Effects of Virtual Reality characteristics on collaboration between learners

Do visualizations of activities have an effect on an individual's situational awareness when collaborating with others inside Virtual Reality?

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A Thesis Submitted to EEMCS Faculty Delft University of Technology,
In Partial Fulfilment of the Requirements
For the Bachelor of Computer Science and Engineering
June 23, 2023

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Final project course: CSE3000 Research Project
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Abstract

Background
This research explores the role of visualization tools in enhancing collaborative learning in virtual reality environments.

Methodology
An experiment was conducted, involving two groups of participants, each tasked with collaboratively solving a complex maze in a virtual reality environment. Both groups experienced two conditions: the experimental condition, where participants had access to visualization tools such as visual cones and highlighting capabilities, and the controlled condition, where these tools were not available. The participants' situational awareness were assessed using both the Situation Awareness Rating Technique questionnaire and the Situational Awareness Linked Indicators Adapted to Novel Tasks framework.

Results
The Situational Awareness Linked Indicators Adapted to Novel Tasks scores were higher for the experimental session for Group 2, while being lower for Group 1. However, the Situation Awareness Rating Technique scores were generally lower in the experimental condition for both groups.

Conclusion
These results demonstrate the potential virtual reality has as a platform for collaborative learning and highlight the need for further research into the design of effective visualization tools and the measurement of situational awareness in virtual reality. Furthermore, this research opens up new possibilities into the design of virtual reality environments for collaborative learning and the potential of virtual reality as a tool for enhancing collaborative learning.

1 Introduction

Virtual Reality (VR) has emerged as a promising tool to enhance collaborative learning, offering unique capabilities that can potentially transform the way individuals communicate and interact. Research indicates that VR can facilitate collaboration and communication among users by enabling the visualizations of interactions between collaborators that are otherwise impossible in the physical world (Zheng, Xie, Liu, 2019; Dobre et al., 2022; Drey et al., 2022). For instance, Klerkx, Verbert, and Duval (2014) demonstrated that users in VR can utilize virtual tools to highlight and identify objects, thereby fostering communication and discussion.

By investigating the intersection of VR and collaborative learning, insights can be gained into the efficacy of VR as a tool for collaborative learning. This study aims to examine whether the visualizations of actions and activities in VR, which would be obscured in real-world settings, can enhance an individual's situational awareness and potentially foster co-construction of knowledge, thus enhancing collaborative learning.

Previous research in this area has yielded promising results. For instance, Drey et al. (2022) found that pair learning in VR significantly increased presence, immersion, and experience while reducing intrinsic load, factors that are crucial for effective learning. However, gaps remain in our understanding of the relationship between VR and collaborative learning. Specifically, the impact of VR on situational awareness and its subsequent effects on collaborative learning have not been extensively explored.

Therefore, this study seeks to contribute to the research on VR and collaborative learning, with a particular focus on the role of VR in enhancing situational awareness and its implications for collaborative learning. This has been done by answering the research question: "Do visualizations of activities have an effect on an individual's situational awareness when collaborating with others inside Virtual Reality?"

2 Methods

The primary objective of this research was to investigate whether visualizations of activities in a VR environment enhances aspects of collaborative learning outcomes. To answer this question, an experiment was designed, where participants were required to solve a maze in VR that would otherwise be unsolvable without collaboration and communication (Van der Meer et al., 2023). The independent variable was the visualization of activities, and the dependent variable was an individuals' situational awareness. The experimental group had access to visual cones and the ability to highlight specific sections of the maze during collaborative problem-solving, while the control group did not have these visualization tools. This setup allowed us to investigate the impact of visualization on aspects of collaborative learning outcomes. The visual below illustrates the difference between the control and experimental group and how the visualization of activities is actually done:

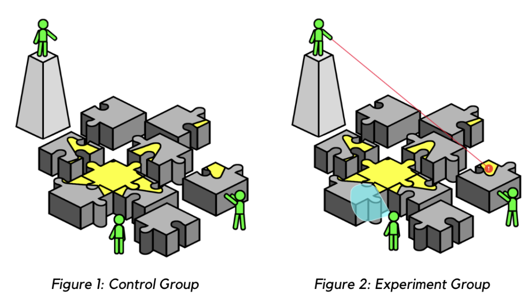

Figure 1: Difference between Control and Experimental groups

Following this introduction, the methodology section will detail the experimental setup, data collection and analysis methods, research tools used, and the collaborative approach within our research group.

