The Impact of Virtual Reality on Social Processes in Escape Rooms

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Abstract

Educational escape rooms have been used for a while, but almost all require the players to be in the same room. This is still true when looking at most digital escape rooms. A way to have people experience the same escape room while being physically distant, is through Virtual Reality. One of the most important aspects of an escape room is the social processes that take place, especially the ability of the players to collaborate. A VR escape room has been created and tested by three groups of participants. Data was gathered through observation, a questionnaire and a guided interview. Results indicate that VR has both a positive and negative impact on collaboration, and especially on communication. Whether the impact is positive or negative is largely dependent on the amount of experience a player has. Negative effects can therefore be reduced when interactions within the escape room are more natural.

Contents

1 Introduction

Education in general is moving more and more towards a digital environment, with a blended learning environment becoming the norm rather than the exception (McNeil et al., 2000). This blended environment contains many different types of digital applications such as forums or online classes. Aside from this, it also opens up the possibility to incorporate video games into education (Susi et al., 2007). These serious games are employed in many fields, allowing players to develop skills they otherwise could not.

In the same trend of using game elements for other purposes, escape rooms are also being adopted by different fields. While still mostly used for entertainment purposes, escape rooms are seeing increasing use in many areas, including education (Fotaris & Mastoras, 2019). Because of their nature, they can create a great sense of collaboration and team accomplishment that can contribute to both the learning ability and the experience of the players.

Now that all parts of education are moving to a blended learning environment, educational escape rooms will also have to be adapted to a digital form. Some digital escape rooms have been developed, but there are still many challenges in their execution. Most digital escape rooms are played with players in the same room, looking at a digital screen. This type of escape room overcomes some traditional obstacles, like the space that is needed, or the time it takes to set it up. However, these experiences often lack the rush gained by solving physical puzzles, and can often not be played from home.

1.1 MasterMind

A few years ago, an educational escape room called MasterMind was created by Utrecht University (Veldkamp, Merx, & van Winden, 2020). This experience had both an educational and a social goal. The main aim of the escape room was to introduce digital tools to university teachers, that they can use in their education. This includes tools used for communication between students and teachers, grading, and uploading class materials, among others. Many teachers are not aware of the existence of these tools, or do not know how to incorporate them into their education effectively. The escape room allows for a playful way to introduce these tools to those teachers. This is achieved by creating puzzles where the solution can be found within these tools. For example, the players have to look up the information of a particular student, and use his grades as a code to open a lock.

The other goal of the escape room is to have groups of teachers experience the escape room together, and have them discuss the tools they learned about in a session after they finish. This allows them to be able to more easily discuss the use of these tools with their colleagues in the future as well. There are also some puzzles implemented that do not require the players to use the educational tools, but instead focus on collaboration. This is especially true for the final puzzle, which is designed to have them experience a feeling of solving the escape room together as a team.

There is a need for this escape room to be translated to a digital environment, because it takes a long time to set up the physical experience each time. With many people working from home, it would also be preferable if multiple people could join the experience from different locations. This should be done in such a way that both the educational and social aspects of the experience stay intact. A screen-based digital version could be created to replace the original, but some aspects would be lost in the translation. One of those aspects would be that the experience would feel less exciting (Pantelidis, 2010). This would very likely lead to less people participating, ultimately undermining the goal of the escape room. A middle ground can possibly be found in Virtual Reality (VR), as it can be immersive enough to make people believe they are in the same room, and simultaneously offers the advantages of a digital application.

1.2 Virtual Reality

VR was first introduced a few decades ago, but was unsuccessful in the consumer market at first (Bown et al., 2017). As technology improved, VR began to see use in therapeutic, entertainment and training purposes, among other. VR has both advantages and disadvantages over a physical environment (Pantelidis, 2010). An example of a disadvantage would be that facial expressions are not visible to other players, which might make communication more difficult. On the other hand, it would be much easier to encourage collaboration, for example by only showing certain information to a single player. In this way the group is urged to work together, in a way that would not be possible in real-life. One of the biggest advantages of VR is that people can experience situations that otherwise would be too dangerous, too costly or simply impossible to experience in real life.

In the case of MasterMind, a VR solution could offer an experience that can be set up quickly when needed, and in any room that has some space. Additionally, people could be connected over the internet, removing the need for all players to physically go to the same location. However, moving the escape room to a virtual space will influence the experience players have, leading to the need to study in what way the experience changes and if the advantages outweigh the disadvantages. This is true for both the educational and social aspects of the escape room. Due to limited time and resources, only the social aspects will be taken into consideration in this study.

1.3 Social Processes in Escape Rooms

There are many different social processes happening in any group setting. As people are working together to solve puzzles, the most important aspect of an escape room is to facilitate team building in a playful way (Wiemker et al., 2015). As this is still a very broad concept, this study will mainly focus on collaboration between the players. There are some other processes, such as social roles, that will be observed, but they will not be focused on.

Collaboration is hard to define, but is often described as people working together towards the same goal. For example, Barfield (2016) describes collaborative teacher development as simply teachers talking to each other. In this way they learn from each other and move beyond their own viewpoints. One big aspect of collaboration, then, is communication. If people are unable to effectively communicate, the amount of collaboration between them will suffer. Collaboration has many different aspects, as is explained in more detail in a following chapter.

1.4 Research Questions

The aim of this study is to determine the impact of a Virtual Reality setting on these social processes. The research question and sub-questions have been defined as the following:

- RQ: What is the impact of Virtual Reality on social processes between players in an escape room?
  - SQ1: Which social processes are the most important in an escape room?
  - SQ2: In which ways can VR be used to influence these processes?
  - SQ3: How do players experience social processes in virtual escape rooms?

The first two subquestions look at existing real-life escape rooms, to determine what an experience should entail. SQ3 identifies different features specific to VR, that can help to reinforce the identified social processes compared to a physical setting. Finally, an implementation is created and evaluated to determine whether the VR features can indeed improve a player's experience. This then leads to the main research question, as the impact of VR on the social processes can be determined. The answer to this question will help in further determining whether VR can effectively be used to replace real-life educational escape rooms.

1.5 Overview of Chapters

The next chapter will look at the existing literature, to provide a more solid background into the subject. Chapter three provides a model of the most important social processes in an escape room, gained from the literature. The fourth chapter described the methods used in this study to set up and carry out the experiment. The implementation is described in detail in the fifth chapter. In chapter six an overview of the results is given, which is further discussed in chapter seven. Chapter eight contains the conclusion of the research, and finally chapter nine offers some options for future research.

2 Related Literature

To gain an understanding of the context of using Virtual Reality for educational escape rooms, a literature study was executed. The chosen method for this study is mostly based the snowballing protocol as proposed by Wohlin (2014). The research by Veldkamp, Merx, & van Winden (2020) analyses the design of MasterMind, and identifies elements that should be included in an educational escape room. As this is the basis of this study, their paper was used as one of the initial papers.

Some more papers were found by searching with the keywords 'educational collaborative learning' and 'collaboration in escape rooms'. Collaboration is the main theme of this study, and should therefore be a topic of most papers that are found in the search results. As a sub-goal is to design an escape room, this topic should also be included the search. Finally, collaboration in other educational settings can be very insightful when creating the design, so this was also included. This search led to the following articles being added to the initial set: (Zea et al., 2009) and (Pan et al., 2017). The research by Zea et al. describes the design process of a multiplayer educational game, providing valuable insights in collaboration aspects. Pan et al. perform an analysis of collaboration and communication within a real-life escape room, using a research method that is very similar to the present study.

Most of the remaining literature was found by snowballing through the references of the three mentioned articles. Some of the minor topics that are less related to educational collaborative escape rooms has been found by using those topics as keywords in a separate search.

2.1 Serious Games

Abt (1987) defines serious games as "games which achieve an explicit, cautious, educational function and whose major feature is not just entertainment. That does not mean games should not be enjoyable; they can be used to impart knowledge in a playful way". Even some of the very earliest video games were serious games, contrary to what many people would expect (Djaouti et al., 2011). The concept of serious game is not limited to video games, as physical games can also be created for purposes other than entertainment. A term closely related to serious gaming is gamification. Huotari & Hamari (2017) define the goal of gamification as "a process of enhancing a service with affordances for gameful experiences in order to support users' overall value creation". The difference between these concepts is that serious games are designed as games with an intent different from entertainment, whereas a gamified experience is an existing serious application, to which playful elements are added. In recent years, the use of both serious games and gamified experiences within education has seen rapidly increasing use (De Gloria et al., 2014).

The escape room created by Veldkamp, Merx, & van Winden (2020), called MasterMind, can be seen as a serious educational game. The concept is very similar to a normal recreational escape room, but some of the puzzles require

the players to learn about the educational tools and perform a certain action with these tools to complete the puzzle. Specifically, there is both a social value in completing the escape room through teamwork, and an educational value in learning to effectively use the tools.

2.2 MasterMind

There are two main goals of the MasterMind escape room. The first and foremost is to introduce certain educational tools to university teachers. Many teachers either do not know of the existence of these tools, do not have the knowledge to use them or are not aware of the advantages they could bring. An escape room was designed, incorporating some of these tools. Examples of some of the tools are Remindo, a tool for online examination and grading, and Scalable Learning, a platform that can be used for blended teaching. Among other features, a teacher can upload videos with course material, and integrate questions for the students. Students are also able to discuss the material and help each other. Teachers can then get a better insight in how their students are progressing.

MasterMind also includes some more traditional puzzles, time pressure and a thematic setting, to create a more playful setting. This helped in motivating teachers to participate. For most of the puzzles however, the team had to execute certain actions within the educational tools. For example, they had to navigate through Scalable Learning to a specific student, to view their progress.

2.3 Educational Escape Rooms

Aside from MasterMind, there are many other educational escape rooms that have been created over the past years. Fotaris & Mastoras (2019) and Veldkamp, van de Grint, et al. (2020) both provide a systematic overview of literature on escape rooms in education. Especially medical and nursing education are very popular (Guckian et al., 2020; Hermanns et al., 2017; Morrell & Ball, 2020; Rhodes, 2020). The more learner-centered approach and team-based methods are essential in the practice of safe modern healthcare.

