# The influence of co-construction and collaborative problem solving in a collaborative team task

Cristina-Ioana Atanasiu-Raileanu

Department of Psychology, University of Twente

Specialisation: Psychology in the Workplace

First Supervisor: Amber van Kampen

Second Supervisor: Marcella Hoogeboom-Hendriksen

Date: 03-07-2025

Wordcount: 9500

**Abstract**

*Introduction:* Working in teams has been a central part of how organizations organize activities, that is seen even more often in the 21st century. Working in teams is also powerful for learning as it can facilitate and stimulate a multitude of behaviours, such as collaborative problem solving. To have an effective team learning process, it is necessary to have an environment where communication between members in which behaviours such as co-construction are present. The goal of this study is to observe how actual collaborative problem solving and co-construction evolve over time in a collaborative team task.

*Methods:* Data was collected from 16 participants that were part of four teams consisting of three or five participants. All teams participated in a collaborative task where they had to rank items based on the survival probability in an imagined scenario where they had to visualise themselves lost at sea and trying to reach the shore, first individually, then in a team. They were given a list of items that were saved from the boat, and the task was to rank these items based on how it would help them survive. At the end, their ranking was compared to the one done by the coast guards. Throughout this task, the participants were video recorded. In addition, participants were required to complete a questionnaire, to collect demographic information.

*Results:* The ranking results showed that only two teams survived and 7 out of 16 participants survived individually. The timelines of the video-coded co-construction and CPS behaviours that were made showed that in the two teams that did survive the task there was almost a pattern between the behaviour's idea development and idea explanation. Moreover, behaviours such as off-topic conversation and loss in detail and repetition seem to be necessary for achieving a good result as they balance out the conversation between participants.

*Conclusion:* The current study highlights the importance of observing how co-construction and collaborative problem solving appear in a collaborative team task. The results emphasize the necessity of teams to continually build on each other's knowledge and share their solutions as they are increasing their chances of arriving at an optimal solution. Further research is needed to delve deeper into this subject on a bigger, more varied sample size.

# Introduction

## Teamwork

Working in teams has been one of the central focuses of how organizations organize activities. During the 21st century new light was shed on the importance of having projects with teams working together to reach the objectives of these projects and tasks, as this is the answer to the challenges faced currently. Some examples of these challenges are increased number of responsibilities and greater task complexity (Harvey et al., 2023). These challenges came to light as the problems faced at work are growing in complexity, requiring the expertise of multiple disciplines in order to solve them (Wiltshire et al., 2017). Organizations responded by having more employees working on certain tasks or project in team-structures (Wiltshire et al., 2017).

The formation of teams is done by humans to successfully solve tasks that they are unable to complete on their own (Smith, 1994). By joining their powers, they will be capable of overcoming problems that could not be solved individually. Moreover, it is a further step as each member will bring their own knowledge to form something new, which creates a group knowledge that can achieve the solution to higher level tasks (Carletti et al., 2020). Furthermore, group thinking can be named collective intelligence (CI) which is a measure that follows the advantage of being in a team in comparison to individual members. It can be defined as "the property of a social structure that originates when individuals interact and result in the acquisition of the ability to solve new or more complex problems" (Szuba, 2001). CI has since gained a lot of attention, and it has been explained as a common factor that can explain the performance of a group on a multitude of tasks (Woolley et al., 2010). Moreover, people tend to

reach towards forming groups when they have to resolve a complex problem as they believe that groups succeed at problem solving skills compared to a single person (Forsyth, 2018).

Hence, there are various benefits to having people working in teams, such as facilitating learning, gaining a deeper understanding of the topic at hand, promoting a sense of agency by observing the real-life solutions that result from collaborative work on interesting topics and practice of constructive dialogue (Barron, 2000). Over time, the importance of certain benefits were especially highlighted, such as collaborative problem-solving (CPS) (Chiriac, 2014). CPS is defined as "a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution" (OECD, 2017, p.136). Moreover, it is important to understand that there are also challenges for teams in this process of CPS, such as unequal participation and rising conflicts (Chiriac, 2014). In order to combat these problems, it is important to choose tasks that are best-suited for a team, such as tasks that are complex and vague, that can have a multitude of possible solutions. By contrast, simple tasks that focus on recall, definitions or finding information are better suited for individual work (Wilson, Brickman & Brame, 2018).

**Collaborative problem solving**

CPS was discovered to be an essential skill for teams in multiple fields, such as at home, in the workforce and in communities (Graesser et al., 2018). Moreover, it is composed of two parts, the first component consists of cognitive skills, and the second one of social skills (Graesser et al., 2018). The cognitive component refers to the members of the team who must be able to name the problem, understand which person knows what is on the team, be able to locate gaps between what is known and what is required, integrate all of these steps into generating a solution and, finally, keep track of the progress of the team goals (Graesser et al., 2018). A factor that has been shown to intensify CPS of teams in the cognitive domain is transactive memory system (Wegner, 1987). Transactive memory refers to the shared division of cognitive labor, most especially the encoding, storage, retrieval, and communication of information from different domains. It allows team members to depend on each other's specialised knowledge without knowing all of the information themselves (Wegner, 1987). A study by Lewis (2004) took a closer look into the relationship between CPS and transactive memory by trying to understand how the development of transactive memory systems within teams influences their performance over time. The teams in his study completed a complex decision-making simulation

for a fictional company. The conclusions showed that over a longer period of time, the teams that developed a more robust transactive memory system, exhibited noticeable higher performance on complex tasks. Transactive memory system fosters effective CPS by allowing a better allocation of expertise and efficiency in collaborative reasoning (Lewis, 2004). Furthermore, past studies have shown that this form of memory can lead to improved efficiency and effectiveness (Brandon & Hollingshead, 2004).

The social component focuses on understanding, actions shared between members and coordinated behaviour towards finding solutions (Graesser et al., 2018). It is of necessity that the team manages to achieve these points, because the successful collaboration can be at risk through a social loafer, or an uncooperative and unskilled member. At the same time it can be facilitated by a strong member who highlights different points of view, helps in negotiating the conflicts, assigns roles, promotes communication in the team and guides the team to overcome obstacles (Fiore, Rossen et al., 2010; Letsky, Warner, Fiore,& Smith, 2008; Salas, Cooke, & Rosen, 2008).

