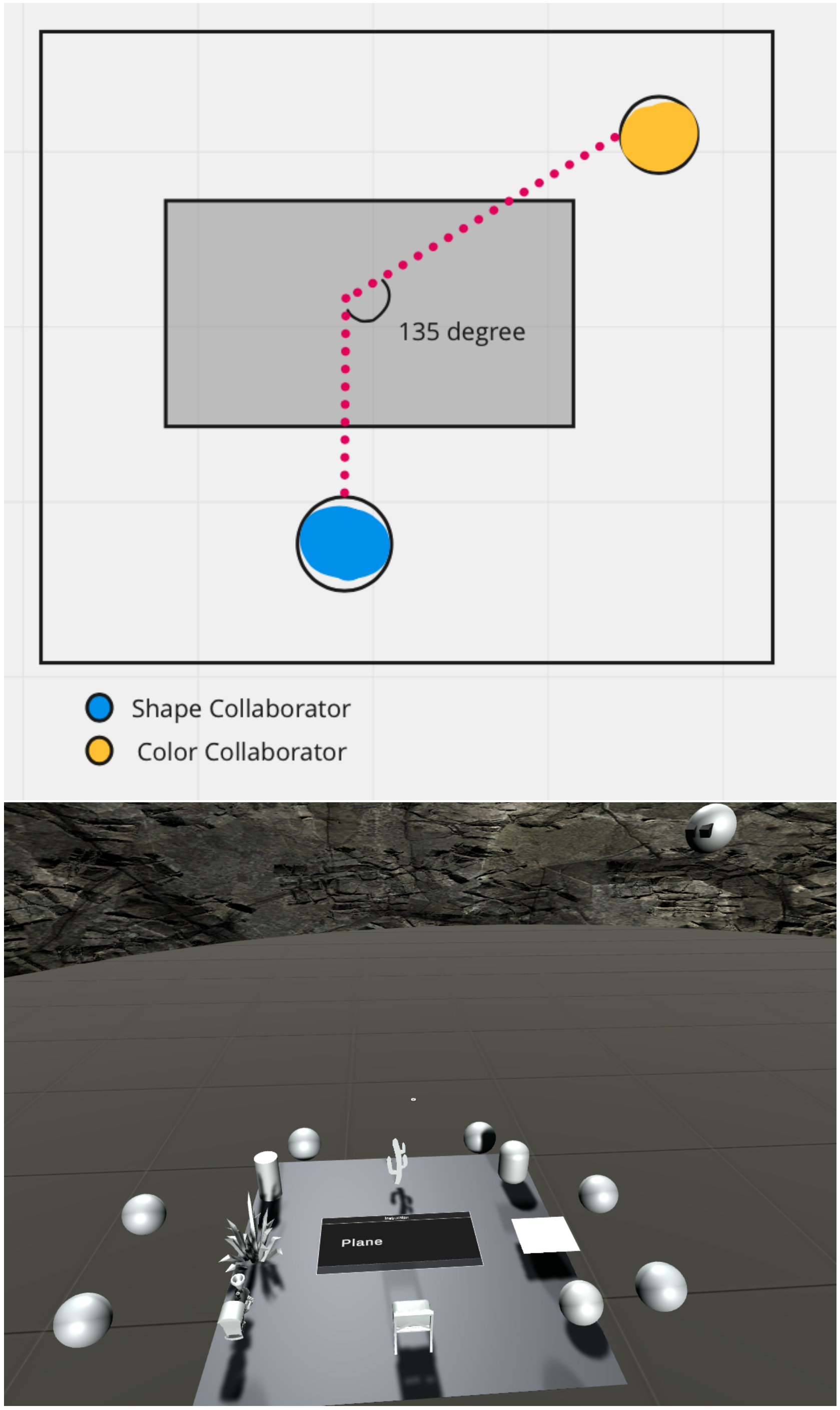

Figure 5.5: Setting 2: The top image shows the abstract of two avatars standing behind a table. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 135-degree angle. The bottom image shows how Shape Collaborator sees the environment.

Group#	Independent Viewpoint	Shared Viewpoint: Shape Collaborator's view	Shared Viewpoint: Color Collaborator's view
1	73.13	60.23	73.41
2	69.87	65.58	99.77
3	65.44	59.49	143.85
4	61.08	56.39	74.39
5	59.16	50.29	73.52
6	63.17	52.26	184.43
7	77.83	63.72	181.72
8	49.4	44.36	71.13
9	97.13	80.62	72.64
10	57.64	38.94	45.88
11	69.27	51.76	70.43
Mean	67.55	56.69	99.19

Table 5.3: Setting 2: Completion times when two avatars stand in the way that if direct lines are drawn from their eyes, the intersection point creates a 135-degree angle.

As Figure 5.6 shows, the mean time to complete scenarios was 67.55 (SD=12.58) seconds when participants had an independent viewpoint. When the Shape Collaborator's viewpoint was shared, the mean time was 56.59 (SD=11.28) seconds. When the Color Collaborator's viewpoint was shared, the mean time was 99.19 (SD=48.13) seconds.

5.3.3 Setting 3: 90 degree

In this setting, avatars stand around a table in a way that if straight lines are drawn from their eyes, two line intersection point creates 90 degrees angle. With Independent viewpoint, Shape Collaborator sees the text properly, and Color Collaborator sees the text upside down.

Table 5.4 shows the completion time for each scenario for different groups.

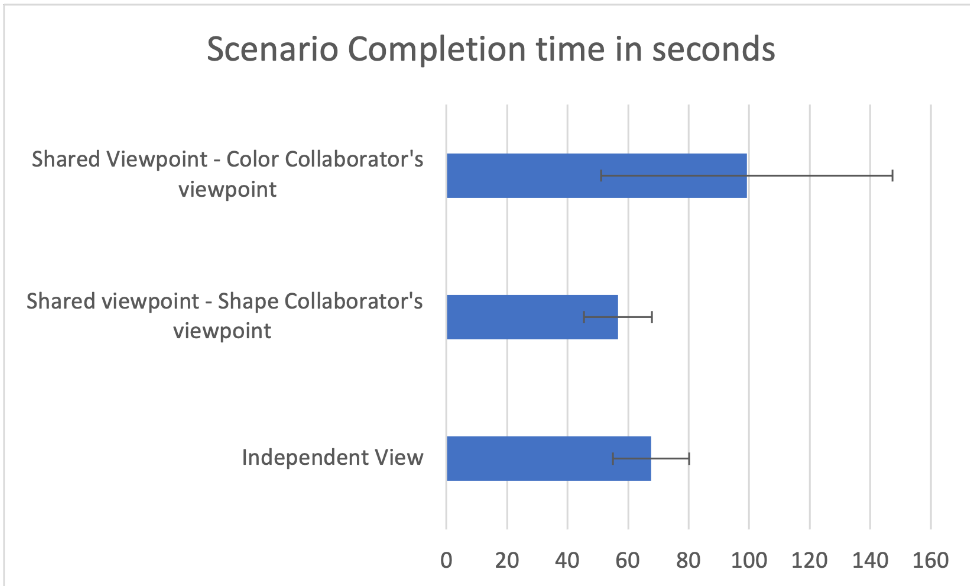

Figure 5.6: Mean and standard deviation of scenarios completion times when collaborators stand in a position where if straight lines are drawn from their avatars' eyes, two line intersection point creates a 135 degrees angle.