Another field of education that is popular for escape rooms is that of mathematics and programming (López-Pernas et al., 2019; Fuentes-Cabrera et al., 2020). Something all of these escape rooms have in common is that they are physical experiences, similar to the traditional escape room for entertainment. While they are shown to be effective in creating a learning environment, there is a need to move this to a digital setting. In the case of MasterMind, the time it took to set up the escape room each time for a few groups of participants was too long. With a digital escape room this can be drastically reduced, while also removing the requirement of the players being in the same physical location.

While there are many more examples of similar educational escape rooms, there is almost no research into digital escape rooms, and even less that make use of VR.

2.4 Digital Escape Rooms

Two main types of digital escape rooms can be identified: screen-based and Virtual Reality (VR) experiences. Most of the existing digital escape rooms, especially in education, fall in the former category. For example, Vidergor (2021) shows the results of an escape room aimed at elementary students who interact with an online escape room. These screen-based experiences have some merits over the traditional physical setting. While it may take longer to develop the application when compared to a physical room, every subsequent time the participant simply needs to launch the application. However, most of these screen-based escape rooms still require the participants to be in the same room during the experience, as they are executed in a classroom. This means that the sense of collaboration and team accomplishment is not much different compared to the physical setting. Especially during the Corona pandemic, it would be preferable if the escape room could be experienced from separate locations, where communication would be through digital means as well. It is a relatively small step to transform this to an online setting where each participant can join from their home, but this introduces different challenges in the design of the experience. For example, people collaborate differently in a digital environment, compared to a face-to-face setting (Schneider et al., 2002).

The second type of digital escape room is the VR experience. While it can be harder to set up, in certain cases it can counteract the collaboration challenges found in screen-based escape rooms. Mystakidis et al. (2021) show that teachers reacted positively to the use of a VR escape room target at biology students. However, VR can be hard to interact with, depending on the type of experience. This is especially true for people who are not experienced in video games. VR applications are quickly rising in popularity, partly because it has the potential to be much more similar to real-life situations than screen-based applications can be. For this reason, it was chosen to use a VR escape room to create the escape room for this study.

2.5 Social Processes

Bardis (1979) identifies many different social processes that take place in any group. These include acculturation, accommodation, cooperation, conflict and competition. In an escape room, all of these can possibly take place. Some processes, such as accommodation, take place over a longer period of time and are therefore not as prevalent in escape rooms. Conflict and competition might be felt in some groups, but in other groups these processes will be less present.

The one social process that is always necessary in an escape room is collaboration, as people are required to work together to efficiently solve the puzzles within a time limit. This study will focus on this process, but others may influence the design of the implementation. Other processes include social roles and shared experience. As they are related to collaboration, they will be touched upon in this study, but it is not the main goal to measure their effectiveness in VR. The model presented in chapter 3 explains the relation between the differ-

ent processes. Another process that can play a role in a group is that of social conflict (Pruitt, 1998). In an escape room, social conflict may arise when people in a team have different strategies for solving a puzzle, or are left out of the decision-making process (Pan et al., 2017). While cases of social conflict might arise in an escape room, this does not often happen. It is therefore not discussed in this research. As it is separate from the other processes mentioned, it is also not included in the model.

2.5.1 Collaboration

Collaboration is very hard to define, as it changes depending on the context and can contain many different aspects. Johnson & Johnson (1987) identify five different components: positive interdependence, individual accountability, face-to-face promotive interaction, social skills and group processing. Zea et al. (2009) provide guidelines for each component, to ensure that an educational game is truly collaborative and complements traditional learning. The focus of these guidelines is on creating a strong sense of team effort, while also maintaining individuality. In this way, people are motivated to work for the team in two ways. Firstly, they need other members of the team to succeed, because it influences their own success. Secondly, their individual efforts are measured, and they will be held accountable if their work is inadequate.

Collazos et al. (2002) also identify five indicators of collaboration. Their approach is based on that of Johnson & Johnson, with the addition of group performance. They define the indicators of collaboration as the following:

- **Applying strategies.** This indicator tries to capture the ability of the group members to generate, communicate and consistently apply a strategy to jointly solve the problem.
- **Intra-group cooperation.** This indicator refers to the use of collaborative strategies.
- **Success criteria review.** This indicator measures the degree of involvement of the group members in reviewing boundaries, guidelines and roles during the group activity. It may include summarizing the outcome of the last task, assigning action items to group members, and noting times for expected completion of assignments.
- **Monitoring.** This indicator is understood as a regulatory activity. The objective of the indicator is to oversee if the group maintains the chosen strategies to solve the problem, keeping focused on the goals and the success criteria.
- **Performance.** This refers to the quality of the proposed solution to the problematic situation. The evaluation of collaborative work takes into account three aspects: Quality (how good is the result of collaborative work), Time (total elapsed time while working) and Work (total amount of work done).

In escape rooms, collaboration is slightly different from other learning environments Pan et al. (2017). People who are in an escape room together often know each other, but this is not always the case. If players do not know each other in advance, they are less likely to share their opinion, and there is more opportunity for social conflict to arise. It is also harder to collaborate, as people do not know how others will react.

In both approaches to collaboration above, there are returning themes that are relevant in an escape room setting. For successful collaboration, there should be clear communication and each person should have a personal contribution. These personal contributions should all contribute to the group work, meaning there is cooperation between the team members. This should be well-coordinated to ensure efficiency. Some aspects are less important in escape rooms, mostly because it is a short-term collaboration. For example, there is no need for the group to perform group processing as identified by Johnson & Johnson.

In video games, and VR escape rooms by extension, certain game mechanics can be used to facilitate or force collaboration. These mechanics have been identified by Wang & Huang (2021), who performed a systematic review of serious games to find different methods used to accommodate collaboration. They grouped these mechanics in six categories:

- **Space.** This includes a virtual space where players are together, and can interact with each other.
- **Objects, Attributes and States.** Objects that can be interacted with be the players can be used as a collaborative tool by for example making a resource tradeable.
- **Actions.** Actions that players take can influence others in the world, creating a need for players to work together.
- **Rules and Goals.** A common goal can motivate each individual player to contribute to the success of the group.
- **Skills.** When players have unique abilities, they will need to find a way to have each use their strengths.
- **Chance.** Giving surprise tasks to a random player can help balance the performance of all group members.

2.5.2 Communication

As the biggest cornerstone of efficient collaboration, communication is extremely important. In an online setting, people will not be able to communicate in the exact same way that they would in real life. In some ways this is more true for VR, while in other ways VR can be closer to real life than communication through a video conference or a chat room.

In a chat room, participants of a discussion are generally more involved than in a physical meeting (Schneider et al., 2002). By not being able to see each other, people feel more comfortable sharing their opinion. Additionally, the discussion leader is more prone to specifically asking each participant for their opinion.

2.5.3 Social Roles

Another main process that is discussed in this study is that of social roles. In any group, people assume a social role that matches their personality and is influenced by what is expected of them (Masolo et al., 2004). As Pan et al. (2017) note, leaders of a group in an escape room are able to quickly create a mental model and share this with the other players. In teams with multiple experienced players they shared the leadership role. When there were no experienced players present, the group structure outside of the escape room would influence the role players take.

Qiu et al. (2009) show that letting people play a game together has a significant positive effect on the group's creativity and collaborative problem-solving skills. In their study, participants played a Wii music game together in a band. They were subsequently asked to perform a collaborative problem-solving task and a creative task. Groups that had played together performed much better than those who played the game individually. The authors speculate that the difference in social identity is the biggest factor in this difference.

Social identity is a widely used term, and can be seen as the way that people see themselves, as well as the way they are seen by the people around them (Jenkins, 2014). In the study by Qiu et al. (2009), the social identity of the participants that had played a game together is different from those that had played alone. By playing and working together, the participants were able to help each other, changing the way they were perceived by their fellow players. This in turn helped with their ability to function as a team in the collaborative task, and allowed them to more easily talk about their ideas in the creative task.

In MasterMind, this same social concept is very important. The experience itself is divided in two parts. The first part is the actual escape room, whereas the second part is a feedback session. Here the participants talk about what they learned about the educational tools in the escape room, and how they can use them in their own education. By incorporating a feeling of teamwork and accomplishment in the first part, the participants are more open to voice their thoughts and help each other understand the tools.

For this study the emphasis is on collaboration between the players, not on social roles or social identity. However, as these concepts might still influence the way people collaborate, they are taken into account.

2.6 Social Processes in Real-Life Experiences

There have been some studies that investigate the role of these social processes in escape rooms, though they mostly focus on real-life escape rooms. One of those

is Pan et al. (2017). They have a setup similar to the present study, where they look at collaboration, communication, social roles and social conflict within an escape room setting. Among their findings was that non-verbal communication is rarely used, whereas verbal communication is used in all cases. Another finding was that expertise in escape rooms can create natural leaders within a group.

Shakeri et al. (2017) found similar results to Pan et al. when studying a distributed escape room. In their experiment, the two players were connected through both a video and audio feed, but most players relied solely on the audio feed to communicate with the person in the other room.

A similar study was performed by Chiu (2022). They performed a quantitative and qualitative analysis of social interaction in real-life escape rooms. They found that players' background plays a major role in how well the group performs, and in how they experience the escape room.

According to Pan et al. (2017), there are always players that take on a leadership role. This is often not discussed, but happens naturally when one person has more experience than others. Hierarchy outside of the escape room, for example if the players are colleagues or a family, can also play a role. Kutzin et al. (2021) would mostly agree, but do state that there is no real leader in most groups. Instead, there is sometimes a person controlling the experience, while anyone can take a leadership role in solving one of the puzzles.

in many escape room settings there are one or more people who assume leadership roles. This is often not done explicitly or in advance, but they observed at least one person in each team direct others. This is often a player experienced with escape rooms, who knows what to look for.