2.1 Experimental Setup

The experiment was designed as a collaborative maze-solving task in a VR environment using HTC Vive headsets and controllers. The VR setup provided a space of approximately 3 square meters per participant, with positional tracking. Participants were placed in the same area with sufficient distance in between them to prevent collision, thus allowing communication to occur verbally. Movement within the VR environment was facilitated through a point-and-click mechanism.

Participants were divided into two groups, each consisting of three individuals who were strangers to one another. The participants were required to have a basic understanding of English, not be colorblind, and not be prone to motion sickness or claustrophobia. They were also required to communicate with others in English.

The task involved trying to exit a VR maze within a 30-minute time limit. The maze was specifically designed to be unsolvable without collaborative efforts. Progression within the maze required codes, and the maze structure limited the participants' view, necessitating collaboration and communication among participants for successful completion.

Below is a quick overview of the whole experiment process:

1. Participants arrive, set-up
2. Informed Consent, explanation of experiment
3. Tutorial in VR
4. Maze session (1)
5. Short break + SART questionnaire filled by participants
6. Continue maze session
7. Ending

Each group experienced two conditions: the controlled condition, where participants were deprived of visualization tools including visual cones and highlighting, and the experimental condition, where these tools were available. The visualization tools allowed participants in the experimental condition to observe the gaze direction of their peers and to highlight specific sections of the maze during collaborative problem-solving.

After a one-week interval, the conditions were swapped between the groups. This counterbalancing approach was designed to ensure that all participants experienced both conditions, thereby enhancing the validity of the findings.

2.2 Data Collection

The data collection process took place during the collaborative maze-solving task. Listed below are all the data collected for the experiment:

1. The point-of-view of participants inside VR have been recorded via screen recording software OBS. This was done to aid the transcription process, where the screen recordings would allow for the audio recordings to be put into context.
2. Dialogue between participants have be recorded, which have been used in the transcription process of each participant.
3. SART Questionnaire filled by participants, which was used to calculate their situational awareness, explained further below.

AI tools were used to efficiently transcribe every verbal interaction between participants, ensuring a comprehensive collection of data. During the short break, participants were administered the Situation Awareness Rating Technique (SART) questionnaire. This questionnaire consists of 10 items, with responses measured on a scale ranging from 1 (low) to 7 (high). The SART questionnaire was designed to assess participants' subjective evaluation of their situational awareness during the maze-solving process (Selcon, S.J. Taylor, R.M. (1989)).

2.3 Data Analysis

The collected data was analyzed to determine the effect of visualization on collaborative learning outcomes. The SART questionnaire and a framework called SALIANT (Situational Awareness Linked Indicators Adapted to Novel Tasks) was used to assess situational awareness. The objective of SALIANT is to provide a theoretically-based method for assessing situational awareness (Muniz et al., 1998). This is done by using a checklist consisting of 5 categories, each having their own subcategories in which binary grading is done for each subcategory. The 5 categories include:

1. Demonstrated Awareness of Surrounding Environment
2. Recognized Problems
3. Anticipated a Need for Action
4. Demonstrated Knowledge of Tasks
5. Demonstrated Awareness of Information

Below is a quick overview of the whole process of SALIANT grading:

1. Coders independently segment the dialogue transcripts based on topic changes.
2. After calculating inter-rater reliability, coders discuss and agree on the final segmentation.
3. The segmented transcript is scanned for instances of four predefined scenarios, each instance is counted. A fifth scenario, "Not Applicable (N.A.)", is used when none of the four scenarios apply.
4. Each segment is then evaluated against the five categories mentioned above classes (with sub-categories). Each participant's contribution to a segment is graded as either acceptable or incorrect. If a participant's contribution doesn't apply to a specific class, it's marked as incorrect.
5. For each scenario instance, participants are individually graded using the scheme; they either score a 0 (only

incorrect responses) or a 1 (one or more acceptable responses).

6. Each participant's final score is divided by the total number of scenario instances, producing a final Situational Awareness score for each participant.

The SART questionnaire captured participants' subjective evaluations of their awareness levels, while the SALIANT framework offered an objective analysis of situational awareness indicators based on the content and dynamics of their collaborative conversations while trying to solve the maze. The use of the SART questionnaire and the SALIANT framework in tandem provided a robust and multi-dimensional assessment of individuals' situational awareness.