CPS includes then the members ability to construct on each other's knowledge through transactive memory, which can lead to combining the knowledge. This means that transactive memory, which includes alternating between sharing new ideas and building on other members' ideas, is a necessary mechanism that CPS promotes which also fosters co-construction through the knowledge it shares (Vogel et al., 2023). A study by Zhou et al. (2022) looked deeper into understanding CPS by investigating the similarities and differences of a team's verbal behaviours, such as asking clarification, providing reasons and offering suggestions, develop temporally during a collaborative physics game. The study focused on college students playing a physics-based learning game through Zoom. The conclusions showed that temporal sequencing, and not just frequency of CPS behaviours differentiate high-quality collaboration from lower effectiveness. The study then highlights that CPS is highly researched in relation to video-based coding, especially in the video game area. However, this concept in team performance lacks research.

**Co-construction**

Effective team learning needs an intended space where communication between team members can occur, in which behaviours such as sharing and co-construction can exist in symmetry; A model formed by Decuyper et al. (2010) shows this need by defining a team's learning process. According to this model, the three basic team learning processes are shared

within the team. This concept is defined as sharing opinions, creative thoughts and knowledge to other members, who had no understanding that they were present in the team before (Decuyper et al., 2010). According to this article, two types of conversational actions appear from sharing, depending on how the team acts: co-construction and constructive conflict. Co-construction can be defined as "the mutual process of developing shared knowledge and building shared meaning by refining, building on, or modifying an original offer in some way… leading to shared knowledge and new meaning that was not previously available to the team" (Decuyper et al., 2010, p.116). Sharing is a necessary pillar for co-construction to happen. Moreover, members of the team take the interaction even further as they participate in repeated cycles of acknowledging, repeating, paraphrasing, questioning, concretizing, enunciating, and forming a shared knowledge, opinion, creative thoughts or competencies (Decuyper et al., 2010). On the other hand, learners are not always able to gain high levels of critical thinking, argumentation or even knowledge. Furthermore, collaboration between teams can be disrupted by socioemotional challenges, such as setting aside other's ideas and their expertise (Naykki et al., 2014). Moreover, even though collaborative learning in teams can be successful, including negotiation and co-construction of knowledge, there are studies in school which have shown that genuine collaboration happens very rarely (Lehtinen et al., 2023). A study named ORACLE looked into this by observing primary schools in their everyday activities in United Kingdom. They found that just because several students were seated together at a table, that did not mean that they were collaborating as well. The students would talk as they would work, and they could possibly talk to each other about their work but the activities that they performed did not encourage them to talk and work as a group (Mercer & Howe, 2012). There seem to be a common problem in schools where the students are working in groups but rarely as groups (Alexander, 2005). Therefore, it is necessary that members are drawn towards collaborating in achieving a great result.

**Connection between co-construction and collaborative problem solving**

Collaborative problem solving is also used to attract learners in collaborative processes which are necessary for gaining knowledge and skills. In this way, learners co-construct their understanding by using transactive memory as a bridge between each other's contributions (Vogel et al., 2023). The aim of collaborative problem solving is to engage learners in discussions and knowledge co-construction. Exchanging and exploring each other's ideas,

arguments, and even reasoning towards certain solutions to a problem is a necessary step towards co-construction of knowledge (Vogel et al., 2023). A study by Rejon et al., (2023) investigated this connection even further by comparing different types of sentence starters, such as novelty and reference. The results showed the sentence starters indicating reference were connected with more engagement in social activities, predicting then that co-construction of knowledge is facilitated in the collaborative learning process. Therefore, co-construction and collaborative problem solving can be connected by building up on each other's characteristics, namely sharing knowledge and finding a solution. The AIFI System which was discovered in a study by Endrejat et al. (2019) comes as an addition by focusing on a group flow and inertia momentum categories. Namely, the researcher used the group flow category as indicating a team's movement towards generating new ideas. This is connected to co-construction as it is building upon each participant's ideas and sharing knowledge into a new meaning that was not accessible to the participants before (Decuyper et al., 2010). The other category, inertia momentum, shows when team members are moving away from generating new ideas. This is related to CPS as the groups having more moments of not focusing on generating new ideas are expected to achieve better solutions (Endrejat er al., 2019).

**Current study**

Previous studies have showcased the impact of collaborative problem solving. For example, a study by Zhou et al., (2022) focused on discovering temporal relationships between collaborative behaviours, i.e., information sharing, clarification request, providing reasoning and such, in successful versus unsuccessful group problem solving attempts. The successful teams had a clear sequence that they followed, participants asked questions to clarify their understanding and others offered logical explanations. Then, the team after establishing the reasoning, proposed new ideas. When the proposals were made in a team it often led to acceptance and coordination action, indicating team alignment. In the end, positive reinforcement maintained the collaboration. In the unsuccessful teams a different sequence can be observed. The team would start with unrelated talk, then quickly offer ideas that are not fully developed. When questions would be asked, they were either ignored or not answered correctly, leading to confusion. Proposed ideas were frequently challenged without offering the necessary follow-up. Moreover, it was observed that the participants would talk over each other or silent stretches which suggest no coherent team management. Moreover, another study by Brundage,

Malespina, & Singh (2023), focused on the impact of co-construction by showcasing the high influence of co-construction in discussions with other teammates through exemplifying that pairs of students commonly solve the problems correctly even when no one knew the answer initially. They analysed this concept based on pre/post response patterns for each group. When no individual had the correct answer in the pre-test, but the group produced a correct answer in the task it suggested that the results was reached in the dialogue through collaboration. The research assumed that the change in answer came from peer explanation, justification and critique and collaborative reasoning. The study found that co-construction was seen variably in the study, it was often seen only when around half of the participants knew the correct answer individually. At the same time, unguided peer collaboration yield better results even when no participant was correct individually. However, still, little literature has focused on the combination of collaborative problem solving and co-construction. This current study aims to further increase understanding of this concept, by looking at the development of team learning during a collaborative team task and observing the influence of co-construction and collaborative problem solving. More specifically, the influence of co-construction and collaborative problem solving in a collaborative team task is studied, where the activity is video recorded and the material will be coded moment by moment. Therefore, the research question is: *"How does co-construction and collaborative problem solving occur in a collaborative team task?"*.

## Methods

This study employed a mixed method study, with quantitative data collected through the ranking values and qualitative data based on the questionnaire questions, to observe the learning behaviours displayed during collaborative team tasks in teams. Participants are assigned to a team in a convenience sample method, in order to form a total of four teams consisting of five or three participants (n=16).