2.7 Comparison of Real-Life and VR

Berkman et al. (2020) studied the effect of VR on players of a puzzle game. Half of the participants played the game on a computer screen, while the other half used a VR headset. They found that VR did not have a definitive impact on user experience or performance. However, they state that players can become more engaged with the dynamics in VR, as the controls have the potential to be much more natural compared to using a keyboard and mouse.

One of the challenges when creating any VR application is that of motion sickness (Chang et al., 2020). Also called VR sickness or cybersickness, this is the phenomenon when the brain receives contradictory information from different senses. Usually this is the eyes telling the user that they are moving, while the vestibular system tells the brain that they are standing still. This will need to be taken into account when designing the implementation.

3 Social Processes Model

The social processes involved with group interaction have been an object of study for many years (Bardis, 1979). There is a huge amount of different types of interaction involved with any group, such as competition, conflict, accommodation and collaboration. As an escape room is performed as a group, all of these processes can be present. The goal of an escape room is to work together to solve puzzles, resulting in collaboration being the most important process in this scenario.

As explained in the previous chapter, collaboration can be seen as cooperation, communication and coordination coming together, and it is also influenced by social roles and the personal contribution of each group member. Below is a model that contains these processes, and how they are related to some other processes. These chosen processes and their relations are based on the literature study in the previous chapter. This chapter explains the meaning of the terms used in the model.

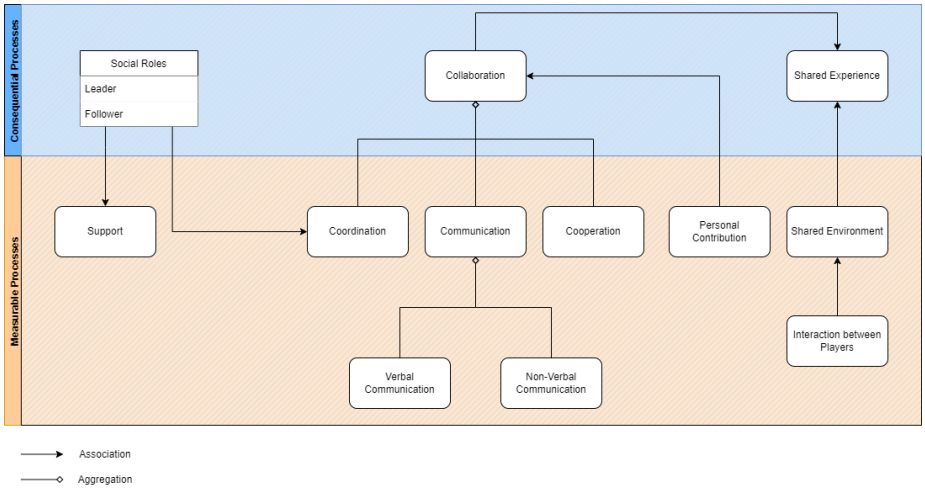

Figure 1: Social Process Model for Escape Rooms

The model consists of two layers. The bottom layer contains processes that can be measured more directly. For example, communication can be measured by counting how many times a person addresses another person, and analysing the flow of a conversation. Support can be measured by the number of times when one person takes an action with the intention of helping another. In the design process of the escape room, decisions can be made to better facilitate these processes as well. A shared Experience can not be directly measured, as it is a subjective feeling and can be different for each group member. Instead, it can be analysed by looking at other processes. When people are effectively collaborating, and are in the same environment, they are likely to feel that they shared an experience (Veldkamp, Merx, & van Winden, 2020).

The top layer contains processes that are the result of other processes or are inherent to a group. The most important process in the model is collaboration, as this is the one required process to complete an escape room.

3.1 Social Roles

In any group, some people are more likely to assume a leadership role than others, and are expected to act according to this role (Masolo et al., 2004). This can be based on multiple things, such as personality traits and a social hierarchy in a different setting, for example in a family. In an escape room, this is often not the case at the start (Pan et al., 2017). However, when a puzzle has to be solved, someone with relevant knowledge is likely to assume a leader role, while others follow their directions. This often happens naturally, as the one taking the leadership role will have authority based on their experience. Being a leader results in different types of behavior, for example a leader taking initiative in coordinating the team, or being able to support a team member that is struggling. Social roles are further defined in section 2.5.3

3.2 Support

Support refers to a social process of one person assisting another. In the case of the escape room, this is often between two people of different roles. For example, this can be a follower type assisting a leader type, as the latter has the knowledge required to solve a puzzle and can direct the former. It can also work the other way around, when one person is struggling with a puzzle, another can assist them in solving it, acting like a mentor. This can happen in other aspects of the experiment as well, such as when one person has trouble with the controls.

3.3 Collaboration

Arguably the most important social process in an escape room is collaboration. True collaboration is achieved when multiple people actively work together on a problem, and are all aware of what the others are doing. Work can be done in parallel, but all people should immediately know the impact of others' work on their own. Collaboration itself can not be measured, but is rather a collection of different processes. In this model there are four key components that have been identified: coordination, communication, cooperation and a personal contribution of each team member.

3.4 Coordination

This is the phenomenon that occurs when one person has the overview of a situation and is able to effectively guide the others in the group in the right direction, giving tasks to each player. Usually, this person would have assumed a leadership role. This is similar to the component called *applying strategies* as

identified by Collazos et al. (2002). It represents the group's ability to formulate a strategy to solve the puzzles in the escape room where the strengths of each team member are used appropriately.

3.5 Communication

Communication can include any way for one person to deliver information to one or more others. In this case, a difference is identified between two types of communication: verbal and non-verbal. The exact channels through which players can communicate in the VR setting will be determined in the design process, but will most likely include voice for verbal communication and hand- and head movement for non-verbal communication. In the work of Collazos et al. this is also incorporated in the component *applying strategies*. In this model it was separated because people are not necessarily able to communicate in the same way in a VR setting, as compared to a physical environment.

3.6 Cooperation

Cooperation is often used as a synonym for collaboration, but there are slight differences. Cooperation can be seen as a process where people work together towards the same goal, possibly at the same time, but are not directly aware of each others' efforts. As defined by Collazos et al., the level of cooperation can be measured by the use of collaborative strategies. If these strategies are used effectively, cooperation can be called collaboration.

3.7 Personal Contribution

The final cornerstone of collaboration in escape rooms is the personal contribution of every player. It is especially important in educative escape rooms that all players have the opportunity to contribute to solving puzzles, and in that way learn from the experience. In an ideal situation each member of a group should feel like they contribute the same amount of effort as the other members. This is related to *personal accountability* and *positive interdependence* as defined by Johnson & Johnson (1987). They describe this as a way to make sure that every team member has a certain level of contribution to the team, and ways for all team members to be dependent on each other to succeed.

3.8 Shared Experience

Aside from collaboration, another preferred outcome of the experiment is that the players have a feeling of having shared an experience with their fellow players. This is achieved in two main ways. The first is being able to collaborate with the others in solving the puzzles. The other is by creating the feeling that players are in the same room, experiencing the same thing at the same time, even though they are physically in different places.

3.9 Shared Environment

To create an experience shared by multiple people, a core aspect is the shared environment. This means that players are able to see each other move and interact with the environment. For example, when one person picks up or moves an object, the others will be able to see this reflected in their own space.

3.10 Interaction between Players

Interaction between people can happen in any number of ways. A big part of interaction in VR escape rooms is included in communication or other aspects of the model, but this process also includes other ways to interact with fellow players. An example of this would be for one person to pick up an object and then hand it to another person. It is interactions like this that can create feelings of sharing an environment and an experience with the other players.

4 Methods

As part of this study a VR escape room has been created. The design and implementation process is loosely based on the P-III framework described by Abeele et al. (2011), as seen in figure 2. This model includes different phases, between which an outside expert will review the current state of the project. There are three phases in total, which are the concept phase, design phase and development phase. Due to limited time available, a few modifications had to be made. The heaviest impact was on the concept phase, as the concept was largely drawn from the literature study.

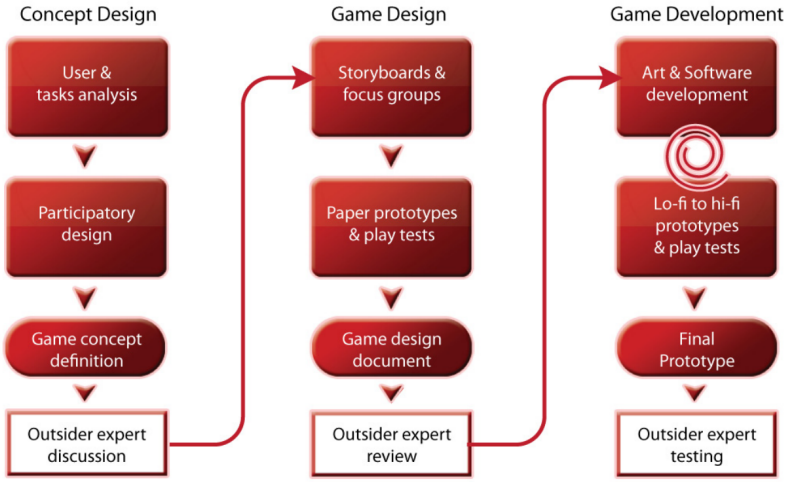

Figure 2: The P-III Framework

4.1 Creation of the Implementation

The first step in the creation process was to define a concept, and find some boundaries within which the implementation should be created. When this was clear, a focus group was organised to identify elements that could be used in the escape room to support collaboration, and especially communication. This was then further discussed with an expert in the field. Together with this expert some puzzles were designed, and finally the actual prototype was created in an iterative fashion.

4.1.1 Concept Definition

The first phase mentioned by Abeele et al. (2011), the Concept Design phase, has been limited to creating the game concept definition. The focus was on what the escape room should achieve, and how this should be made possible. It was decided that it would be playable with four people simultaneously, all

in VR. There should be multiple ways for these players to communicate both verbally and non-verbally. No strict requirements were placed on the length of the experience, but there had to be enough puzzles to gather a sufficient amount of data. Finally, the puzzles themselves should encourage or even require collaboration between the players.