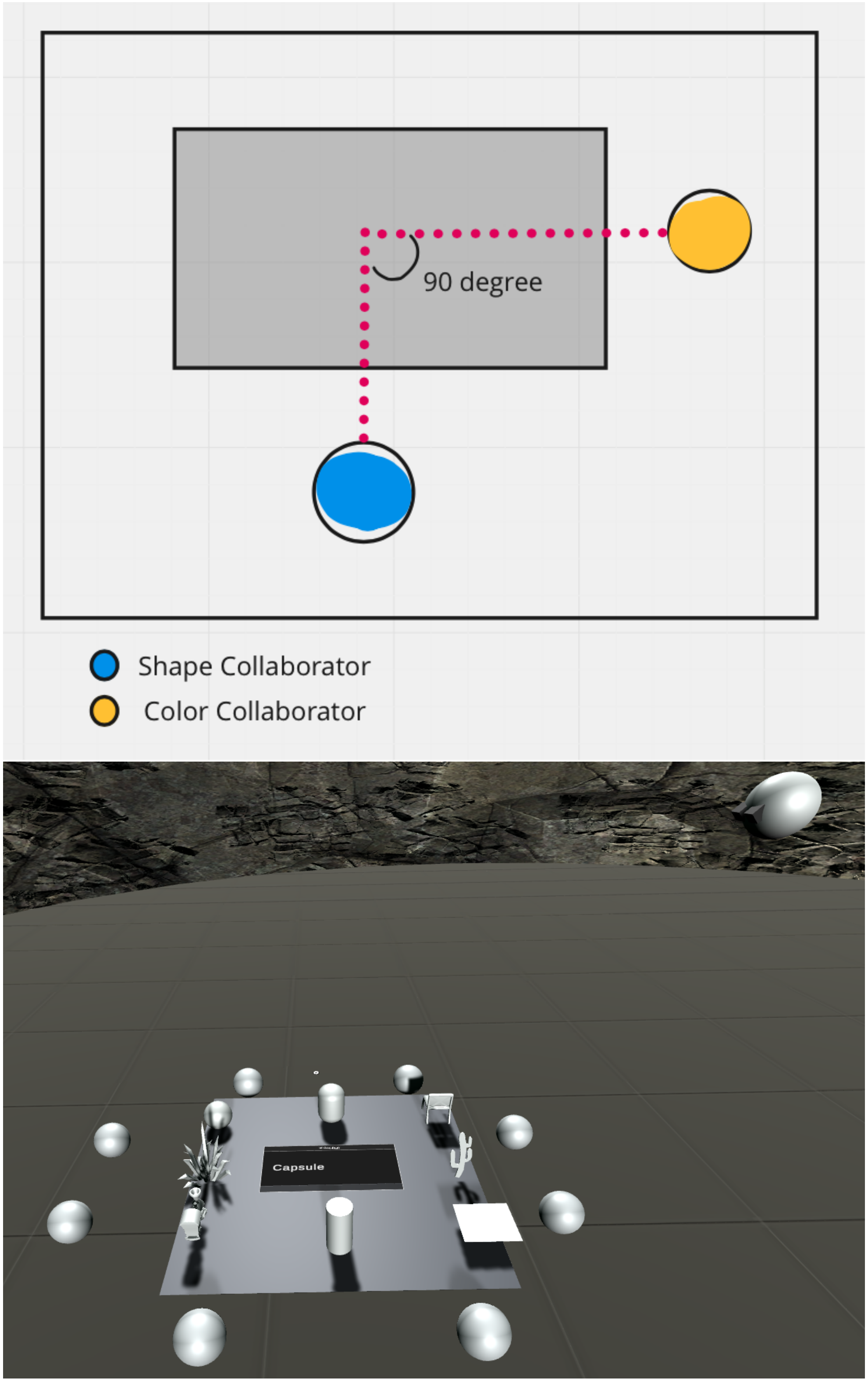

Figure 5.7: Setting 3: The top image shows the abstract of two avatars standing in front of each other behind the table. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 90-degree angle. The bottom image shows how Shape Collaborator sees the environment.

Group#	Independent Viewpoint	Shared Viewpoint: Shape Collaborator's view	Shared Viewpoint: Color Collaborator's view
1	92.39	115.2	101.69
2	103.19	56.78	87.3
3	79.89	59.66	73.47
4	93.58	64.67	65.65
5	74.87	55.75	56.93
6	90.66	56	57.2
7	99.84	62.95	116.57
8	62.6	56.35	68.94
9	106.86	81.98	97.7
10	78.39	62.37	50.14
11	88.21	54.96	67.05
Mean	88.22	66.06	76.60

Table 5.4: Setting 3: Completion times when two avatars stand in the way that if direct lines are drawn from their eyes, the intersection point creates a 90-degree angle.

As Figure 5.8 shows, the mean time to complete scenarios was 88.22 (SD=13.26) seconds when participants had an independent viewpoint. When the Shape Collaborator's viewpoint was shared, the mean time was 66.06 (SD=12.73) seconds. When the Color Collaborator's viewpoint was shared, the mean time was 76.60 (SD=21.28) seconds.

5.3.4 Setting 4: 45 degree

In this setting, avatars stand around a table in a way that if straight lines are drawn from avatars' eyes, two line intersection point creates 45 degrees angle. With Independent viewpoint, Shape Collaborator sees the text properly, and Color Collaborator sees the text upside down.