### Participants and procedure

The sample of the study consists of 16 adults (75% female, 18.75% male and 6.25% non-binary), ages starting from 18 and older ($M$=22.12, $SD$= 1.78). The selection of participants had the following selection criteria: being 18 or older and speaking English. Participants were recruited in two ways. Firstly, participants could sign up for the study through the SONA-platform of the University of Twente. In this case, participants were assigned SONA credits after

they had attended the study. Furthermore, to gather as many participants as possible, participants were also personally recruited through platforms such as WhatsApp. These participants were not rewarded with the SONA points in this case. The study was conducted in accordance with the Ethical Committee of the University of Twente, with the ethical approval number: 250302.

**Intervention**

For this research, the participants were informed that they will be video recorded throughout the experiment. Before diving in the activity, each participant signed up the consent form and completed a short questionnaire focusing on their demographics (Appendix A). Participants in the teams had to attend an hour long study in a one time session. The researcher informed them of the questionnaire and the activity that they had to perform. After completion of the survey, participants moved on to the collaborative task, known as the Lost at Sea task (Nemiroff & Rasmore, 1975). The Lost at Sea task is described the following way: you are imagining you are adrift on a private yacht in the South Pacific, a fire of unknown causes affecting the yacht and its contents. The yacht is now slowly sinking, you are unsure of your location and the crew is trying to bring the fire under control. You are given a list of fifteen items that survived the damage and a serviceable, rubber life raft with oars large enough to carry yourself, the crew and all of the items listed. In the survivor's pockets you find several packets of cigarettes, several books of matches and five one-dollar bills. The task is to rank the fifteen items in terms of their importance to your survival. The first part of the task consists in ranking the items individually, where the participants were offered 10 minutes to make their choices and the second part is ranking the items together as a team, for this part the participants were given 20 minutes to complete. In the end, you will observe the difference in scores between the individual and team ranking. Based on the score, you will find out if you survived or not (Nemiroff & Rasmore, 1975). This scenario was chosen as it is realistic for the participants to imagine themselves in and it creates an environment where participants must constantly communicate and engage in shared decision-making. Moreover, it offers the opportunity for the participants to promote and justify their choices while reaching a common solution (Nemiroff & Rasmore, 1975).

Throughout the ranking process, the participants also had a column available, where they were required to explain why they chose each item to be ranked this way. This could help them promote their own ideas and reasoning in the team part of the task. The whole session was video

recorded. Furthermore, each participant was fitted with a heart monitor. The data of the heart monitor was collected to be used in a different study and was therefore not analysed in this research.

## Measures

### *Background and study characteristics*

Participants provided information regarding their age and gender, as well as their nationality and their relationship with the other participants. For the assessment of gender, the provided options were: a) Female, b) Male, c) Other:...., d) Not willing to mention. Additionally, for the nationality assessment the offered options were: a) African, b) Asian, c) European, d) North American, e) South American, f) Oceania/Pacific Islander and g) Middle Eastern. For the assessment of relationships between participants in one single session, they were asked to answer how many participants they know and to indicate if they are: a best friend, friend or acquaintance. Moreover, another question referred to if the participants participated in a similar study, where they were asked to answer with yes or no.

### *Video recording*

The participants were video recorded throughout the experiment using a GoPro camera. The teams formed of three to five participants were recorded from the beginning of activity, namely the questionnaire, until the end, the team ranking. The videos were coded in the Noldus Observer XT software. The code book used for the coding of the videos is based on the AIFI system (Endrejat et al., 2019), which can be seen in Appendix B. This system was used as a tool in better understanding how co-construction and CPS occur in a collaborative team task. Namely, the behaviours that are presented in the AIFI system, such as Idea Exploration, Idea Development and such are necessary when understanding the concepts, as they provide a base between participants to understand the contribution of each participant, observe the gaps in knowledge and trying to reach a common conclusion reaching in the end a new meaning. The system was created to observe critical moments of learning and innovation throughout a team collaboration, which made it possible to understand that this will come as a helping tool to this analysis. This system will be able to transform complex social interactions into observable behaviour which will identify how knowledge is constructed and problems are solved in a team.

## Analysis Plan

The data obtained from the video recordings were put into the Noldus Observer XT software where each session of the experiment was coded, and the results were then exported into an Excel file which was later on analysed in R Studio. The codes used in R studio can be found in the Appendix C.

For the coding, the codebook is based on the AIFI System, which differentiates two recurring team states: *group flow* versus *inertia momentum*. The group flow theme indicates a team's movement toward generating and developing new ideas. As opposed to this group flow theme, the inertia momentum category shows when team members are moving away from generating new ideas. Behaviours that did not fall in either of the categories, were coded as *neutral behaviour*. All of the videos were coded once using this system. The final codes were allocated to these three themes, with the complete distribution of the codes being further elaborated in the result section, and the codebook which can be found in Appendix B.

Additionally, the information gathered was imported to RStudio. A document was formed based on the answers in the questionnaire concerning the age and gender in order to observe the variation. Furthermore, this programme was used to calculate the percentage of each category to observe the data further. After the videos were coded in Noldus, an Excel file was exported to RStudio, to form the timelines that will be described further in the Results section.

## Results

### Demographics and performance category table

All the information from the questionnaire was imported into RStudio, where a dataset was formed from the questionnaire showcasing information such as age, gender, nationality, but also the score that each participant achieved. While looking at the dataset, the first step was to observe the range of the results on the individual ranking task.

For this to be possible, a calculation was performed, in the interest of visualising the data that will be further analysed in the timelines. This analysis was performed to observe the scores of each individual participant, in the order from the highest score to the lowest score. The result showed that the scores varied from 84 to 46. In order to have a better understanding of this variation, a table was formed showing the individual scores of each participant in each team, while also including the team score.

**Figure 1**

*Team and individual scores on the Lost at Sea task*

| | Team 1 | Team 2 | Team 3 | Team 4 |
|---|---|---|---|---|
| Participant 1 | 76 | 74 | 80 | 56 |
| Participant 2 | 46 | 74 | 58 | 73 |
| Participant 3 | 58 | 84 | 72 | 66 |
| Participant 4 | 80 | 62 | | |
| Participant 5 | 76 | 58 | | |
| Team Total | 74 | 56 | 70 | 73 |

*Note.* This table shows the individual scores and the team scores of each team. The green scores are the participants that survived the Lost at Sea task based on the Coast Guard ranking

This table shows that the team scores and the individual scores varied, while also showing that team 3 and 4 had only three participants each. The team scores varied from 84 to 56.