4.1.2 Focus Group

After setting up these guidelines for the implementation, the project moved to the Game Design Phase. A focus group was organized, for which three people were invited. One participant has a large amount of experience with VR, having worked with multiple companies that develop and offer VR experiences, including VR escape rooms. Another is an IT specialist, with much experience in building and designing different types of software. The final participant of the focus group specializes in social psychology, to provide an insight from an entirely different viewpoint.

With the focus group, some existing VR experiences were analyzed, identifying ways to incorporate channels of communication between players. Some of the most common systems are:

- **Voice Chat.** The most important and intuitive way for people to communicate is verbally. This can be achieved within or with external software. It can also be implemented in a way that all players can hear each other, or more realistically in a way so that only nearby players can hear someone talk.
- **Gestures.** Body language is often used to support verbal communication. This can be achieved in a basic way by tracking the hands of a player. It is also possible to use Inverse Kinematics to simulate an entire body, but this is often not very accurate.
- **Pings.** Giving players the ability to place a marker that shows up for others would make communication more efficient. This marker could be placed anywhere in the world, and stays for a few seconds until it disappears. This feature could assist in indicating what a player is talking about.
- **Marking Objects.** Similar to Pinging, this would be limited to only the ability to make certain objects light up or otherwise indicate them.
- **Writing Text.** The ability to write text, either with a virtual pen or with a keyboard, would offer an alternative way for players to communicate. This could also help for certain puzzles where they need to remember a code or something similar.

In the second part of the focus group, these systems were discussed, to decide which should be implemented. Voice chat and gestures were seen as necessary for all types of communication, while pings or marking objects would be useful

in many situations. The ability to write text was deemed very situational, and would not be used except for when a puzzle specifically demanded a player to do so.

Other studies have also found verbal communication the most important communication channel, and non-verbal communication in a lesser amount Pan et al. (2017); Chiu (2022); Berkman et al. (2020). Other features are deemed to be less necessary to accommodate collaboration, but can in some situations be useful.

In the final part of the focus group, some basic functionality of puzzles was identified that would force players to work together.

- **Actions Influence Others.** This influence can be either positive or negative. If an action that one player takes has consequences for another, they will need to communicate clearly about this effect so that they can help each other to solve a puzzle.
- **Actions in Parallel** If players are required to take multiple actions at the same time, they are required to work together to achieve the correct timing for their actions.
- **Information Spread.** By giving one person more or different information than another, they will have to communicate so that all players are on the same page.
- **Different Abilities.** Similar to information spread, giving different players unique abilities would force them to involve each other in the different puzzles.

These mechanics coincide with those identified by Wang & Huang (2021). A VR escape room also makes use of other mechanics as described by Wang & Huang, such as a shared virtual space, expression and gesture, common goals and a group victory. After the focus group, these mechanics would be used to design the specific puzzles for the experiment.

4.1.3 Expert Interview

After the focus group was held, work began on a first prototype. This included a basic setup with VR interaction. As the final step in the design phase, the current prototype was discussed with an outsider expert, and a brainstorm for the puzzle design was carried out. This expert has been involved with many VR escape rooms, as well as a VR Arcade company.

Feedback on the prototype was positive, with the expert confirming the results of the focus group. During the brainstorm and further design process, the collaborative game mechanics identified by Wang & Huang (2021) were taken into account, as well as those identified by the focus group. In this interview a design for the puzzles was created, with a focus on creating many opportunities for collaboration between players. One of the most important ideas from this brainstorm was the one to split the room in two, and create puzzles that required

items or knowledge from the other room. In this way, players are required to collaborate with each other to solve the puzzles.

4.1.4 Influencing Social Processes With VR

With the information gathered through the focus group, the expert interview and literature, an answer can be given to the second sub-question of this study. VR can be used to influence social processes in two distinct ways: it can add a layer of functionality on top of what is possible in real life, and some possibilities of real life are made easier because it is a virtual world.

An example of creating new possibilities is the pinging system. By adding the possibility to mark certain objects in the world, communication can be made easier. Similarly, giving a player the ability to teleport around in the world allows him to move quickly between locations, which results in a better ability to quickly assist a team member that is requesting help.

Some game mechanics that allow for collaboration, as defined by Wang & Huang (2021), are easier to implement in a virtual simulation when compared to real life. The best example of this is information division. In real life, it can be challenging to make sure that only one player receives a certain clue, unless this is done before the escape room starts. In a digital escape room, it is relatively easy to only show things to a certain player.

VR also has some negative influences on social processes. This is most prominent in the fact that it is impossible to see facial expressions or subtle gestures of other players. This has some impact on the ability of people to communicate, though most communication is verbal (Shakeri et al., 2017). Verbal communication can also be influenced by VR, depending on the way it is implemented. A positional system can be used that is effectively the same as real life, or a system can be used where each player can always hear all others. This could make communication more easy.

4.1.5 Development Phase

During the development of the implementation, the guidelines presented by Cohen et al. (2020) have been followed. They state that researchers should always keep in mind their research question when designing an escape room. As this study has a focus on collaboration, the puzzles should create many opportunities for players to work together. This can be done in many different ways, as discussed by Wang & Huang and the focus group and interviewed expert.

The implementation was created in Unreal Engine 4.26, using many of the available features to more easily create the different puzzles. It was created with an iterative process, by testing and improving upon each feature as it was built. The first iteration, which was created before the expert interview, contained a basic setup for VR movement, a single object that could be picked up, and a way for the player to place a ping in the world.

After discussing this with the expert, a second iteration was created. This included a first puzzle, and networking functionality so that four players could be in a virtual room simultaneously. Next, some templates were made with which multiple puzzles could be more easily created. The final iteration contained all of the puzzles.

All iterations were tested before moving on, and some time was taken to fix problems or adjust puzzles. A detailed description of each puzzle and system in the escape room can be found in the next chapter.

4.2 Experiment

Similar to some existing research, the experiment consisted of three separate ways to gather data (Pan et al., 2017; Chiu, 2022; Shen & Mazalek, 2010). By using observation, a questionnaire and a guided discussion, both quantitative and qualitative data can be gathered. As there is some overlap between the data, this can serve as validation.

When signing up for the experiment, participants were asked for their basic information such as age and gender. This form also included an informed consent that the experiment would be recorded with both video and audio, and that their data would be used for this study.

Before a group of participants started the VR escape room, there was a short introduction. This contained an overview of what they were expected to do, and an overview of VR, including an explanation of the controls. Afterwards, they had the opportunity to get used to moving around and interacting with objects before the escape room began. This took a varying amount of time depending on the experience level of the participants in each group. During the experiment, the participants were in the same room, but each has their own play area set up to avoid them hitting each other or the walls. The participants were recorded both in the virtual and physical space. Afterwards, they filled in a questionnaire on their individual thoughts. Finally, a group interview was conducted in which the players could discuss how they experienced the escape room as a group.

4.2.1 Participants

Three groups of four people participated in the experiment, for a total of twelve participants. All of them are aged 22-28, and are current students or recent graduates at a university or a university of applied sciences. Eight of the participants are male, while four are female. There was one all-male group, while the others were mixed. Three participants had never experienced a physical escape room before, while only one had experienced more than five. In terms of experience with VR, three people have a lot of experience, and three had never used it before. The remaining six had used it a few times. Three people had also played a VR escape room before, while nine had no such experience.

On average, the amount of experience within each group was nearly the same. Groups that contained one or more people with no prior experience also contained at least one person that had a high level of experience.

4.2.2 Observation

The room used for the experiment is equipped with four cameras, each aimed at a single participant. These were used to record the experiment, and be able to gather observational data at a later date. For the same reason, the VR display of each participant was also recorded, including data from the microphone of each headset. As a backup, there was a single microphone in the middle of the room that recorded all participants. Aside from the recording, an observer was present in the room to take note of any interesting behaviour. One of the headsets streamed to a laptop, so the observer can follow the progress of the group. This observer can also assist any participants experiencing technical difficulties.

Examples of the type of data gathered in this way is the time each group needs to complete each puzzle, and whether all players are actively involved in the experience or one person is assuming a leadership role. Additionally, it is noted whether the participants have any trouble with the controls.

4.2.3 Questionnaire

After the group finishes the escape room, they are presented with a questionnaire that they are asked to fill in. This questionnaire contained four sections. First, a few general questions were asked regarding their age, gender, and experience with VR, escape rooms and the combination thereof. The second section contains the social presence module of the Game Experience Questionnaire (IJsselsteijn et al., 2013). These questions are used to determine how involved each player felt with the others in their group. All questions in this section are answered on a 1-7 scale.

The third section of the questionnaire contains the Task Load Index (Hart & Staveland, 1988). This scale is often used to obtain the workload estimates of operators in any field, and can in this case be used to measure how easy or difficult the participants find the VR technology to work with. These questions use a 1-7 scale. The final section contains a few questions regarding the ability of each player to collaborate with their group. Examples are 'I feel like we were able to work as a team' and 'Every person was able to contribute to the solving of the puzzles'. These are answered on a scale of 1-5.

4.2.4 Guided Discussion

When the participants finished the questionnaire, there was a short guided discussion. The purpose of this discussion is to have the participants discuss questions similar to the final section of the questionnaire. This includes questions about how they perceived the ability to collaborate with each other during the escape room. They were also asked to reflect on the impact that VR had on their experience, both in general and for the escape room specifically.

5 Escape Room Design

In this chapter, a detailed look will be taken at the implementation created for the experiment. The implementation consists of two major systems that are the core of the experience. The first is the VR system, that allows for users to use their headset and controllers to move around in and interact with the world. The other core system is the networking system, that enables multiple users to connect to the same world, and have a change that one player makes be reflected for the others. Aside from these core systems, some minor systems were created to allow for the creation of the puzzles. The implementation runs on a Meta Quest 1 headset. This headset was chosen because it is one of the best standalone headsets on the market, meaning that is does not require a PC to run the application. It also does not rely on external cameras for tracking, making it very easy to set up in a new location.