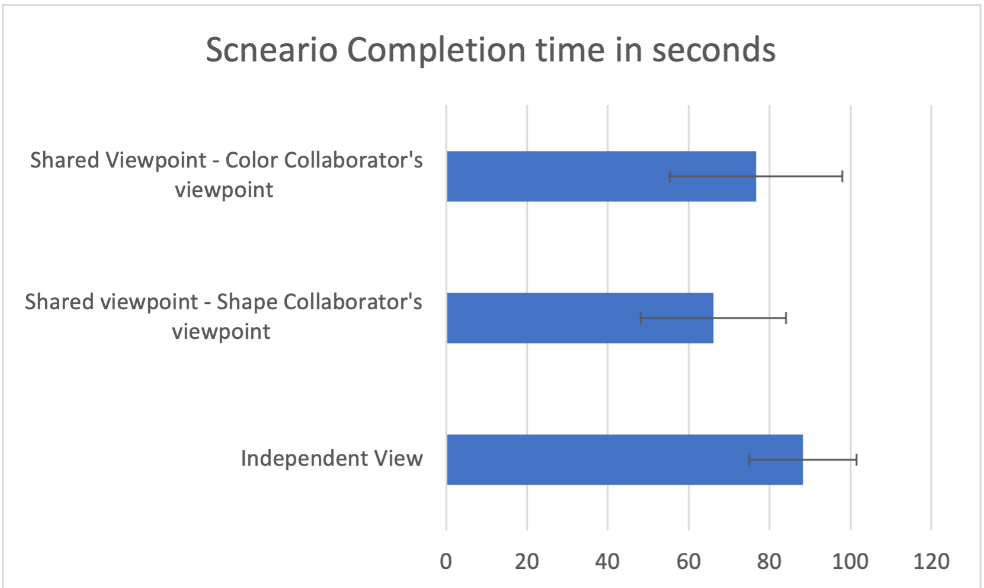

Figure 5.8: Mean and standard deviation of scenarios completion times when collaborators stand in a position where if straight lines are drawn from their avatars' eyes, two line intersection point creates a 90 degrees angle.

Table 5.5 shows the completion time for each scenario for different groups.

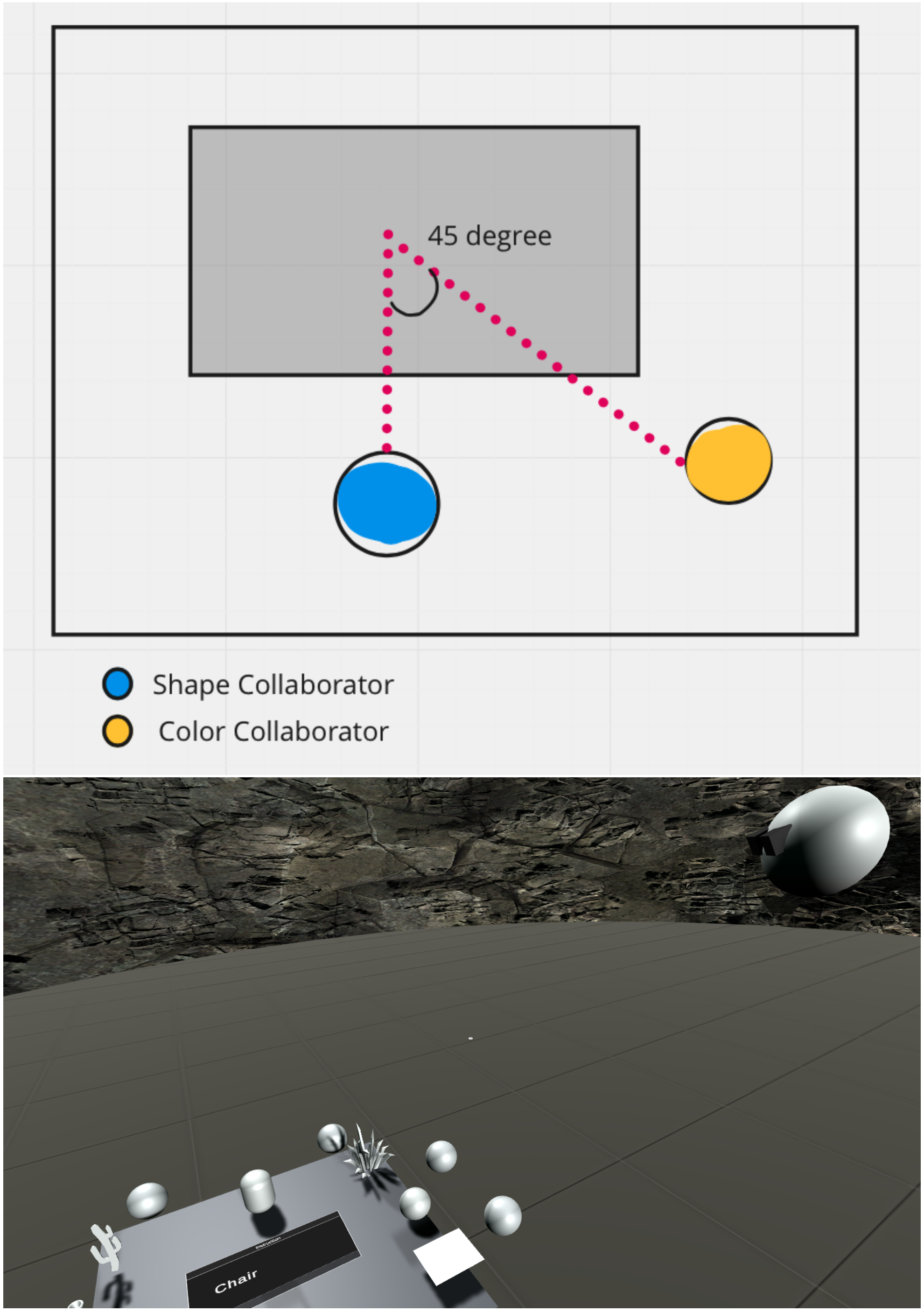

Figure 5.9: Setting 4: The top image shows the abstract of two avatars standing in front of each other behind the table. If straight lines are drawn from avatars' eyes, the intersection of these two lines creates a 45-degree angle. The bottom image shows how Shape Collaborator sees the environment.

Group#	Independent Viewpoint	Shared Viewpoint: Shape Collaborator's view	Shared Viewpoint: Color Collaborator's view
1	55.93	58.85	73.6
2	65.46	51.86	70.92
3	80.01	56.31	62.48
4	70.46	60.33	80.85
5	61.6	47.91	54.48
6	45.53	53.28	64.53
7	56.57	61.27	87.36
8	43.7	45.34	52.53
9	87.48	72.35	85.43
10	62.5	52.89	84.12
11	154.99	53.87	72.1
Mean	71.29	55.84	68.30

Table 5.5: Setting 4: Completion times when two avatars stand in the way that if direct lines are drawn from their eyes, the intersection point creates a 45-degree angle.