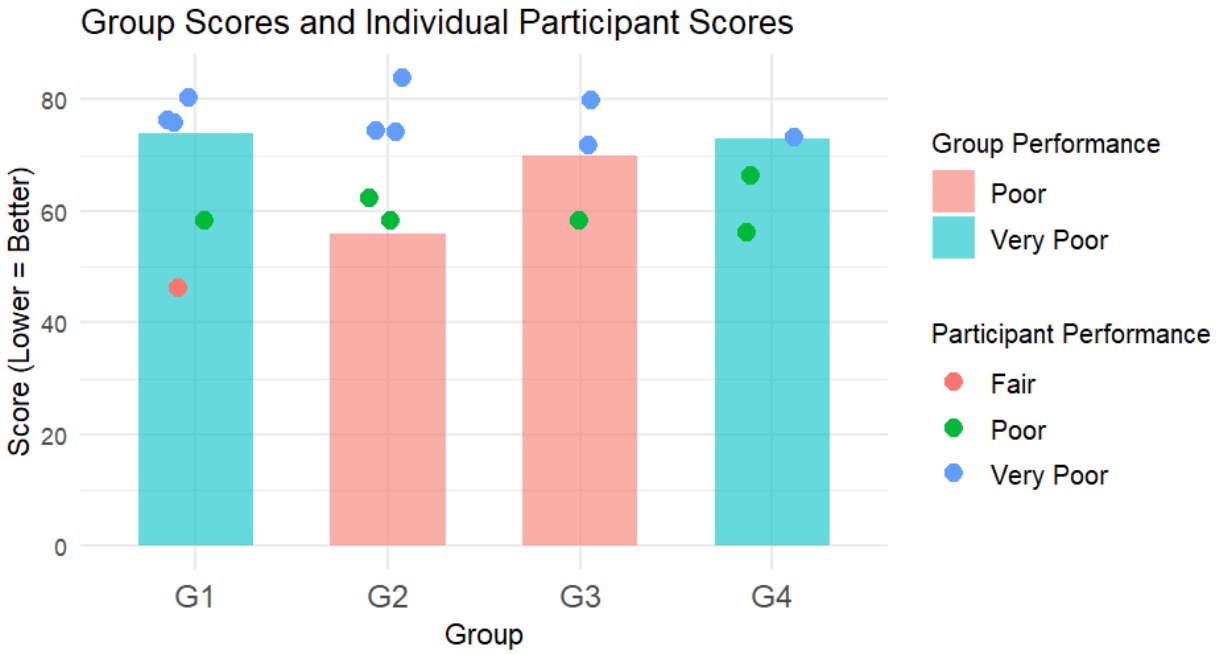
For a closer look, another calculation was performed categorising the individual scores of each participant in the individual task, based on the ranking scores of the Coastal Guard rankings. This categorisation was also offered to the participants during the experiment and this is how they found out if they survived or not. The Coast Guard ranking categorised the scores into six categories, namely excellent, good, average, fair, poor and very poor. For the first category, excellent, the participant had to score between 0 and 25 points, for the good category between 26 and 32 points and for average between 33 and 45. For the last three categories, for fair the participant had to have between 46 and 55 points. For the poor category, the participant had to score between 56 and 70 and for the last category, very poor, the participant had to have a score of 71 or higher.

Furthermore, it can be observed that in the individual tasks 7 out of 16 participants survived and they were categorised in the teams of Fair, Poor and Very Poor. There were no participants that reached the levels of Average, Good or Excellent. Regarding the teams, two out of four teams managed to survive based on their ranking. The teams that survived this challenge were categorised into the Poor scores. No team reached a high level of ranking.

Moreover, a further graph was formed showcasing the teams and their assigned participants in order to observe the individual scores of the participants in comparison to their team score.

**Figure 2**

*Within-team variation*




This visualisation highlights how, even if half of the participants in a team managed to have a fair or poor performance individually, overall as a team they could still score a differing value, such as a very poor value. The cut-off score was set at 71, every team that reached a value higher than this automatically did not survived the task. For the group score value, a calculation was performed by calculating the differences in the team rankings and the Coast Guard ranking and adding the difference up. The lower the total score, the higher the chances of surviving.

**CPS and co-construction results**

All teams spent around twenty-three minutes for the experiment, with the exception of the first team, where the analysis in the software was only possible for a part of the video recording, as the other part of the video was encrypted. This time was expected, as the participants were offered twenty minutes for this section of the experiment.

For a better understanding of the differences between the four teams it is necessary to observe the timelines of each experiment and see the differences that occur there. This will offer

insight into the differences between teams and help us understand how the collaboration between members was when trying to reach a common solution. The code book for this study was based on the AIFI System which has three big categories, namely Emergent State, Process and Behavioural Codes. For the Emergent State, there are three other subcategories, namely Group Flow, Neutral and Inertia Momentum. For the Process category, there are several subcategories, such as idea facilitation, team spirit facilitation, idea inhibition and team spirit inhibition. For a better understanding of this system, the codebook can be seen in Appendix B.

A frequency table was formed to observe the frequency of each coded behaviour throughout the teams.

**Figure 3**

*Frequency of each coded behaviour*

| Nr. | Behaviour | Team 1 | Team 2 | Team 3 | Team 4 | Total |
|---|---|---|---|---|---|---|
| 1. | Humour | 1 | 3 | 0 | 4 | 8 |
| 2. | Idea Development | 1 | 2 | 3 | 2 | 8 |
| 3. | Idea Expression | 0 | 4 | 3 | 2 | 9 |
| 4. | Idea Explanation | 1 | 2 | 1 | 4 | 8 |
| 5. | Knowledge | 1 | 1 | 0 | 3 | 5 |
| 6. | Loss in detail and repetition | 0 | 2 | 2 | 2 | 6 |
| 7. | Off-topic conversation | 1 | 1 | 2 | 1 | 5 |
| 8. | Process Organisation | 0 | 0 | 0 | 1 | 1 |
| 9. | Silence | 0 | 0 | 0 | 3 | 3 |
| 10. | Support | 0 | 1 | 4 | 2 | 7 |