Given the small sample size of our study, focusing on providing descriptive results and engaging in detailed discussions based on those results was found to be more appropriate, rather than conducting extensive statistical analyses. This approach allowed us to delve deeper into the nuances of our data and draw meaningful insights, which might have been overlooked in a purely statistical analysis. Furthermore, statistical tests are most effective and reliable when applied to larger sample sizes. With a small sample size, the power of statistical tests to detect true effects is reduced, and the likelihood of obtaining false-positive or false-negative results is increased.

Additionally, our research was exploratory in nature, aiming to investigate a relatively unexplored area of study. In such contexts, qualitative analysis and descriptive statistics can often provide more meaningful insights than complex statistical tests. Thus, our analysis focused on interpreting the data in the context of our research question and drawing insights that can contribute to the broader understanding of collaborative learning in VR environments.

3 Responsible Research

In conducting this research, we upheld the highest standards of ethical and responsible research practices. Our research methodology was designed to ensure the protection of participant rights, the integrity of data collection and analysis, and the overall credibility of our findings.

Participant Rights and Consent

All participants were informed about the purpose of the study, the nature of the tasks they were asked to perform, and the data that was collected. This was done in 2 ways: by sending interested participants an email that informed them of our experiment and via an informed consent form that they signed before beginning the experiment. They were assured of their right to withdraw from the study at any time without penalty. Informed consent was obtained from all participants prior to their involvement in the study.

Privacy and Confidentiality

The privacy and confidentiality of all participants was insured. Any data collected, including transcriptions of verbal interactions, was anonymized to protect participant identities. This was done via giving ID's to participants instead of using their names and by giving them color codes. Personal information was not disclosed without explicit consent from the participants.

Data Integrity

Rigorous data collection and analysis procedures were adhered to to ensure the integrity of our findings. The use of AI tools for transcription and the SALIANT framework for analyzing situational awareness helped ensure objectivity and accuracy in our data analysis. To further ensure objectivity, common grounds among team members were discussed when grading each participants Situational Awareness score to obtain unbiased results.

Risk Mitigation

Given the VR nature of the experiment, steps were taken to minimize potential risks to participants, such as motion sickness or disorientation. Initially, a survey was sent to each potential participant, asking questions such as whether they easily got motion sick to prevent any discomfort for participants. Furthermore, participants were briefed on how to use the VR equipment safely, and breaks were provided as needed to prevent fatigue or discomfort.

Collaboration and Fairness

Within our research team, tasks were allocated equitably, and all contributions were acknowledged in any resulting publications. A collaborative environment was fostered, that respected diverse perspectives and promoted open communication.

Transparency and Reproducibility

We committed to transparency in our research process. Our methodology was clearly described to allow for the reproducibility of our study. We were open to critique and willing to address any questions or concerns raised by other researchers or stakeholders.

To summarize, our commitment to responsible research practices supported every aspect of our study. We believe that this commitment ensured the ethical conduct of our research and also also enhanced the validity and reliability of our findings, contributing to the advancement of knowledge in the field of virtual reality and collaborative learning.

4 Results

This section presents the results of the experiment, including the SART and SALIANT scores of the participants in both groups.

4.1 SART Scores

Figure 2 below illustrates the SART Scores for Group 1:

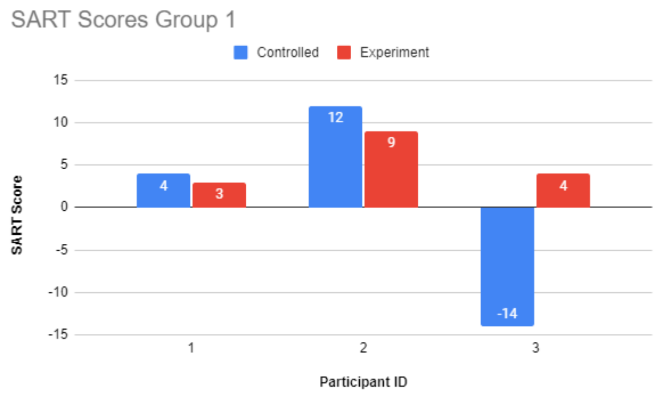

Figure 2: SART Scores for Group 1

The SART scores for Group 1 participants in the controlled condition ranged from -14 to 12, with an average of 0.67. In the experimental condition, the scores ranged from 3 to 9, with an average of 5.33. Participant 1's score decreased from 4 in the controlled condition to 3 in the experimental condition. Participant 2's score also decreased from 12 in the controlled condition to 9 in the experimental condition. Interestingly, Participant 3's score increased from -14 in the controlled condition to 4 in the experimental condition.