5.1 Creation Process

The first decision that had to be made was the choice for which game engine would be used for the implementation. Both Unity 3D and Unreal Engine are viable options that offer a lot of features making the process easier and faster. The two core systems and the minor systems would all be possible to implement in either engine.

There were two templates available that could be used as a starting point for this implementation. The first was a VR escape room created for a single player by the author for a previous study. The downside was that this would require a lot of work to adapt to a networked multiplayer project. The other available template was found online, and incorporated both VR and networking features on a detailed level. Both templates were created in Unreal Engine, so the choice for engine was easily made. The external template was chosen, as it seemed that this would require the least amount of additional work.

Unfortunately, this template turned out to contain many bugs that prevented it from working correctly. Ultimately the choice was made to switch to the other template. One core system, VR interaction, was already implemented here, but the networking system still had to be created.

5.2 Gameplay Systems

As mentioned above, there were two core systems implemented. The first is the VR interaction system. This included the ability for a player to move around their head to look around the world, and also see their hands tracked in real time through the controllers. This system is necessary to enable interaction with puzzles. Being able to see other players move their hands also allows for non-verbal communication, which would aid in collaboration. Though less important than verbal communication, it can still be a valuable supporting feature (Shakeri et al., 2017).

Players were able to physically walk around, which was reflected in the game world. In an ideal situation, the player would be able to physically move around in a space that is as large as the virtual area. However, this is rarely ever the case, and so another system is needed. There are two ways this can be done: with smooth movement or teleportation. As smooth movement can often cause VR sickness, a choice was made to include a teleportation system instead (Chang et al., 2020). Pressing a certain button on either controller showed a line exiting from the relevant controller. By pointing this line at the ground and releasing the button, the player was teleported to the location they pointed at.

Figure 3: Two sets of hands and heads representing two other players

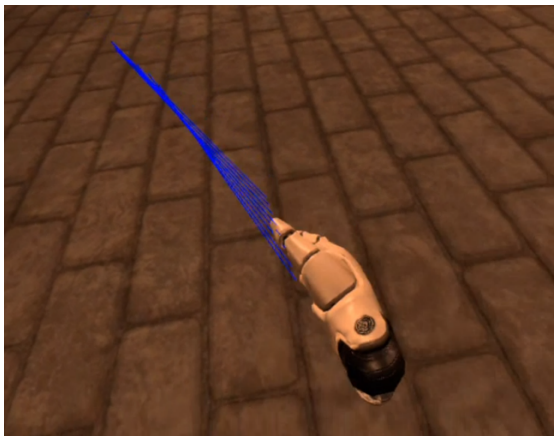

Figure 4: A player aiming a teleport

As one of the outcomes of the focus group, a pinging system was seen as a useful way to support communication between players. Similar to the teleportation system, when the player pressed another button on a controller, a

differently colored line appeared. By aiming this at any object and releasing, a small marker was displayed for five seconds, visible to all players. With this, a player could indicate to others what they were talking about. As a final feature of the VR interaction system, the player was able to interact with different types of objects. They were divided among two types: the first was the button, that simply registered the interaction as a button press and played an animation for the button to resemble it being pressed. The second type is objects that can be picked up. These objects are attached to a hand used to pick it up for as long as the button was pressed by the player. This allowed the players to move objects, which was necessary for some of the puzzles.

Figure 5: A ping placed on the ground by a player

The other core system was the networking system. The basic server setup provided by Unreal Engine was used to accomplish this. The system allowed for the first headset to create a server, that other headsets on a local network would automatically find and join as a client. All interactions by the player that changed the state of the world were executed on the server, and then replicated to each client. This ensures that all players view the exact same world, regardless of who takes which action. This type of network was chosen as it was the easiest to implement, while still offering all necessary functionality.

Aside from these two core systems, there were a few minor systems that were required for the puzzles. These included the ability to check if objects overlap certain other objects, or linking objects to each other. Instead of explaining all these features here, they are better understood by explaining the puzzles that required them.

5.3 Puzzles

The implementation consisted of two main areas. The first area was made up of two rooms, divided by a wall with a window. When the puzzles in both rooms were completed, the group could move on to the next area, where they were all together to solve the final puzzle.

5.3.1 Split rooms

The first rooms each contained three puzzles. One was the same in both rooms, while the others were slightly different. The puzzles could be solved in any order, but all required players to collaborate. The window in between the room was used for the players to be able to see each other, and to give items to the players in the other room.

In both rooms, three cogwheels of different sizes were spread around. In both rooms there were also cogwheels on mounted on the walls, with spaces in between them where the other cogwheels needed to be attached. Each room had three cogwheels, and there spots where they had to be attached. However, both room had one cogwheel of a size that did not fit on their wall. These needed to be traded with the other team through the window. This puzzle is based on a type of *tradeable resource* as described by Wang & Huang (2021), as well a system similar to *information spread* as identified by the focus group and Wang & Huang.

Figure 6: A player attaching a cog to a wall

A second puzzle was the same for both rooms, and based on the *actions in parallel* functionality described by the focus group. Two low pillars with buttons

on top were in each room, that only remained active for a single second. They needed to be active at the same time, meaning that both players would have to stand at a button and press it at the same time.

Figure 7: A player interacting with a button

The final puzzle in the first rooms was solved by inputting the correct digits on some displays. This was solved in an entirely different way for each room. In one of the rooms were three colored displays. Hidden throughout both rooms were numbers of the same colors, indicating the solution. In the other room there was a list of three objects next to the displays, where each list item corresponded to a display. The items on the list were found as objects scattered through both rooms. By counting how many of each item there were, and inputting it in the correct order, the puzzle could be solved. Though these puzzles are different in execution, they both require information from the other room. This is based on the *Information Spread* as described by both the focus group and Wang & Huang (2021).

Each room also contained a door, with three red lights above it. For each solved puzzle, one of these lights would switch to green. When all puzzles were solved, the door disappeared and the players were able to progress to the final area.

5.3.2 Final Area

The final puzzle was based on a maze. It was set in a large empty space, with some ground floors that were colored red. These red floors indicated that players could not walk on them. By pressing a button, some of these floor tiles were colored green, meaning they could be traversed. However, many buttons also disabled other tiles when they were pressed. Players had to split up and press buttons that allowed others to progress. The others could then find buttons that allowed the first player to continue as well. This functionality is based on the *Actions Influence Others* mechanic found by the focus group, as well as

Figure 8: Displays to enter a code, with clues on the table

Indirect Action as identified by Wang & Huang (2021), to some extent. This maze finally lead to a small room that contained a message that the players had successfully completed all puzzles.

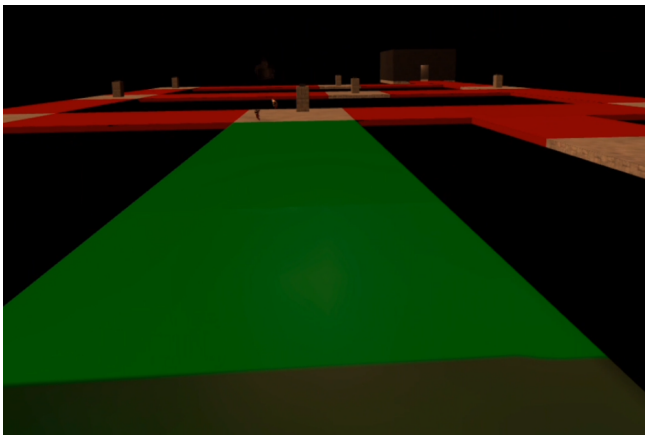

Figure 9: The final puzzle, the first tiles are activated

6 Results

In this chapter the results gathered from the experiment are investigated. There were three groups of participants in total, which will be referred to as groups 1, 2 and 3. In some cases, participants are divided by their level of experience in VR. Table 1 shows an overview of each player, with their prior experience and age and gender. Each four consecutive players in the table formed a group, meaning that players 1 through 4 were part of group 1. Experience is based on both experience with VR and with escape rooms. A high level of experience means that either a player has a high amount of experience with VR and has some experience with escape rooms in general, or the other way around. Low experience means that a participant has no experience in either subject, or some experience in either category.

On average, the experience of each consecutive group increased, which was also reflected in the time it took them to complete the puzzles. The first group took 14:15 minutes, while the second group took 10:07 and the final group only needed 6:33. This is already an indication that more experienced players are able to communicate much better from the start, which will be explained in more detail in this chapter.

Player	Experience Level	Age	Gender
1	High	26	Male
2	Low	23	Female
3	Low	24	Female
4	Low	24	Female
5	Medium	22	Male
6	Medium	26	Male
7	Medium	25	Male
8	Medium	26	Male
9	Medium	28	Male
10	High	24	Male
11	Low	25	Female
12	High	27	Male

Table 1: Experience, age and gender of each player.

6.1 Observation

6.1.1 Group 1

This group consisted of one player with a high level of experience, and three with almost no experience in VR. The more experienced player will be referred to as player 1, while the others will be referred to as player 2, 3 and 4. Players 1 and 2 were in the same room, as were 3 and 4. From the start, all people were able to use the headset and controllers to look around the virtual world.

Players 3 and 4 were soon waving at each other, as well as showing off some dance moves with their hands. Player 1 had no trouble using the controllers to move around, but for the others this was challenging in the beginning. Players 3 and 4 especially struggled with using the controllers to teleport themselves. It was immediately clear to everyone how they could pick up objects. Even though interacting with the different buttons was functionally the same, this was less intuitive for players 2, 3 and 4.

At the start of the escape room, player 3 found the list of items that was the hint for their three-digit code. They understood that they should count the number of each type of object. Player 1 remarked that they had the same objects in their room, upon which all people agreed that they should count the objects in both rooms and add them together. Player 3 then took initiative by calling out each object on the list, and asking the other players how many they could find. Player 4 counted the objects in their room, while player 1 counted the objects in the other room. Player 4 also looked through the window into the other room. Player 3, tried to interact with the buttons to change the displayed number, but was unable to find out the right controls. Player 4 tried to explain it, but after a few seconds took over and put in the code themselves. After finishing the puzzle, players 3 and 4 performed a virtual high five.