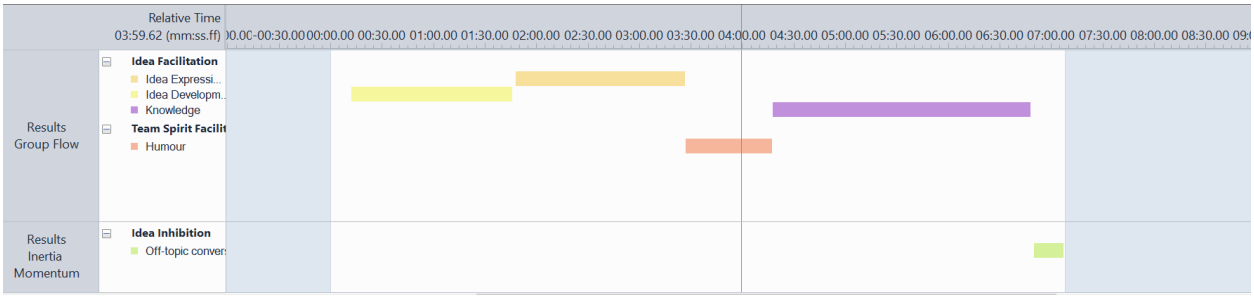
*Note*. This table shows the frequency of each behaviour in each experiment session

This table shows that the most frequent coded behaviours are Idea Expression, which was seen nine times throughout the teams, Idea Explanation was seen eight times, Humour

was present eight times and Idea Development was also seen eight times. All the behaviours that were mentioned as most frequently used are all part of the Group Flow category. Some of the behaviours that are seen very rarely displayed throughout the experiments are Process Organisation and Silence. Both behaviours are seen in team four.

**Figure 4**

*Timeline for Team 1*



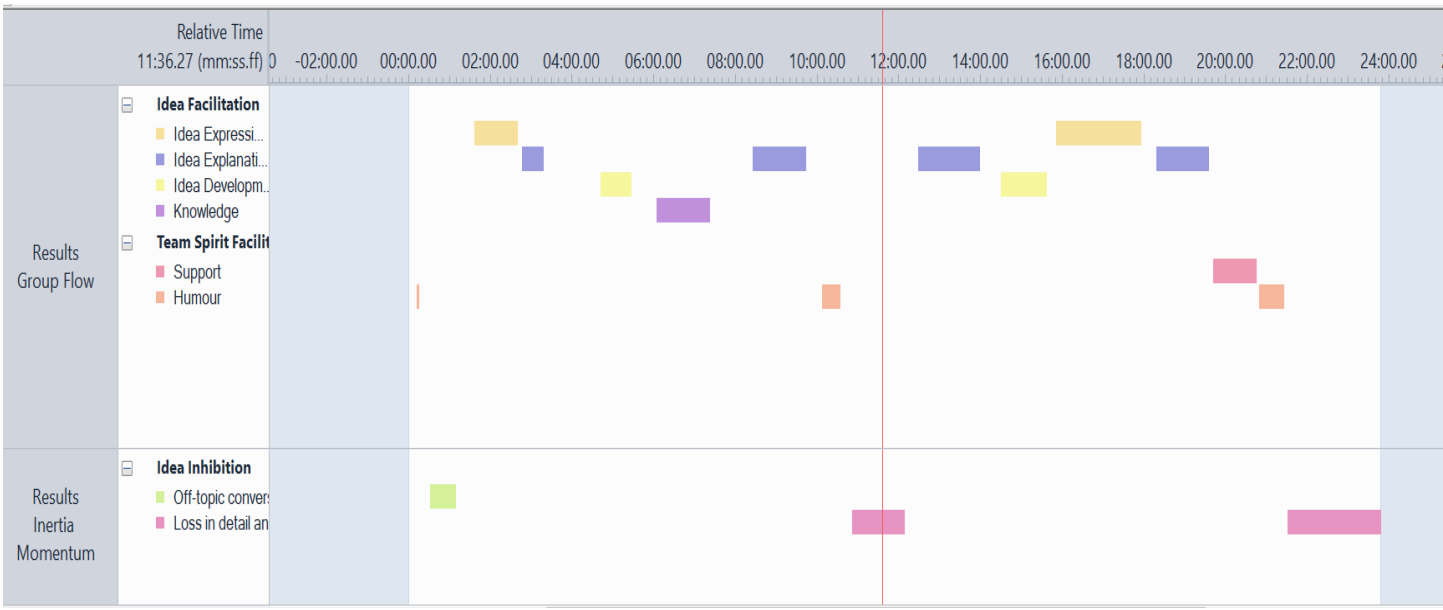

After observing this timeline, it can be observed that the timeline is on the shorter side, compared to the other teams. This is a result of one of the videos not working to be coded into the Noldus software, as the video was encrypted. This means that for the first team the timeline is formed of half of the experiment that the participants took part in. While looking at this short timeline, a calculation was performed to observe the exact percentages of time spent in each category, namely the Group Flow and Inertia Momentum categories. This calculation showed that 96.06% of the time is spent in the Group Flow category and the rest 3.94% in the Inertia Momentum category.

For the three most common behaviours, the analysis in R Studio showed that the most common are Knowledge, Idea Expression and Idea Development. To be more exact, Knowledge is seen as a behaviour in this team 36.57% of the experiment. Idea Expression is seen 24.04% with Idea Development being seen 22.94% throughout the experiment.

The timeline shows that the group spent the big majority of the experiment in the group flow category, with the behaviours that are part of this category being in a sequence of idea development, idea expression, humour and then knowledge.

**Figure 5**

*Timelines for Team 2*




For the second team, the visualisation shows that the team presented behaviours that are part of the sections Group Flow and Inertia Momentum. While looking at the visualisation it can be observed that a bigger proportion of the time was spent in the Group Flow category. To be more exact, a calculation was performed based on the amount of minutes spent in each category and then calculated to observe the values in percentages for a better understanding for the reader. The calculations showed that the second team spent 86.49% of the experiment in the Group Flow category and 13.51% in the Inertia Momentum category.