As Figure 5.12 shows, the mean time to complete scenarios was 71.29 (SD=30.70) seconds when participants had an independent viewpoint. When the Shape Collaborator's viewpoint was shared, the mean time was 55.84 (SD=7.34) seconds. When the Color Collaborator's viewpoint was shared, the mean time was 68.30 (SD=11.48) seconds.

5.3.5 Statistical Significance

Using the ANOVA approach to analyze our data is the obvious approach. ANOVA has the assumption of data normality distribution which is frequently ignored [40], leading to an inaccurate estimate of p-value [40][2]. Therefore, given the continuous completion time

[2]Our data is not normally distributed. See Appendix G for the histogram.

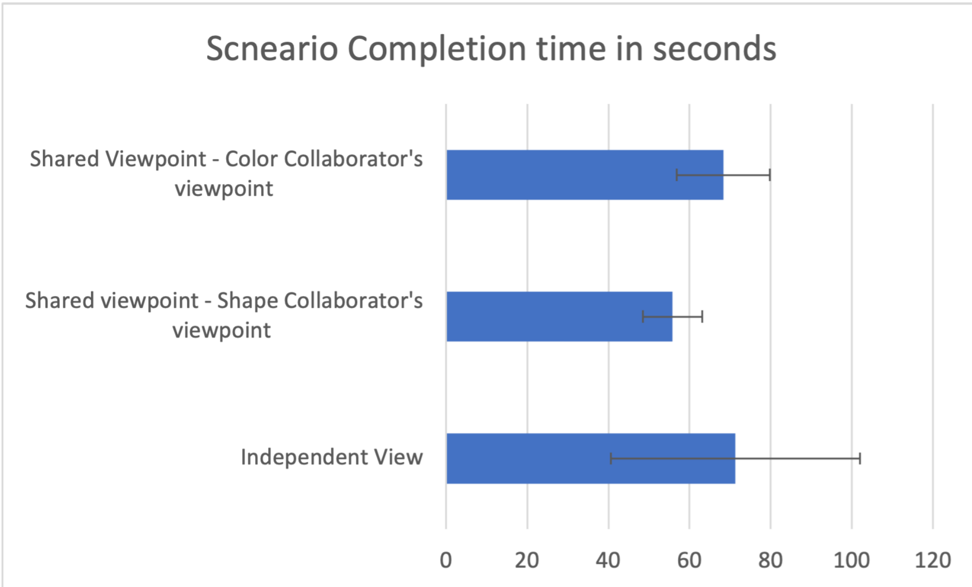

Figure 5.10: Mean and standard deviation of scenarios completion times when collaborators stand in a position where if straight lines are drawn from their avatars' eyes, two line intersection point creates a 45 degrees angle.

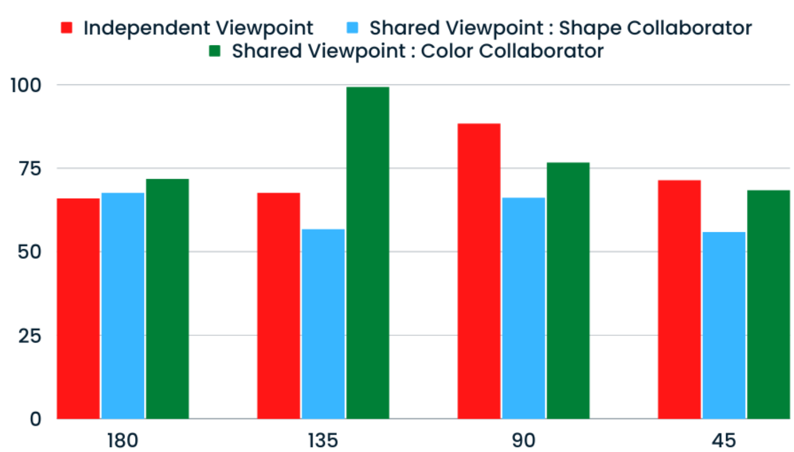

Figure 5.11: The mean of scenarios completion time for different settings and viewpoint modes.

and repeated measurements, we performed a linear mixed effect analysis of the relationship between Viewpoint mode (i.e., shared: Shape Collaborator's viewpoint, shared: Color Collaborator's viewpoint, independent) and relative position of avatars to each other (i.e, 180, 135, 90, 45) on scenario completion time, using lme4[4, 22] and lmerTest[52] packages in R[46, 15]. As fixed effects, we used viewpoint mode, relative position of avatars to each other, and the interaction between viewpoint mode and relative position of collaborators to each other. We used groups as a random effect. Although mixed effect models are robust against the violation of normality assumptions [74], visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity. Moreover, although some people do not consider the absence of influential data points as an assumption for the model [84], observing DFbeta values did not reveal any influential data point for our model. The model results are reported following the guideline from Meteyard et al. [62].

Variables	Estimate	Standard Error
Intercept	65.89	6.143
Shared viewpoint - Shape Collaborator	1.60	7.53
Shared viewpoint - Color Collaborator	5.77	7.53
Relative position(135)	1.66	7.53
Relative position(90)	22.33	7.53
Relative position(45)	5.40	7.53
Shared viewpoint - Shape Collaborator * Relative position(135)	-12.47	10.66
Shared viewpoint - Shape Collaborator * Relative position(90)	-23.77	10.66
Shared viewpoint - Shape Collaborator * Relative position(45)	-17.06	10.66
Shared viewpoint - Color Collaborator * Relative position(135)	25.86	10.66
Shared viewpoint - Color Collaborator * Relative position(90)	-17.40	10.66
Shared viewpoint - Color Collaborator * Relative position(45)	-8.76	10.66

Table 5.6: Coefficient table from the linear mixed effect model analysis

The fixed effects coefficients represent the average change in the response variable (scenario completion time) for a change in the independent variable while holding all other independent variables constant.

In order to evaluate the significance of the association between the independent variables and the dependent variable, p-values are calculated. The null hypothesis for each p-value is that the fixed factor term does not significantly affect the response. The significance level is assumed to be 0.05. To calculate the p-value, the lmerTest package is used. The package uses Satterthwaite approximations to calculate p-value [58], which is an acceptable approach even for small samples [58].