Next, players 3 and 4 started working on the cogwheel puzzle in their room. Player 4 picked up a cog and tried to attach it to one of the spots on the wall. Player 3 took a few seconds to figure out the controls, but then managed to do the same. Meanwhile, Player 2 asked them what they needed to count the objects for and if that was finished, to which player 4 gave an affirmative answer. Player 3 managed to attach one of the cogs, but the other two fell on the ground because they were trying to attach them in the wrong place. Player 4 then went to the window and asked players 1 and 2 if they had spare cogwheels. They both answered that they had some cogs, but they also needed those themselves. Returning to the wall, player 4 attached a second cog. Player 3 then gave their remaining cog to player 2, through the window. When talking about the final cog and available spot on their wall, player 4 gestured to the wall to indicate what they were talking about.

In the room with Players 1 and 2, the more experienced Player 1 took the lead. While the people in the other room started working on the cogwheel puzzle, player 2 found out they could press a button that released after a second. Player 1 immediately knew that both buttons had to be pressed at the same time, and instructed player 2 to press their button after a countdown. They then noticed that one of the indicators above their door had turned green.

Afterwards, players 1 and 2 moved to the cogwheel puzzle in their room. Talking about which cog should be attached to which spot on the wall, they tried to solve it together. Both players also used their virtual hands to gesture towards what they were talking about. After some time they had attached three cogs to their wall, but one was not properly attached. When player 3 gave them an extra cog, players 1 and 2 discussed which cog should be replaced. Player 2 indicated a certain cog, upon which player 1 switched the two around. They then returned the final cog to the other room, where player 4 picked it up and

attached it.

The players then all confirmed that both rooms had two green indicators above the doors. Player 4 tried to orchestrate that everyone would press one of the timed buttons at the same time. Players 1 and 2 argued that they had already solved that puzzle for their room, but then went along with the plan. This unlocked the door for players 3 and 4, while the others still needed to solve a puzzle. Players 3 and 4 proceeded with the final puzzle, and they both used their hands to point at specific buttons and indicate them to the other. After some time, player 4 suggested they should help the others.

Meanwhile, players 1 and 2 were trying to find the solution to their colored displays. After some time, player 1 found one of the hidden numbers, and pointed it out to player 2. Immediately, they entered the number in the corresponding display. As the other players returned to their room, player 1 asked them if they had any numbers written on the ceiling. They then proceeded to look for numbers hidden in other places as well. Player 1 found the red number as well, but players 3 and 4 gave up searching after some time. Finally the final number was brute-forced, and the door opened.

As players 3 and 4 had already looked at the final puzzle, they took the initiative here. Player 1 recognized how the puzzle worked quickly as well, directing other people to move towards certain buttons. All players discussed what each button did as they arrived at them, allowing for them to solve the puzzle as a group. Pinging was not used in this segment, but all players used their hands to point at different locations. At the finish, player 3 initiated a virtual high five with everyone again.

Locomotion. Some players tried to move around physically in the space they had, especially those less comfortable with the controls.

Controls. One person had a lot of trouble with understanding the controls, but after some time and with the help of a team member they managed to use them effectively.

Communication. Most of the communication between the players was achieved through verbal communication. At times, all players also made use of their hands for gesturing, to support what they were saying. The pinging system was only used on a few occasions. Some gesturing was used without verbal communication, such as for a high five.

Cooperation. For most of the time, all players were cooperating well by continuously working towards a common goal. However, when one room was finished, the players of that room went on without helping the others finish their room first. At this point some players had different goals, resulting in a lot of time lost for all players.

Coordination. While the one player with more experience assumed a leader role more naturally, other players were able to do so as well when they found the solution to one of the puzzles.

Collaboration. In most cases, collaboration was efficient with one person asking assistance of another, upon which the second player replied immediately. The only exception was when half of the players had moved on while the others

were struggling with the final puzzle in their room.

6.1.2 Group 2

Group 2 consisted of four people with a medium level of experience with VR, but all had a high amount of experience with video games in general. This allowed them to easily grasp the controls and interact with the environment in the way they wanted to. Participants in this group are number 5 through 8, with 5 and 6 being in the same room. Before the official start of the escape room, all players were waving at each other, and interacting with the others' avatars.

When the escape room started, player 6 immediately called to the players in the other room to describe what they saw. Player 6 did the same for their own room.

Aside from this initial interaction, there was not much communication between the rooms at the start of the experiment. In both rooms, the players started working on the cogwheel puzzle. All contributing by trying to place cogs on the wall. There was some verbal communication between the players within each room, to coordinate which cog should go to which location. Player 8 raised their hands as an expression of frustration when the final cog could not be attached.

Deciding that they would return to this puzzle later, players 7 and 8 moved towards the list of objects and the number displays. Together they deduced that they should count the objects. Player 8 started to put in the numbers, until player 7 remarked that they might have to count objects in the other room too.

Meanwhile, player 6 tried to start a conversation with the whole group to figure out the cogwheel puzzle. All players joined in, upon which player 5 suggested they swap the cogs that they could not attach in their own rooms. These cogs were then correctly attached by players 5, 6 and 7.

When player 8 asked the players in the other room about numbers on the wall, they started working on their display puzzle as well. Player 6 quickly found two of the hidden numbers, and player 8 remembered that they had previously found a colored number in their room as well.

To solve the other numbers puzzle, player 7 asked whether the other room contained any objects on the list. Player 6 gave the answer, and this puzzle was quickly solved.

Player 6 noted that they had one red light above their door, upon which player 5 suggested they all press their timed buttons at the same time. No countdown was used, but in both rooms the buttons were pressed at roughly the same time, which opened both doors.

In the final puzzle, the players automatically split up in two teams again, in the same formation as in the previous rooms. Each player contributed in solving this puzzle, communicating to the others when they wanted to know what effect a certain button had, or when they wanted another person to press a certain button.

Locomotion. None of the players in this group moved around a lot physically, instead they all stood still and used the teleport functionality to move.

Controls. All players understood the controls intuitively, except for one player when trying to press one of the timed buttons. There was no trouble with moving around or picking up objects at all.

Communication. Most communication in this group was verbal. Hand gestures were used on occasion, but they did make more use of the pinging mechanic to indicate objects to the other team members.

Cooperation. Due to a lack of communication at the start, players were all working on different puzzles at the same time. This can be seen as cooperation, as they did all have the same goal of solving all puzzles. In the end it was helpful, as each player found the solution to the puzzle they were working on, and immediately asked others for help when needed.

Coordination. As each player figured out the solution to the puzzle they were working on, they easily coordinated one or more others to help them solve the puzzle. One player was trying to coordinate all puzzles as a group effort from the start, but this was mostly ineffective for this group.

Collaboration. In this group, collaboration was mostly efficient. Though not as communicative as the other groups, when the need arose they would quickly ask others for help and efficiently solve a puzzle.

6.1.3 Group 3

The final group consisted of one person with no experience, and three people with high levels experience in VR and/or video games. Similar to the groups before, the players are number 9 through 12, with 9 and 10 being in the same room.

Upon starting the escape room, all players were moving around their respective rooms, describing to each other what they saw and what they expected to be solutions to some of the puzzles. All players were talking over each other, which resulted in them being unable to understand each other in some situations.

Players 9 and 10 started with the cogwheel puzzle, attaching two of the three cogs to their wall. They then surmised that they should swap their cog with one in the other room and tried to get the attention of the other players. Meanwhile, player 11 was looking around their room for clues, and player 12 was looking at the list of objects and counting how many objects there were. They were both communicating about their puzzles to each other, with the result that they did not listen to players 9 and 10.

Giving up on trying to reach the other room, player 10 asked player 9 if they could press a button at the same time as them. Player 12 noticed they had the same buttons in their room, directed player 11 to move towards a button and initiated a countdown. After all players had pressed a button, player 12 placed a ping at the green light above the door to indicate that it had changed.

Players 9 and 10 moved back towards the cogwheel puzzle, discussing they still needed a cog from the other room. Players 11 and 12 tried to solve the numbers puzzle by together counting the objects in their room. When this was

not the correct solution, player 9 remarked that they also had some objects in the other room. All players then worked together to solve this puzzle.

When players 11 and 12 arrived at their cogwheel puzzle, the other players quickly explained how it worked and that they should swap a cog with them. All players efficiently worked together to solve this puzzle, communicating to each other about who should do exactly which action.

For the final numbers puzzle, player 10 asked the players in the other room if they could find any colored numbers. Having already found one, player 12 quickly communicated this. Player 10 then found another, and asked player 9 to put it in. Player 12 stayed in their room to search for more numbers, while player 11 tried to understand the final puzzle.

The final puzzle went very smoothly, even though the players did not communicate much. Each player started pressing buttons that they could reach, almost instantly finding the solution.

Locomotion. All players in this group only used teleportation for locomotion, at times moving slightly in the physical space.

Controls. All players were able to understand the controls, but the one without experience was unable to use them as efficiently as the others and therefore moved slightly slower.

Communication. Even more than group 2, the communication was almost entirely verbal. Some hand gestures were used, and two people made some use of the pinging functionality to communicate as well.

Cooperation. At the start, players did not cooperate much as they were all finding different puzzles. Multiple people were speaking at the same time, resulting in one room not being able to continue. Afterwards, the group managed to focus on one puzzle at a time, with every player being involved.

Coordination. In the first few minutes, there were two people trying to coordinate what the group would do, resulting in chaos. When this was resolved, each player was able to take on a leader role and instruct others to solve a puzzle they had found.

Collaboration. For most puzzles, the players all worked together very efficiently. They discussed each puzzle as it came up, and anyone who knew the solution instantly instructed the others on what to do. All information was shared between all players, which allowed for them to be the most efficient group.