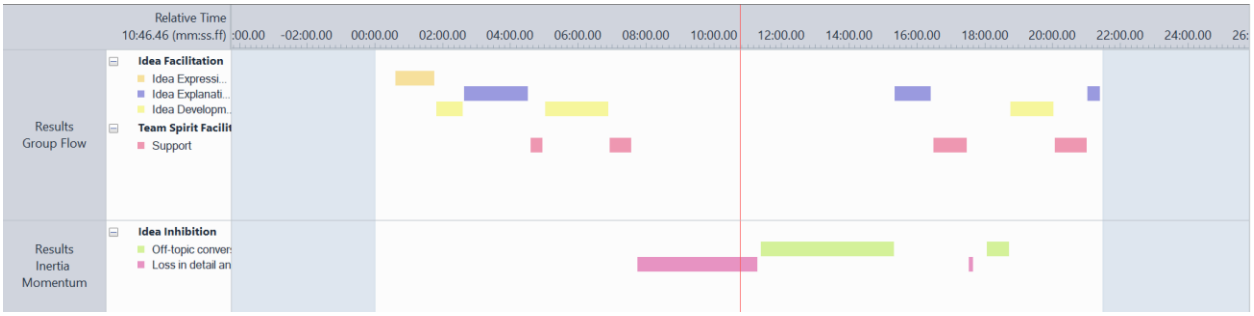
For the second team, the top three behaviours displayed for the longest period of time were as follows: Idea Explanation, Loss in detail and repetition and Idea Expression. To be more precise, idea explanation was present 26.62% throughout the entire duration of the experiment, loss in detail and repetition 20.59% and idea expression 18.1%.

While looking at this visualisation, certain points can be highlighted. First, when focusing on the behaviours that are part of the group flow category, a certain sequence can be observed. Namely, idea explanation building up towards idea development or humour. When looking at the timeline, it can be observed that the group start with idea expression, then the next participant comes and builds upon it with idea explanation, the idea is developed further then the knowledge of others is shared and idea explanation comes again for the next item. Second, it is also important to observe the short moments where behaviours that are part of the inertia momentum group are used, at the beginning, in the middle and at the end, which can indicate the need of a

short break from the focus of ranking or losing the attention to the task to focusing too much on certain details. Lastly, the presence of behaviours such as humour and support, seem to also be part of a good flow, as they appear in short periods of time and sporadically throughout the entire experiment.

**Figure 6**

*Timelines for Team 3*




For the third team the visualisation showed that the team had behaviours attributed to the categories Group Flow and Inertia Momentum. For a better understanding, a calculation was performed transforming the minutes spent in the entire Inertia Momentum category and also for the Group Flow category in order to observe the percentages. This resulted in 61.58% of the experiment spent in the Group Flow category and 38.42% in the Inertia Momentum category.

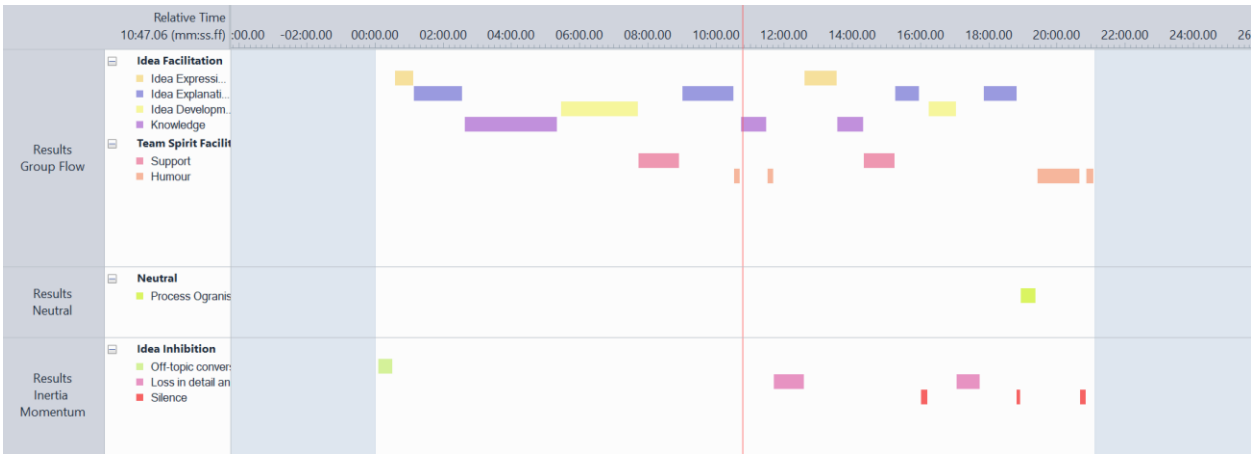
This team also showed three behaviours that were most common based on the timeline. A calculation was performed to signal how long each behaviour was exhibited throughout the duration of the experiment, using percentages. The three most common behaviours were Off-topic conversation, Idea development and Loss in detail and repetition. For the off-topic conversation 23.44%, the idea development was 20.02% seen throughout the experiment and loss in detail and repetition was observed 18.77%.

When observing this group certain aspects seem to be highlighted. While looking at the group flow category, the behaviours idea explanation and idea development seem to be interconnected, as the group starts with idea development, then moves to idea explanation, then idea development and then again exchanging these two behaviours throughout the experiment. It is also necessary to mention, that support is also seen often throughout the experiment but is being used for short periods of time. Lastly, the behaviours that are part of inertia momentum category are also present, but this time they are most often seen in the middle of the experiment

for a long period of time. This can indicate the need of the participants to decompress from the activity and wanting to just discuss with the other participants.

**Figure 7**

*Timelines for Team 4*




For the last team, the visualisations show that the team also had behaviours that are part of the Neutral category. The same calculation was performed for a better understanding. For the last team, 86.7% of the experiment, the participants displayed behaviours that are part of the Group Flow category, 11.30% of the experiment was part of the Inertia Momentum category and the rest 2% was spent in the Neutral category.

For this last team the three most common behaviours are Idea Explanation, Knowledge and Idea Development. To be more exact, idea explanation is seen in this team 22.8%, knowledge is present 21.05% in the experiment and idea development is present for 15.31% throughout the experiment.

For the last group, certain conclusion can be drawn. When looking at the group flow category of behaviours, it is easy to observe that the group starts with idea expression, continues with idea explanation, but then switches to knowledge and then idea development. In this group there seems to be an almost pattern of interchangeable behaviours by using first idea explanation and then continuing with knowledge. When looking at the behaviours that are part of the neutral category, it seems to be used only once as it is process organisation, for a short period of time. The behaviours that are part of inertia momentum category seem to be used more often in the second part of the experiment and at the very beginning, with silences also being used for short amount of the times towards the end of the experiment.

Overall, all teams spent around twenty-three minutes for the experiment, with the expectation of the first team, where the analysis in the software was only possible for a part of the video recording. This time was expected, as the participants were offered twenty minutes for this section of the experiment.