Figure 3 below illustrates the SART scores for Group 2:

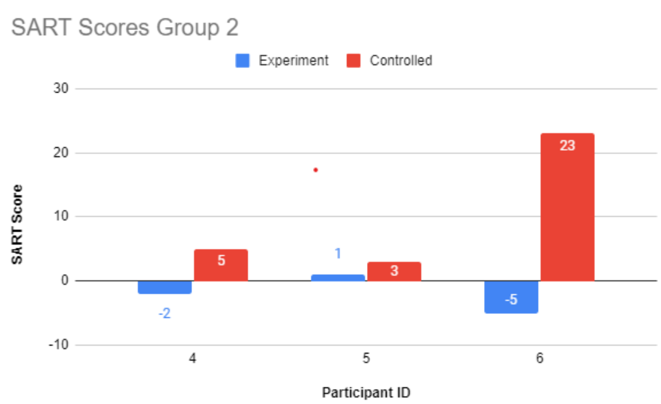

Figure 3: SART Scores for Group 2

For Group 2, the SART scores in the experimental condition ranged from -5 to 1, with an average of -2. In the controlled condition, the scores ranged from 3 to 23, with an average of 10.33. Participant 4's score increased from -2 in the experimental condition to 5 in the controlled condition. Participant 5's score also increased from 1 in the experimental condition to 3 in the controlled condition. Moreover, Participant 6's score increased significantly from -5 in the experimental condition to 23 in the controlled condition.

4.2 SALIANT Scores

Figure 4 below illustrates the SALIANT scores for Group 1:

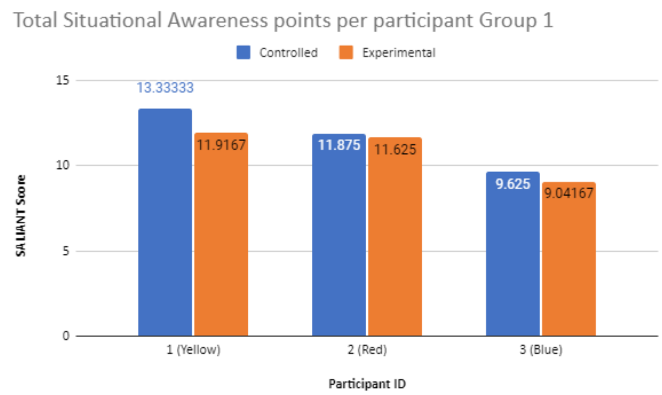

Figure 4: SALIANT Scores for Group 1

The SALIANT scores for Group 1 participants in the controlled condition ranged from 9.625 to 13.333, with an average of 11.611. In the experimental condition, the scores ranged from 9.042 to 11.917, with an average of 10.861. All participants' scores decreased in the experimental condition compared to the controlled condition.

Figure 5 below illustrates the SALIANT scores for Group 2:

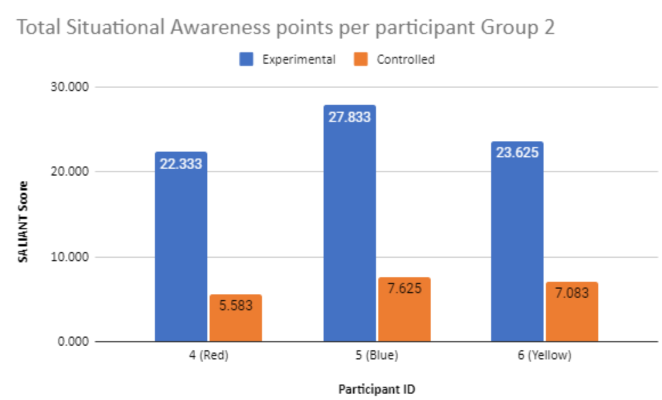

Figure 5: SALIANT Scores for Group 2

For Group 2, the SALIANT scores in the experimental condition ranged from 22.333 to 27.833, with an average of 24.597. In the controlled condition, the scores ranged from 5.583 to 7.625, with an average of 6.764. All participants' scores decreased in the controlled condition compared to the experimental condition.