6.1.4 Common Observations

One of the things that was immediately visible was that the amount of prior experience heavily influenced the amount of time players needed to familiarize themselves with the controls. As expected, those with VR experience could easily grasp the way locomotion and interaction worked. Those without experience were able to use the controls to achieve the same things, but their movements were not as fluid. This resulted in them navigating the virtual world more slowly, and sometimes they were a few steps behind others because of this and

could not contribute as much to the collective effort as they otherwise would have. This was especially noticeable in group 3, where one person was sometimes simply following along without being able to contribute as others were solving puzzles while they were still moving towards the puzzle.

Another common observation was that most groups did not have any one person directing the rest of the group, but instead all players were able to contribute roughly equally. Again, this was somewhat influenced by the players' level of experienced. Those with experience in either VR or escape rooms naturally took on a leading role, as they intuitively knew better how to solve the puzzles. This was not always the case however, and all players without experience were also able to contribute to solving many puzzles.

Communication between players was efficient in most cases, but sometimes there was some difficulty in getting the attention of a specific team member. As there was no positional voice chat, players could not identify the origin of a person talking, meaning that they did not know who exactly was speaking. This was especially the case for Group 1, where it would lead to inefficient communication on multiple occasions.

6.2 Questionnaire

Table 2 describes the results gained from the first part of the questionnaire, which is the social presence module of the Game Experience Questionnaire (IJsselsteijn et al., 2013). This section contained a total of 17 questions, each of which contributed to one of three components: *Psychological Involvement - Empathy*, *Psychological Involvement - Negative Feelings*, and *Behavioural Involvement*. The value for each component is calculated as the average value of its associated items. Results are presented as the average of all participants, as well as for each individual group.

Component	Total Average	Group 1	Group 2	Group 3
Empathy	3.9	4.2	3.5	3.9
Negative Feelings	2.4	2.8	1.9	2.4
Behavioural Involvement	3.5	3.5	3.4	3.5

Table 2: GEQ results, scored on a scale of 1-5. Higher scores are better.

As can be seen in the table, Empathy scores high, while Negative Feelings scores low. This means that the average player enjoyed the experience, and to some extent felt a positive connection to the other players. Behavioural Involvement scored slightly above average for each group, indicating that players felt they were influenced by the actions of others, and could influence them in turn.

In table 3, the results of the NASA Task Load Index (NASA-TLX) questions are presented. These were six questions in total, each measuring a single attribute. The TLX measures the work load of a given task. In this case the

task is solving the puzzles of the escape room. As with table 2, the results are presented as the total average and the average of each group.

Attribute	Total Average	Group 1	Group 2	Group 3
Mental Demand	3.1	3.3	2.5	3.5
Physical Demand	2.3	2.8	1.8	2.5
Temporal Demand	3.3	2.3	4.3	3.5
Performance	3.3	3.8	3	3
Effort	3.4	4	2.8	3.5
Frustration	1.4	1.5	1.5	1.3

Table 3: NASA-TLX results, scored on a scale of 1-7. Lower scores are better.

On all attributes, the players gave above average scores. Levels of frustration were very low for all groups, meaning that the observed difficulty some people had with the controls did not significantly result in any frustration while solving the puzzles. Physical demand was also very low, which was expected as the players did not need to physically strain themselves.

The final part of the questionnaire contained statements about the players' ability to work together. This can be seen in table 4.

Statement	Total Average	Group 1	Group 2	Group 3
We were able to work as a team	4.1	4.3	3.5	4.5
Effective collaboration within room	3.9	4.8	3	4
Effective collaboration between rooms	3.9	3.8	3.5	4.5
There was a leader	2.2	2	2.5	2.3
Every person was able to contribute	4.4	4.8	4.3	4.3
It was easy to communicate with the others	4.1	3.8	4.3	4.3

Table 4: Collaboration questions results, scored on a scale of 1-5. Higher scores are better.

These results show that, on average, the players felt they were able to work together to solve the puzzles. The only statement they did not agree with was about the presence of a single person that took leadership. This was also observed, and means that multiple people would take initiative to solve a puzzle.

6.3 Interview

The focus of the interview with each group was to receive feedback on how they felt their collaboration was impacted by the use of VR. Questions included 'Did you feel you could work together in the same way as in real life?', 'Did you behave differently because it was a VR experience?', 'Was there anything you missed here that would be possible in real life?', and 'Did VR make collaboration easier in any way?' With the help of such questions a discussion was started

in which all players could voice how they experienced the experiment. For all groups, the discussion took between 15-20 minutes.

In the first group, multiple people mentioned that they had difficulty knowing what others are doing at any moment. In a physical setting you could simply look over, but in VR this is harder. This is partly the case because only the hands and head are tracked. Another reason is the limited visual fidelity of the headset, making it harder to see details. As a result of knowing less of other players' activities, they reported they had trouble keeping an overview of the escape room as a whole. Interestingly, this was only true for the inexperienced members of the group. The one more experience player reported they even had a better overview than in a physical setting, because they could move around more easily and see what others were doing. In the second and third groups, players responded in a similar fashion, but some also reported that they did not feel either impaired or aided by VR in this way.

Related to this is the comment from multiple players that it was easier to move around the rooms than it would be in real life, and their ability to quickly move from one spot to the next resulted in being able to quickly respond to questions and work on multiple puzzles at the same time.

Some of the people in group 3 mentioned that they felt they could work together less effectively in VR. As part of the reason they argued that they were more involved with themselves, to move around and interact with the puzzles, and had less room available to work together with the others. At certain moments it was hard to get the attention of others, especially those in a different room. As soon as they were all aware of how they should work together, communication was very efficient, and they could collaborate as well as in real life. This issue was only the case for group 3, the other groups did not have as much trouble in this aspect.

When looking at communication, there were two major points of feedback. The first is that some people were hindered by the fact that they could only see each others' heads and hands, resulting in a lack of body language. This limited their ability for non-verbal communication, and as a result changed the way they needed to communicate. Again, this was experienced slightly differently by the more or less experienced players. Those with a lot of experience were less hindered, as they are more used to being limited in this way.

This lack of body language and facial expressions also resulted in people not being as aware of each other as they would have been in real life, which in turn influenced their ability to coordinate their actions. As an example: in group 3 were two people that immediately understood how to solve the final puzzle, and they went ahead to do so. The others were left behind, and just followed along without being able to contribute anything. In real life they would have more easily understood the actions taken by the others, or asked them to explain what they were doing.

The other aspect of communication that was impacted by VR is verbal communication. Because all players were physically close, they could still speak to each other. To some players, this was confusing at first, because the sound did not come from the same direction as the would expect in the virtual space. For

the most inexperienced players, this hindered their ability to effectively communicate. However, for the most players this had a positive impact. By being able to talk to anyone at anytime, regardless of their in-game position, they were able to communicate with people in another room without the need to move towards their position. One other downside of this way of verbal communication was that people could all hear each other, so it was difficult to indicate who you were speaking to. Additionally, There could not be two conversations at the same time, as they would talk over each other.

Some players remarked that there was less communication in this setting when compared to a physical escape room. Normally, they would first create an action plan and have people work on different puzzles. In this case everyone would scatter at the start, each trying to solve a puzzle on their own. Other players argued that in a real-life escape room people usually scatter at first as well, and only when some puzzles and clues are found would they create a plan of action.

The pinging system was deemed helpful by some players, while others barely used it. Usually, the more experience a player had with similar systems, the more they used it. Those who did use it often remarked that it had aided them in communicating with their other team members, making up for the difficulties in communication described above.

7 Discussion

This section will look at the impact VR had on the ability of players to collaborate within an escape room. First, the results from the questionnaire will be compared to studies of physical settings, to determine the level of impact. Afterwards, the interview results will be discussed in more detail, to find the specific features that influenced the participants. Finally, some limitations are discussed that may have impacted the results.

7.1 Experience

The level of experience that a participant had in VR, or in video games in general, had a very large impact in all of the results. A high level of experience allowed a player to instantly know how to use the controls to move around and interact with the world around them. Additionally, experience with video games allowed players to easily talk to others without being able to see their face or being able to tell where a voice is coming from.

In contrast, those with less amounts of experience in both VR and video games had a lot more trouble with understanding the controls. They needed more time at the start to find out how to move and interact, even after having been given some time before the experiment started. Throughout the experiment, these players often still had trouble interacting with certain objects, resulting in them being less efficient when solving puzzles. It also resulted in those players having more trouble communicating with the other players, as they were confused by the discrepancy between the origin of the voice they heard and the location of the corresponding avatar.

These difficulties might be overcome by creating an implementation that is closer to reality. The addition of positional audio with limited range might improve realism, and make it easier for the inexperienced players to use the system. As another example, creating a button that reacts to hand movement instead of requiring the player to press a button on their controller might also make interaction more intuitive.

In real-life escape rooms, the amount of experience a player has also plays a role in how they interact with an escape room (Pan et al., 2017; Chiu, 2022). With more experience comes a deeper understanding of how puzzles work, which leads to higher efficiency in both puzzle-solving and communication.

7.2 Communication

Communication in the experiment can be divided into verbal- and non-verbal communication. When a player wanted to communicate to another player, they used verbal communication in almost all cases, which was sometimes supported by non-verbal communication. Very rarely was non-verbal communication used on its own. In the questionnaire, the participants in groups 2 and 3 indicated that they could communicate with the other players very well, while group 1 gave slightly lower scores on average. This can be explained by the fact that the

players in the first group had less experience with communicating in this way. Nevertheless, they did indicate that they were able to communicate clearly with each other on most occasions.

Verbal communication was audible for every other player, which led to some confusion. However, most players quickly adjusted to the situation and made sure that no two players were talking at the same time. They more clearly indicated who they were talking to as well, to avoid confusion. When the players had gotten used to the method of communication, it even made collaboration easier because they could talk clearly to each other even if their avatars were far apart.

Non-verbal communication was possible through two channels: with hand gestures and with the pinging functionality. It is interesting to note that the more inexperienced players used the most hand gestures, while the most experienced players rarely did. Instead, they more often made use of the pinging system. In most cases, non-verbal communication was used to support verbal communication. For example when two players were talking about a cogwheel puzzle, and one player recommended to the other that they should try to attach a cog at a certain location.