Moreover, it can be observed that certain teams displayed similar sequences of behaviours, resulting in almost a pattern. Namely, teams two and three both used idea explanation and idea development interchangeably. Moreover, both teams have short moments where behaviours such as support and humour are used which offers a good balance and flow to the conversation. The same thing can be mentioned to the behaviours that are part of the inertia momentum category, namely off-topic conversation and loss in detail and repetition seem to have a positive impact on the results of the task, as they offer a break in the experiment from the ranking process and also strengthen the conversation between participants. For the first team as the video was encrypted, not a lot can be said when looking at the timeline. It can be seen that humour is also present in there for a long period of time, the same thing can be mentioned for the behaviours in the group flow category, with the mention that idea explanation is not used there. The behaviours that are part of the inertia momentum category they are present at the beginning, middle and end of the experiment. The last team also uses for a short period of time a behaviour that is part of the neutral category. The behaviour that are part of the group flow category have a different sequence by using idea explanation in relationship with knowledge throughout the experiment. Moreover, this team displays also short moments of silence towards the end of the experiment.

For an even closer look at each behaviour, a table was formed that shows the percentage for each team. The table is based on the codebook scheme, showcasing the three categories, namely Group Flow, Neutral and Inertia Momentum and their assigned behaviours.

**Figure 8**

*Percentage of each coded behaviour*

| Emergent state | Behavioural codes | Team 1 | Team 2 | Team 3 | Team 4 |
|---|---|---|---|---|---|
| | Idea expression | 24.04% | 18.1% | 5.48% | 7.33% |
| | Idea explanation | 0% | 26.62% | 17.06% | 22.8% |

| | | | | | |
|---|---|---|---|---|---|
| Group Flow | Idea development | 22.94% | 10.93% | 20.02% | 15.31% |
| | Knowledge | 36.57% | 7.56% | 0% | 21.05% |
| | Support | 0% | 6.09% | 14.87% | 10.51% |
| | Humour | 12.33% | 6.44% | 0% | 8.91% |
| Neutral | Process organisation | 0% | 0% | 0% | 2.12% |
| Inertia Momentum | Off-topic conversation | 4.12% | 3.66% | 23.44% | 2% |
| | Loss in detail and repetition | 0% | 20.59% | 18.77% | 7.72% |
| | Silence | 0% | 0% | 0% | 2.24% |

*Note.* This table shows the percentage of each coded behaviour in each team

This table shows the distribution of each coded behaviour across all teams in percentages. It offers an even more detailed description of how much each behaviour was observed across all teams. It can be observed that behaviours such as silence or process organisation are not used that often throughout the teams. In contrast, behaviours such as idea expression or idea development are present throughout the teams and have varying percentages. This comes as no surprise as idea expression is seen to be used in almost every group as a behaviour in the start of the experiment by having one participant taking the lead in expressing their point of view. Moreover, idea development is used in every group, sometimes interchangeably, with idea explanation. This is especially seen in team two and three where an almost pattern ca be detected when looking at the timelines. Moreover, humour and support seem to be necessary in almost all teams as they offer a good conversation flow and strengthen the relationship between participants. The behaviour process organisation which is seen in the last group does not seem to offer any added value. The same conclusion can be made about silence, as it is only observed in one team and does not seem to have a big impact on the team's results. But the behaviours that are part of the inertia momentum category, namely off-topic conversation and loss in detail and repetition seem to be present in almost all groups and seem to be necessary when being part of a team. As they seem throughout the experiment, being present for quite some time based on the percentages and seem to add to reaching a good score by connecting the participants through discussing different related topics.

When taking a closer look to team two and three, the only teams that survived the task, they seem to both have high percentages and frequencies of behaviours such as idea explanation, idea expression, idea development and loss in detail and repetition. The first three behaviours are part of the Group Flow category, which is no surprise, as the timelines also showed the strong connection between idea explanation and idea development. Moreover, the loss in detail and repetition strengthens the necessity of behaviours that are part of the inertia momentum category, as they are a tool when it comes to a good flow in conversation and it also connects the participants through the topics that are developed in this conversation. In the second team with the best score on the task, it is seen that loss in detail and repetition is seen at the beginning, middle and end of conversation, indicating a natural occurrence of these behaviours and not a long amount of time was spent at any one point.

## Discussion

The current study aimed to observe the influence of collaborative problem solving and co-construction displayed during a collaborative team task. The analysis was conducted using the data from 16 participants, who in teams, collaborated to solve a task at hand. Results show that only two out of four teams managed to survive in the ranking process and seven out of sixteen participants survived in the individual part of the task.

For the timelines analysis it can be seen that all of the teams had a significant portion of their time in the experiment spent in the Group Flow and Inertia Momentum categories and one team, team four, also had behaviours that are part of the Neutral category. Looking at the frequency of behaviours that are part of the group flow, neutral and inertia momentum categories, throughout all teams it is easy to observe that some behaviours have a higher frequency than others. Namely, idea expression, idea explanation, idea development and humour are the most frequent behaviours seen in the entire experiment. All of these behaviours are part of the Group Flow category. On the other hand, behaviours such as process organisation, silence, knowledge and off-topic conversation are the least frequent behaviours. Process organisation is part of the Neutral category, while the rest of the behaviours are part of the Inertia Momentum category. The teams paid more attention to matters surrounding group flow, rather than matters which oppose this. This could be a result of trying to finish the activity in the designated time as

well as offering their opinions without taking breaks or focusing on other matters. It is in line with the research by Walker (2010), where it can be observed that in order to maintain a group flow it is necessary that the participants are either absorbed in a task or in a group-centered focus.

At the same time, it is necessary to observe the percentages of each behaviour throughout the experiment as there are some interesting findings to take into account. Namely, behaviours such as off-topic conversations and knowledge which have a low frequency overall, but a high percentage. That means that off-topic conversation and knowledge are not repeated actions, as observed in the frequency table, but the time spent by the participants in that behaviour is high, as it can be observed in the percentage table.

A factor that could have influenced the outcomes of this study, is the difference in the ranking per person, when comparing an individual's personal scores between the solitary task, and the team task. It seems that the main difference that is seen between the teams is the behaviours that are displayed in the team task. Namely, it seems that the teams 2 and 3 that survived the task, tended to spend more time generating and developing new ideas, compared to teams that did not survive the task. Having a high frequency of behaviours that are part of the group flow category indicates a team's movement towards generating and developing new ideas. The findings emphasize the importance of co-construction as it is a pillar for the decision making process in a team by combining all of the knowledge of each participant until the team reaches an idea that was not available before (Decuyper et al., 2010). Collaborative problem solving also has a high influence on this aspect as it coordinates behaviours towards finding a solution and generates a solution based on the skills of each member (Graesser et al., 2018).