Variables	F-value	p-value
Viewpoint mode	11.10	0.003
Avatars' Relative positions	3.12	0.028
Viewpoint mode * Avatars' relative positions	4.35	0.0005

Table 5.7: p-values for fixed effect variables in the linear mixed effect model

There is a statistically significant association between the viewpoint mode variable and scenario completion time (p=0.003). Also, there is a statistically significant association between avatars' relative positions to each other and scenario completion time (p=0.028). Moreover, there is a statistically significant association between the interaction of viewpoint mode and avatars' relative positions to each other and scenario completion time(p=0.0005). Using estimates calculated by the result of the mixed effect model shown in Table 5.6, the following observations are made for our data:

1. For reference level (setting 1 - 180 degrees), the fixed effect of Shared viewpoint - Shape Collaborator is 1.60 seconds, with a standard error of 5.86, which means changing the viewpoint mode from Independent viewpoint to Shared viewpoint - Shape Collaborator caused an increase in scenario completion time by 1.60 seconds. Also, the fixed effect of Shared viewpoint - Color Collaborator is 5.77 seconds, with a standard error of 7.53,

which means that changing the viewpoint mode from Independent viewpoint to Shared viewpoint - Color Collaborator caused an increase in scenario completion time by 5.77 seconds.

2. The interaction effects of Shared viewpoint - Shape Collaborator * Avatars' relative position and Shared viewpoint - Color Collaborator * Avatars' relative position indicate that the effect of Shared viewpoint on scenario completion time varies depending on the relative position of avatars to each other, as indicated by the interaction effects of Shared viewpoint - Shape Collaborator * Relative position(135) being -12.47 seconds, Shared viewpoint - Color Collaborator * Relative position(135) being 25.86 seconds, Shared viewpoint - Shape Collaborator * Relative position(90) being -23.77 seconds, Shared viewpoint - Color Collaborator * Relative position(90) being -17.40 seconds, and Shared viewpoint - Shape Collaborator * Relative position(45) being -17.06 seconds and Shared viewpoint - Color Collaborator * Relative position(45) being -8.76 seconds with a standard error of 10.66.

5.4 Discussion

Given the results, we can answer the research questions provided in Chapter 1. We will also discuss the answers.

5.4.1 Answers to research questions

Preference question

The first research question asks,

Do users prefer a shared viewpoint by separating viewpoints from avatars in a collaborative virtual reality application while collaborating to complete a task?

To answer this research question, we built a collaborative virtual reality application to share a viewpoint between users by separating viewpoints from avatars. Users mentioned their preferences in semi-structured interviews after completing scenarios. Eighteen participants out of twenty-two mentioned they prefer this approach rather than having independent viewpoints. The reasons behind this preference are given in Section 5.2.

Therefore, the answer to the first research question is :
"most participants prefer having a shared viewpoint by separating viewpoints from avatars rather than having independent viewpoints while they are collaborating in the virtual reality application."

Scenario completion time question

The second research question asks,

Does sharing a viewpoint between two collaborators by separating viewpoints from avatars decrease task completion time in a collaborative virtual reality application?

To answer this research question, we created four settings; each has three scenarios. Settings are different from each other by avatars' relative positions around a table. Table 5.8 shows the mean of completion times for different settings and scenarios.

Avatars' relative position	Independent Viewpoint	Shared Viewpoint : Shape Collaborator's view	Shared Viewpoint : Color Collaborator's view
180	65.89	67.50	71.67
135	67.55	56.69	99.19
90	88.22	66.06	76.60
45	71.29	55.84	68.30

Table 5.8: Mean completion times for different settings and scenarios.

The results of the analysis show that the viewpoint mode has a significant effect on scenario completion time (p=0.003), and the relative positions of avatars to each other also have a significant effect on scenario completion time (p=0.028). Additionally, the interaction between the viewpoint mode and the relative positions of avatars to each other has a significant effect on scenario completion time (p=0.0005).

The results suggest that the impact of a shared viewpoint achieved by separating viewpoints from avatars on scenario completion time can vary depending on the relative positions of the avatars in the scene:

1. Setting 1 - 180 degrees: The fixed effect of Shared viewpoint - Shape Collaborator is 1.60 seconds, with a standard error of 5.86, which means changing the viewpoint mode from Independent viewpoint to Shared viewpoint - Shape Collaborator caused an increase in scenario completion time by 1.60 seconds. Also, the fixed effect of Shared viewpoint - Color Collaborator is 5.77 seconds, with a standard error of 7.53, which means that changing the viewpoint mode from Independent viewpoint to Shared viewpoint - Color Collaborator caused an increase in scenario completion time by 5.77 seconds.

2. Setting 2 - 135 degrees: The interaction effect of Shared viewpoint - Shape Collaborator * Relative position(135) is -12.47 seconds, with a standard error of 10.66. Changing the viewpoint mode from independent to Shared viewpoint - Shape Collaborator when avatars' relative positions are 135 degrees caused a decrease in scenario completion time by 10.86 seconds. However, The interaction effect of Shared viewpoint - Color Collaborator * Relative position(135) is 25.86 seconds, with a standard error of 10.66. Changing the viewpoint mode from independent to Shared viewpoint - Color Collaborator when avatars' relative positions are 135 degrees caused an increase in scenario completion time by 31.64 seconds.

3. Setting 3 - 90 degrees: The interaction effect of Shared viewpoint - Shape Collaborator * Relative position(90) is -23.77 seconds, with a standard error of 10.66. Changing the viewpoint mode from Independent to Shared viewpoint - Shape Collaborator when

avatars' relative positions are 90 degrees caused a decrease in scenario completion time by 22.16 seconds. The interaction effect of Shared viewpoint - Color Collaborator * Relative position(90) is -17.40 seconds, with a standard error of 10.66. Changing the viewpoint mode from Independent to Shared viewpoint - Color Collaborator when avatars' relative positions are 90 degrees caused a decrease in scenario completion time by 11.62 seconds.

4. Setting 4 - 45 degrees: The interaction effect of Shared viewpoint - Shape Collaborator * Relative position(45) is -17.06 seconds, with a standard error of 10.66. Changing the viewpoint mode from Independent to Shared viewpoint - Shape Collaborator when avatars' relative positions are 45 degrees caused a decrease in scenario completion time by 15.45 seconds. However, The interaction effect of Shared viewpoint - Color Collaborator * Relative position(45) is -8.76 seconds, with a standard error of 10.66. Changing the viewpoint mode from Independent to Shared viewpoint - Color Collaborator when avatars' relative positions are 45 degrees caused an increase in scenario completion time by -2.98 seconds.

So, the answer to the second research question is :
"The effect of having a shared viewpoint on task completion time varies based on the position of the avatars relative to each other. Often, having a shared viewpoint can decrease task completion time"

5.4.2 User study Observations

During the user study, we saw users try to develop a common language to guide each other. Because of simple interactions in the virtual reality application and completing training scenarios, even inexperienced users had no problem completing scenarios.