To summarize, the SART scores showed that the majority of the participants had higher situational awareness in the controlled session compared to the experimental session. However, the SALIANT scores are lower in the experimental condition for all participants in Group 1, while being higher for participants in Group 2.

5 Discussion

The data collected from the Situation Awareness Rating Technique (SART) and the Situational Awareness Linked Indicators Adapted to Novel Tasks (SALIANT) framework present a picture of how visualization affects individuals' situational awareness and, consequently, their collaborative learning outcomes.

The SART scores present a general trend of lower scores in the experimental condition compared to the controlled condition. This suggests that the presence of visualization tools such as visual cones and highlighting capabilities may not necessarily enhance situational awareness as measured by the SART questionnaire. However, it is important to note that the SART scores are subjective evaluations of situational awareness and may not fully capture the complexity of the construct.

On the other hand, the SALIANT scores present a different perspective. In Group 1, the scores were slightly lower in the experimental condition compared to the controlled condition, mirroring the trend observed in the SART scores. However, in Group 2, the SALIANT scores were significantly higher in the experimental condition. This suggests that the visualization tools may have facilitated more effective communication and information exchange, leading to enhanced situational awareness as captured by the SALIANT framework.

The discrepancy between the SART and SALIANT scores highlights the multifaceted nature of situational awareness and the challenges of measuring it accurately. While the SART questionnaire provides a subjective measure of situational awareness, the SALIANT framework offers an objective analysis based on observable indicators. The combination of these two measures allows for a more comprehensive assessment of situational awareness in collaborative learning in VR.

It is also worth noting the variation in scores within each group and condition. An example to this would be the relatively high SALIANT Scores for group 2, compared to group 1. This suggests that individual differences may play a role in how participants interact with the VR environment and utilize the visualization tools. Future research could explore these individual differences in more detail to further our understanding of collaborative learning in VR. However, this can also be a mere grading bias on our end, as each experimental and controlled transcript has been graded by different peers in our group. Although inter-rater reliability has been conducted on our end before the grading process, the subjectivity of the grading scheme can result in each individual grading participants differently, leading to varied results.

In conclusion, our findings suggest that visualization tools can potentially enhance collaborative learning in VR by improving situational awareness, as indicated by the SALIANT scores. However, the impact of these tools may not be immediately apparent to the users themselves, as suggested by the SART scores. These findings underscore the complexity of collaborative learning in VR and the need for further research in this area.

6 Conclusions and Future Work

This research aimed to investigate the impact of visualization tools on collaborative learning in VR environments. Specifically, we sought to understand whether the use of visual cones and highlighting capabilities could enhance individuals' situational awareness and, consequently, improve collaborative learning outcomes.

Our findings suggest that visualization tools can potentially enhance situational awareness, as indicated by the Situational Awareness Linked Indicators Adapted to Novel Tasks (SALIANT) scores. However, the subjective evaluations of situational awareness, as measured by the Situation Awareness Rating Technique (SART) questionnaire, were generally lower in the experimental condition where visualization tools were used. This discrepancy highlights the complexity of measuring situational awareness and the potential gap between subjective perceptions and objective indicators of situational awareness.

The main contribution of this research is the empirical evidence it provides on the role of visualization tools in collaborative learning in VR. Our findings underscore the potential of VR as a platform for collaborative learning and the importance of designing effective visualization tools to enhance situational awareness.

However, several open issues and potential improvements emerge from this work. The variation in scores within each group and condition suggests that individual differences may play a role in how participants interact with the VR environment and utilize the visualization tools. Future research could explore these individual differences in more detail to further our understanding of collaborative learning in VR.

Additionally, the discrepancy between the SART and SALIANT scores raises questions about the most effective ways to measure situational awareness in VR. Future research could explore other measures of situational awareness and investigate how they correlate with collaborative learning outcomes.

In conclusion, this research explores the design of VR environments for collaborative learning. By continuing to explore these questions, we can harness the full potential of VR as a tool for enhancing collaborative learning.

7 References

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Figure 1. Difference between Control and Experimental group. Source: Van Der Meer (2021). Puzzle_NoVisualization_1257x1257_res300.

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