On some occasions, non-verbal communication was used for other means. An example is when a player wanted to find out with whom they were in the same room, they would raise their hands and ask the others who could see the avatar with raised hands. One player in the first group gave people high fives after completing a puzzle as well, imitating real-life behaviour.

These results are similar to those found in a real-life escape room (Pan et al., 2017). In real-life, most players also relied mostly on verbal communication for awareness gathering. They also note that body language was rarely used for communication, as most players were working on different puzzles while they were talking to each other. The same is confirmed by Shakeri et al. (2017). They found that players in a distributed escape room relied mostly on an audio connection, even though there was a video feed available as well.

7.3 Collaboration

In the questionnaire, participants indicated that they felt involved with each other in a positive way. They also indicated that they were able to work together effectively with all other players, both in the same room and in the other room. This was also confirmed in the observation and interview. For most puzzles, people clearly communicated with each other about clues they found, and asked others to take certain actions when they felt this was required.

When one player was stuck, they often asked others for help. Even when they were not asked to do so, players often supported others when they were working on a puzzle. On many occasions, the group was only working on a single puzzle at any time. This means that everyone was working towards the same goal, and on those occasions all players were able to contribute to achieving this goal. At times, both rooms were working on different puzzles, but even then the players in the same room were actively working together to find the solution to

a single puzzle. The only occasion where collaboration was less effective was at the start of the experiment with group 3. While the players in one room needed the help of the other room, the other players were trying to solve another puzzle and did not interact with the players in the first room.

In group 1 the one more experienced player functioned as a leader for most of the puzzles. In group 2, where every player had a similar amount of experience, all players took initiative for different puzzles. Group 3 had one player with less experience than the others, who noticeably took less of a leadership role. This is similar to results found by Pan et al. (2017), where they found that leadership roles often change between players, especially in smaller groups. However, for groups of four or more they found that there is usually one player that takes on the role, and who keeps it for the entire duration. In this study, this was only the case for the first group, that had a single player with much more experience compared to the others.

Similar results were found by Kutzin et al. (2021), who found that there was never a single group leader. Instead, in some groups there was someone that controlled the experience, but was not the actual leader. This means that others were always free to take over when they found a new clue or solution. Additionally, they noted that forced interaction was important for encouraging teamwork. In the present study, results also indicated that this had a positive effect. In groups where players did not previously know each other, they worked more quietly until they were forced to collaborate on a puzzle.

Pan et al. (2017) also describe that their participants often changed between a tight and loose coupling style. A tight coupling style is described as team members closely working together and requiring each other. Similar to this study, the players first often worked in parallel to find the different puzzles. Then, when they required another player, they switched to a tight coupling style to solve a puzzle. Afterwards they would often transition back to a loose coupling style, and work on different aspects again.

Schneider et al. (2002) found that in an online setting people are generally more equally involved. In an offline setting there are usually a few very vocal people that dominate a discussion, while in an online setting all participants can more easily voice their opinions. While Schneider et al. studied communication through a chat room, the same principle might be true in the case of a virtual escape room. The lack of physical presence and body language might make it easier for players to be involved in a discussion.

7.4 Impact of VR

As stated before, the efficiency of collaboration was highly dependant on the participants' level of experience. Even when taking this out of the equation, there are multiple areas where VR has made an impact in how people collaborate. Because all players were physically in the same room, it was easier to communicate with people in another virtual room when compared to a real-life escape room. This did also make it harder to communicate to people in the same room, as one might be interrupted by a conversation in the other virtual

room.

For some people it was easier to have an overview of the different puzzles, because they could move around the room in a much faster way than they would physically be able to do. This also meant that they could more easily assist other players when they called for help.

Some participants noted that the lack of body language and facial expressions gave them the feeling of being somewhat less involved with others, and as a result they focused more on themselves. However, this was not represented in their answers on the questionnaire, and all participants were actively working together for all puzzles.

7.4.1 Comparison to real-life examples

Chiu (2022) looks at the interaction between players in a real-life escape room. For their quantitative analysis, they use the Game Experience Questionnaire, including the social presence module that is also used for this study. The results they found are very similar to the ones found in this study. The feeling of Empathy was scored a 4.2 in the real-life escape room, and 3.9 in the VR setting, a difference of 0.3 on a scale of 1-5. The difference of the Negative Feelings and Behavioural Involvement components are both only 0.1. This would suggest that the involvement players feel with the other players is not impacted by the use of VR when compared to a physical escape room. This is supported by Berkman et al. (2020), who found that the user experience or user performance in puzzle games when comparing different amounts of immersion.

When looking at the second part of the questionnaire, the NASA-TLX, some small differences can be found. In this case the results are compared to those found by Shen & Mazalek (2010). They had built a physical puzzle system where players assembled jigsaw puzzle pieces on an interactive table. Mental Demand was scored similarly in the physical puzzle and the VR escape room. The VR escape room scored better on Physical Demand, Performance and Frustration, and worse on Temporal Demand and Effort. The biggest differences are in Temporal Demand, Performance and Effort.

At least part of this difference can be explained by the fact that one had time constraints while the other did not. This would automatically result in higher Temporal Demands, and when people are under time pressure they might have to put in more effort than they would have had to otherwise. The difference in Performance is less meaningful, as it is more likely due to the difference in tasks than the difference in modalities.

7.5 Player Experience of Social Processes

Some social processes that are discussed in this study, such as the social roles, are not different from real-life escape rooms. People with more experience are still more inclined to take a leader role. However, experience with VR systems now also plays a role. If a player is experienced with escape rooms, but not with

VR, they may have a hard time keeping up with others, resulting in them not taking the leadership role.

This indirectly influences which player is coordinating the group effort, but the process of coordination itself is not changed. A process that is influenced more is communication. To some players, communication is easier because they could always reach any other player. To others, this system was confusing as they did not know where a speaker was located in the virtual world. Communication was also negatively influenced because players could only see limited avatars of each other, lacking facial expressions and with limited body language. This made some players feel detached, while others did not mind.

Cooperation was influenced by some people by the fact that they could move around the room more easily than in real life. This allowed them to have a better overview of what others were doing.

When comparing the results of the questionnaire with similar research of real-life escape rooms, it gains very similar results on both the social module of the Game Experience Questionnaire and the NASA-TLX. This indicates that players are not influenced much by the use of VR compared to a physical setting when looking at the involvement they felt with others or the effort it took to complete the puzzles.

7.6 Limitations

There are a few factors that have played a role in the results as presented in the previous chapter. First of all, there was a relatively low amount of participants. Results gathered from these participants are very valuable as qualitative insights, but with a low sample size it is possible that there is an unintended bias. Additionally, all participants were familiar with the author, and might have reacted more positively to the experiment than strangers would have.

Another factor to take into consideration is the implementation itself. While care was taken in the design of the puzzles and other features, a different implementation might yield very different results. Some of the results are a direct consequence of certain design decisions. For example, some people had trouble communicating effectively because there was no positional audio, or because of the reduced capabilities for non-verbal communication. Both of these features could be implemented, but unfortunately had to be cut from this research due to time constraints.

Finally, this study only looked at collaboration in a VR implementation. While this provides an insight into the effectiveness of VR, it is hard to make a comparison to a physical escape room. To get a better understanding of exactly how VR influences peoples' behaviour in specific situations, a physical escape room with the exact same puzzles would be needed for comparison.

8 Conclusion

This study looked at the impact of VR on social processes in escape rooms. From the results found, it can be surmised that there are indeed certain factors that influence the way people collaborate.

First of all, the magnitude of this impact is heavily influenced by the players' level of experience. While inexperienced players may find certain elements of VR an obstacle to carry out teamwork, more experienced players are more used to the different approach and can see it as a positive effect. This is true for all areas of gameplay that are affected by VR. This effect can be reduced by making the implementation closer to reality.

The first such area is the lack of positional audio. This can be confusing to some, but the fact that it is possible to always communicate with every other player is also sometimes seen as an improvement. A common problem with communication in VR is the lack of body language and facial expressions. Some players also found this to have a negative effect on collaboration, but others were not influenced by it at all.

In VR, it is also harder for some people to have an overview of what others are doing, but this is easier for others. This is related to peoples' ability to effectively use the controls to quickly move around the virtual environment.

A lack of facial expressions and body language had an impact on communication, with players relying more heavily on verbal communication.

According to the results from the questionnaire, even though some players were negatively impacted by the use of VR, they were still able to effectively work together.

To answer the research question: VR does have an impact on communication between players on multiple levels, both positively and negatively. In turn, this influences the way people collaborate with each other. By creating a simulation that is closer to reality, the negative effects can be made much less prevalent.

9 Future Research

This section will look at some suggestions for future work, to expand upon this research. As this study only gathered data from twelve participants, further data would be needed to be able to draw definitive conclusions.

Another large improvement would be the addition of a physical escape room to the study. By including both a physical and a virtual environment, with the same settings, the differences found would almost exclusively be caused by the change in modality. This does also mean that the VR version would need to be as realistic as possible, and the only difference between both versions should be specific features of VR.

As part of this, the VR implementation can be changed in ways to make it more accessible for inexperienced players. By adding positional, limited-range audio, the way people talk to each other would be more natural and therefore easier to understand. Adding full bodies to avatars that are fully simulated might also be an improvement over the avatars with only heads and hands, that are used in this study. These additions would take away most of the negative impact of VR for inexperienced people.

Similarly, adding more natural ways for players to interact with the world might make it easier to understand for inexperienced people. For example, being able to actually press a button with a finger or hand would be more natural than having to press a button on a controller.

Finally, some more additions to the VR environment could be made that make use of features that are only available in a virtual setting. These might help give a VR application an edge that a physical experience could never achieve. However, these features would have to be easily accessible. The current system of pressing a button and aiming the controller to place a ping in the world could be replaced by a system that uses gesture recognition to do this automatically. This way, even more inexperienced players would be able to use it efficiently.

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