Based on the viewpoint mode, each group devised a communication technique to solve scenarios, and they stuck to the technique until the last scenario. Coming up with an

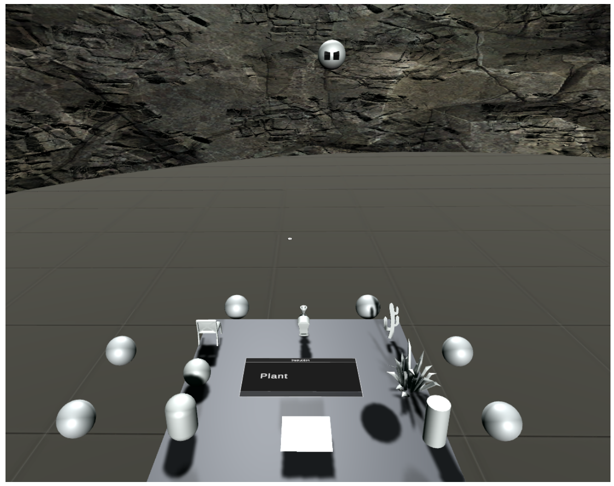

Figure 5.12: Based on our observations, collaborators could easily coming up with an effective communication technique when they were at the table's edges.

effective communication technique when viewpoints were at the corner of the table seemed hard to users. However, when viewpoints were at the edges, they could communicate better. Most collaborators chose one person as the reference and guided each other based on that reference's viewpoint. When they had shared viewpoints, they did not need to choose anyone as the reference. As an example of one conversation when the Color Collaborator was talking to the Shape Collaborator, we can mention this:
"The color is at your left. Choose the third color".

5.4.3 Possible Explanation on the effect of having a shared viewpoint by separating viewpoints from avatars

Initially, we thought having a shared viewpoint in a collaboration virtual reality application decreases task completion time in all cases. However, our findings indicate that this is not the case for some scenarios. For example, when users are in "setting 1: 180 degrees", having an independent viewpoint causes less task completion time than having a shared viewpoint. One possible explanation is that collaboration between two people usually happens in this setting in a day to day life. Therefore, we are used to this setting, and collaborating with this setting seems intuitive to us. Having a shared viewpoint is a new setting that people are

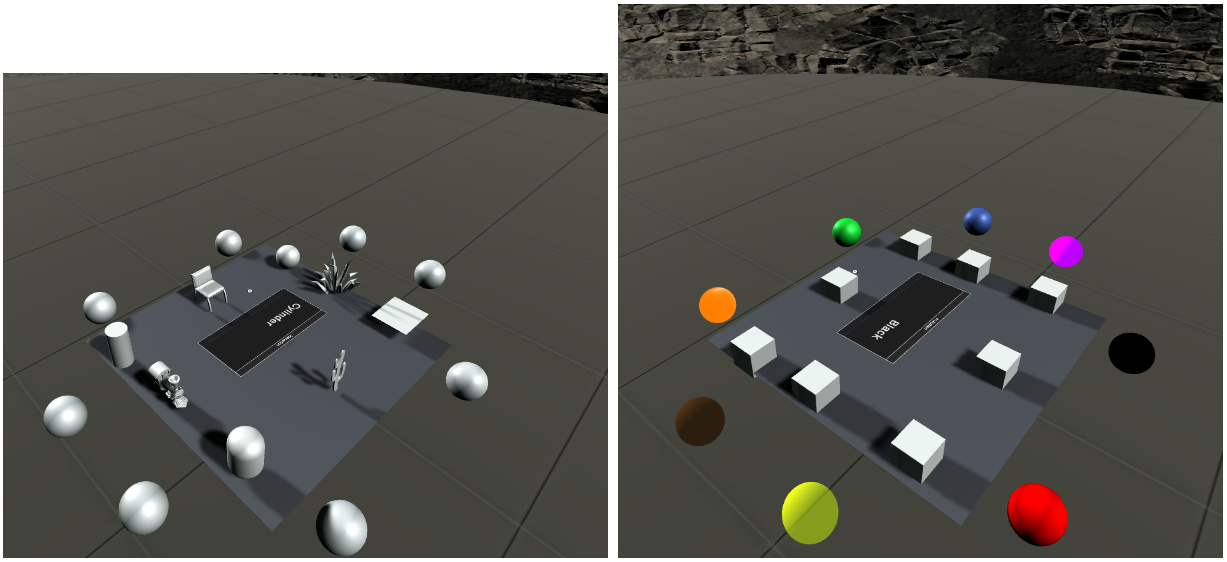

Figure 5.13: Based on our observations, coming up with an effective communication technique when there is a shared viewpoint at the corner of the table is not intuitive for collaborators.

unfamiliar with. Therefore, familiarity with the position setting causes proper collaboration performance and changing the viewpoint mode increases task completion time.

When avatars' positions were based on "setting 2: 135 degrees", sharing Color Collaborator's viewpoint increases scenario completion time in comparison to when they have Independent viewpoints. Based on our observation during the user study, when participants' avatars were positioned at corners, it was not intuitive for them to come up with an effective way to communicate and guide each other. This might be why having a shared viewpoint led to an increase in scenario completion time when the relative positions of the avatars to each other was 135 degrees, and Color Collaborator's viewpoint was shared.

In all four settings, when Shape Collaborator's viewpoint was shared among collaborators, the scenario completion time was lower than when Color Collaborator's viewpoint was shared among them. A possible explanation is that when Color Collaborator's viewpoint is shared with the other, both collaborators see the text field on the table at an angle. However, when the viewpoint of the Shape Collaborator is shared among collaborators, they can properly read the text field. This might be the cause for the observation in our data.

5.4.4 Interpretation of results

Given the results, we can conclude that having a shared viewpoint by separating viewpoints from avatars can decrease task completion time most of the time and is a preferred approach by users. Moreover, most participants did not find it hard to complete tasks when they had a shared viewpoint. Therefore, if task completion time is an important objective in a collaborative virtual reality application, it is recommended to consider using this approach. Furthermore, putting the viewpoint of the operator (i.e., Shape Collaborator) in a place where they can read the text properly can decrease task completion time. Therefore, when two collaborators want to collaborate and share one viewpoint, they should choose the viewpoint that causes them to read texts more efficiently, or the text should be adjusted so they can easily read it.

Chapter 6

Limitations, Future Work and Conclusion

In the last chapter, we acknowledge limitations in the study and possible improvements. Then, we present some future work. At last, we provide a summary of the work done in this thesis.

6.1 Limitations

The first limitation is the lack of diverse backgrounds and limited participants. Eleven groups participated in the study. It would be more ideal to have more participants to test the virtual reality application and hypotheses. Moreover, fourteen participants out of twenty-two had a degree in computer science. It would be more ideal to have more participants from other backgrounds and fields.

Another limitation of the study is the task defined to test our hypotheses. Although we tried to devise a task that is simple and domain-agnostic, we cannot generalize our findings to all fields. The effectiveness of having a shared viewpoint during collaboration and having a collaborator whose viewpoint is separated from their avatar position depends on the given task. Our findings indicate that we can decrease task completion time when we share a viewpoint between two collaborators and separate a collaborator's viewpoint from their avatar position in some scenarios. The results could be different if we define other tasks. It is worth to note that developing a general cross-domain approach remains an open problem [68].

6.2 Future Work

One extension to this study can be having more than two collaborators in the scene. In this study, we only had two users for collaboration. However, having more than two collaborators can create new challenges and questions. A user study can be conducted to determine the effect of sharing a viewpoint between more than two collaborators while users' viewpoints are separated from their avatars' positions.

Another follow-up for the study can be to test the proposed approach with other tasks. Having a shared viewpoint and separating users' viewpoints from their avatars for the given task was tested. To generalize the results, it can be helpful to conduct user studies to find the effect of having a shared viewpoint by separating users' viewpoints from their avatars with new tasks and scenarios.

Another follow-up for the study can be devising an approach to find a proper viewpoint to share between users during a collaboration. In this study, the viewpoint of one user is shared with the other; however, it may be more efficient to share a viewpoint that is not the viewpoint of anyone. Finding the best viewpoint for sharing between collaborators can be challenging, and user studies can be conducted to evaluate its effect on collaboration.

The next follow-up to this study is sharing a viewpoint between users while users' viewpoints are separated from their avatars and let them move. In this study, we did not let participants move during the collaboration. They were sitting on a chair while they were collaborating. Having a shared point of view and the ability to move can be a challenging problem, and user studies need to be conducted to determine its effect on collaboration.

Another extension to this study can be comparing the proposed approach in this thesis with teleporting avatars next to each other. Although some participants mentioned that having avatars in the scene while their viewpoints are separated can be distracting, if a high-fidelity avatar is used in the scene to share information about a user's emotions or other relevant information, not being able to see the avatar while collaborating might deteriorate collaboration quality. Therefore, comparing teleporting avatars next to each other with separating viewpoints from avatars can be a reasonable extension to this study.

Finally, this study was designed for collaborative virtual reality applications. The last possible follow-up to this study can be to test the proposed approach for Augmented Reality and Mixed Reality environments. For example, an environment where one collaborator is using Augmented Reality and the other collaborator is using Virtual Reality. User studies need to be conducted to determine whether the proposed approach works effectively for other points in the reality-virtuality continuum.

6.3 Conclusion

In this thesis, we investigated the effect of having a shared viewpoint between two collaborators while users' viewpoints are separated from their avatars in a collaborative virtual reality application. We created a collaborative virtual reality application and devised 12 scenarios, different in the avatars' positions around a table and users' viewpoints' modes. Two participants were needed to complete each scenario. When a user's viewpoint was shared with the other one, the avatars' initial positions were kept the same; it created an environment in which a user's viewpoint was independent of its avatar position. We conducted a user study with twenty-two participants grouped in teams of two people wearing Oculus Quest 2. After analyzing the data, we found that users prefer a shared viewpoint while viewpoints are separated from avatars rather than having independent viewpoints during a collaboration. The reasons for this preference were discussed. Moreover, we found a statistically significant association between viewpoint modes and task completion time. Depending on the relative initial positions of users' avatars to each other, the proposed approach can increase or decrease task completion time. Finally, the thesis was concluded by providing limitations of the study and possible future work based on them.

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Appendix A

Ethics Approval Certification

Conjoint Faculties Research Ethics Board
Research Services Office
2500 University Drive, NW
Calgary AB T2N 1N4
Telephone: (403) 220-4283/6289
cfreb@ucalgary.ca

CERTIFICATION OF INSTITUTIONAL ETHICS REVIEW

The Conjoint Faculties Research Ethics Board (CFREB), University of Calgary has reviewed and approved the below research. The CFREB is constituted and operates in accordance with the current version of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS).

Ethics ID:	REB22-0712
Principal Investigator:	Frank Maurer
Co-Investigator(s):	
Student Co-Investigator(s):	Amir Aminbeidokhti
Study Title:	User studies for understanding collaboration perspective in Virtual Reality
Sponsor:	Computer Science

Effective: 10-Aug-2022 **Expires:** 10-Aug-2023

The following documents have been approved for use:

- Recruitment Notice for User Experiment
- Study Consent Form
- post-task Interview
- post-study questionnaire
- Usability of immersive Technology Pre Survey
- Experiment Interview

Restrictions:

This Certification is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to the CFREB for approval.
3. An annual application for renewal of ethics certification must be submitted and approved by the above expiry date.
4. A closure request must be sent to the CFREB when the research is complete or

terminated.

Approval by the REB does not necessarily constitute authorization to initiate the conduct of this research. The Principal Investigator is responsible for ensuring required approvals from other involved organizations (e.g., Alberta Health Services, community organizations, school boards) are obtained.

Approved By:	**Date:**
Jenny Godley, PhD, Chair, CFREB	10-Aug-2022 11:50 AM

Note: This correspondence includes an electronic signature (validation and approval via an online system).

Appendix B

Residual Plot

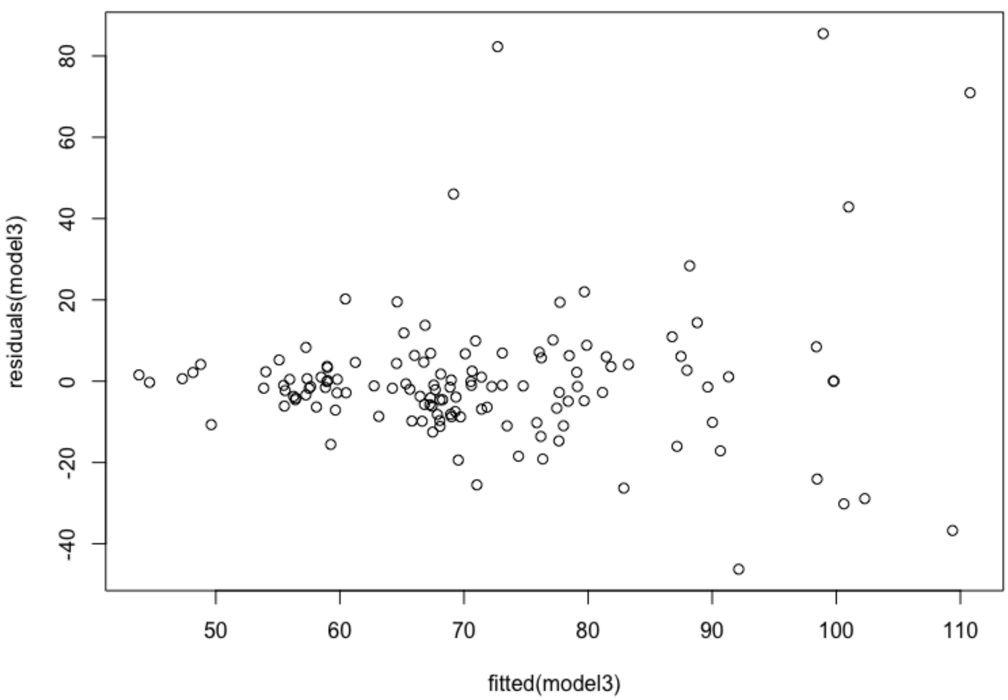

Figure B.1: Residual Plot for Linear Mixed Effects Model, showing the relationship between residuals and fitted values.

Appendix C

Pre-Study Questionnaire

Pre-Study Questionnaire

1. Age: Please circle your answer.

(18-20) (21-25) (26-30) (31-35) (36-40) (40+) (Prefer not to answer)

2. Gender: Please circle your answer.

Female Male Self-Identify: _______ (Prefer not to answer)

3. How often have you used virtual-reality devices? Please circle your answer.

N**ever A few times total Daily Weekly Monthly Yearly (Prefer not to answer)**

Appendix D

Post-Study Questionnaire

post-study questionnaire

1. How difficult did you find it to complete the tasks when the other participant's perspective was different than what you expected in the real-world?

0	**1**	**2**	**3**	**4**	**5**

Not at all difficult **Very Difficult**

Appendix E

Semi-structured Interview Questions

Semi-Structured Interview

1- Which one of two approaches was more preferable to perform tasks? Why? Which one was less preferable? Why?

2- How useful was the approach for collaboration in Virtual Reality?

3- What did help you the most to complete tasks?

4- What did bother you when performing the tasks?

5- How can we improve the approach?

6- Any additional comments or feedback?

Appendix F

Non-abstracted (Detailed) Results of Linear Mixed Effect Model

```
Formula: Task.Completion.Time ~ 1 + View.Point + Position + Position:View.Point +      (1 | Group)
   Data: data

     AIC      BIC   logLik deviance df.resid
  1174.8   1215.2   -573.4   1146.8      118

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.6163 -0.3789 -0.0744  0.2323  4.8355

Random effects:
 Groups   Name        Variance Std.Dev.
 Group    (Intercept)  66.04    8.126
 Residual             312.57   17.680
Number of obs: 132, groups:  Group, 11
```

```
Fixed effects:
                            Estimate Std. Error      df t value
(Intercept)                   65.894      5.867  98.903  11.232
View.PointShape                1.609      7.539 121.000   0.213
View.PointColor                5.779      7.539 121.000   0.767
Position135                    1.663      7.539 121.000   0.221
Position90                    22.332      7.539 121.000   2.962
Position45                     5.400      7.539 121.000   0.716
View.PointShape:Position135  -12.471     10.661 121.000  -1.170
View.PointColor:Position135   25.862     10.661 121.000   2.426
View.PointShape:Position90   -23.774     10.661 121.000  -2.230
View.PointColor:Position90   -17.401     10.661 121.000  -1.632
View.PointShape:Position45   -17.061     10.661 121.000  -1.600
View.PointColor:Position45    -8.766     10.661 121.000  -0.822
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Correlation of Fixed Effects:
            (Intr) Vw.PnS Vw.PnC Pst135 Pstn90 Pstn45 V.PS:P1 V.PC:P1 V.PS:P9 V.PC:P9 V.PS:P4
View.PntShp -0.642
View.PntClr -0.642  0.500
Position135 -0.642  0.500  0.500
Position90  -0.642  0.500  0.500  0.500
Position45  -0.642  0.500  0.500  0.500  0.500
Vw.PnS:P135  0.454 -0.707 -0.354 -0.707 -0.354 -0.354
Vw.PnC:P135  0.454 -0.354 -0.707 -0.707 -0.354 -0.354  0.500
Vw.PntS:P90  0.454 -0.707 -0.354 -0.354 -0.707 -0.354  0.500   0.250
Vw.PntC:P90  0.454 -0.354 -0.707 -0.354 -0.707 -0.354  0.250   0.500   0.500
Vw.PntS:P45  0.454 -0.707 -0.354 -0.354 -0.354 -0.707  0.500   0.250   0.500   0.250
Vw.PntC:P45  0.454 -0.354 -0.707 -0.354 -0.354 -0.707  0.250   0.500   0.250   0.500   0.500
```

Appendix G

Data distribution

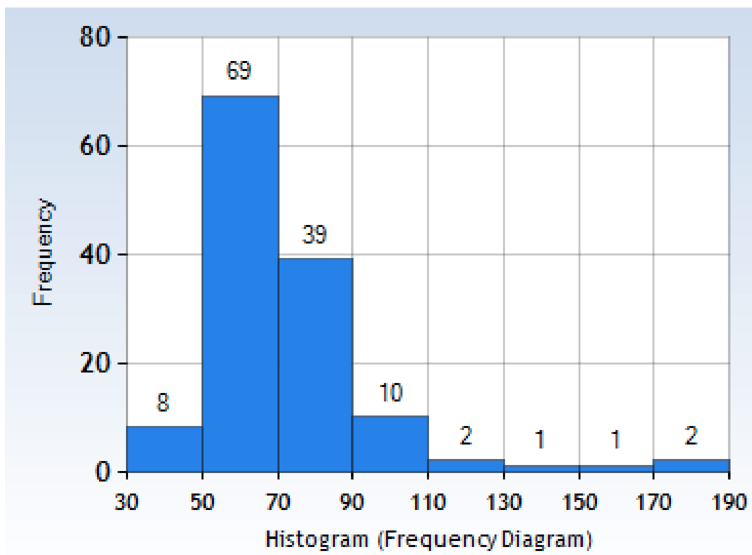

Figure G.1: The sample distribution that shows the sample is not ditributed normally.