**Influence of co-construction and collaborative problem solving**

The findings presented that teams that continually build on each other's knowledge and share their solutions are more likely to arrive at an optimal solution. This has been observed in the timelines, as the participants moved through different phases of group flow, building on each other's ideas. Behaviours such as idea expression, idea explanation and such are seen to have a positive impact on the ranking activity, namely being part of the group flow category it increases the chances of surviving the imagined scenario. The timelines also came as an aid in understanding better when and how the co-construction happened. In team two and three an almost pattern can be detected when looking at the timelines, as the participants build upon each

other's ideas by using first idea development and then continuing with idea explanation. These two behaviours are seen to be used interchangeably between the teams. Furthermore, behaviours such as humour and support seem to be necessary in almost all of the teams as they offer a good conversation flow. Behaviours that are part of the inertia momentum category and can be seen in almost all groups in the timeline seem to offer an added value, as they have a high frequency in the teams that did survive the task. It seems to offer a possibility to the participants to connect to each other by having discussing beside the ranking process. These results are in line with the study by Zahedi et al. (2017) where timelines effectively relieved the influence of co-construction by analysing the team session and locating when and how did it showed and paying close attention to tensions and contradictions between team members, which ended up in co-constructed outcomes. The aim of the study was to discover how designers engage in co-creation and mutual alignment during ideation sessions. The findings showed that team had noticeable moments where individuals combined different perspectives to reach new conclusions. Moreover, successful design outcomes were closely related to participants verifying common understanding through verbal confirmations, gestures, shared references. These behaviours and moments were most seen when teams had a stable understanding of tools, roles and constraints. This can also be observed in this study, as each member builds upon each other's knowledge throughout the experiment, moving through the different stages of group flow or inertia momentum. It is important to note that the inertia momentum phases throughout the experiment, helped in forming a co-constructed outcome, as they helped in having a more relaxed atmosphere between members. This can be especially seen in the teams 2 and 3 that did survive, as they had quite a high percentage in behaviours that are part of this category. The behaviours loss in detail and repetition and off-topic conversation being observed to have a low frequency overall throughout the teams, but when looking at the percentages, it can be observed that the teams spent a more time in this stage, compared to other behaviours. Another thing that was observed was when did these behaviours occurred. Namely, they happened in the middle of the experiment, with a bit of time spent in the end and beginning. This shows that the participants took breaks from the ranking, discussing other topics as well. Moreover, this study delve deeper by linking success through observing the coded sequences, connecting them to the task score and taking into consideration negotiation measures.

The collaborative team task influenced the participants to integrate their diverse perspectives and form a shared understanding. Throughout the experiment, it was possible to observe that certain teams, namely team 2 and 3, managed to achieve a better result as a team than individually. This shows that in those cases, the team managed to reach a high level of collaboration and to reach different conclusions than the ones in the individual part. This is also supported by the study of Laughlin et al., (1998), where the group performance equalled that of the best individual and even managed to significantly outperform the other standings. This highlights that collaboration can rival top individual performances. The strength of the team was seen to lay in carefully selecting the right option and maintaining that position. This can be especially seen in team two and three as the groups had a better score as a team then individually. This difference can be explained through the options the team made when discussing the ranking process. Namely, the building upon each other that is seen in the timelines, through behaviours such as idea development and idea explanation, whereas individually this interchange between behaviours will not be possible when only having one opinion. This study then adds up even further onto the information provided by Laughlin et al., (1998) as this study delves even deeper through video-recorded interactions that are then coded moment by moment.

For the other teams, team 1 and 4, the participants had better results for the individual part then the team one. This could maybe be attributed to the fact that they had a low frequency of behaviours attributed to the group flow category such as idea development and idea expression. Moreover, both teams have a low percentage of behaviours that are part of the inertia momentum category. It can be assumed that both teams did not survive the collaborative task, because they did not reach a good balance between generating ideas and focusing on other aspects of collaborating as well.

The timelines showcased the influence of certain behaviours that were part of the group flow category. The group flow category is described as a team's movement towards generating and developing new ideas. Behaviours such as idea expression, idea development and such are the moments where each participant understood the other members ideas and developed them even more with their own knowledge. The study by Noel et al. (2022) has a similar view to this, by analysing how multimodal timeline visualisations can support teachers in analysing collaborative problem solving in face-to-face educational settings. The study showed that

timeline visualisation was the perfect tool for observing when and how collaborative behaviours happened. Moreover, they were able to detect phases of idea proposal, elaboration and co-regulation throughout teamwork. This supports the idea that timelines are necessary when analysing movement toward collaborative problem solving and co-construction. The timeline observed in the study of Noel et al. (2022) focused on visualising non-verbal collaboration signs, while this study is focusing on investigating cognitive and social processes in CPS and co-construction in a collaborative team task through verbal interactions. This shows that using the timelines for this analysis requests verbal behaviour that can be then carefully coded moment by moment.

**Limitations and future research**

While this study provided more information to the limited body of knowledge on the influence of both collaborative problem solving and co-construction on a collaborative team task, it is important to understand the limitations, and provide recommendations for future research. One of the challenges that this study was faced with was the very limited sample size, there were only four teams that totalled sixteen participants. Future research should be conducted with ten teams with a total number of fifty participants at least, for more accurate results (Van Voorhis & Morgan, 2007). Another limitation that is related to the small sample size, is the unequal distribution of participants throughout the teams. The first two teams had five participants each, whereas the last two teams had three participants each. For a better analysis, an equal distribution of participants between the teams would yield more accurate results (Noel et al., 2022). Furthermore, no team has managed to reach a very good result with the only teams having scores that are part of the poor and fair category. For a better analysis, diversity in team scores can offer a diverse range of approaches between participants (Horwitz & Horwitz, 2007).

Moreover, another limitation that had a significant impact on the results of the ranking activity was that one participant took part in a similar study before. This was seen to have a high impact, as that participant managed to reach the best individual score in the ranking activity. This score was a 46 which entered the fair category based on the coast guard ranking. It is the only score in this experiment that surpassed the very poor and poor category of the individual and team rank standings. However, it could also be that this preexisting knowledge can have no significant effect on a study. For example, a study by Wieman & Holmes (2015) faced the same issue of having participants who took part in similar studies in this case. The conclusion that they

reached was that there was no significant difference between the participants that took part in a similar lab or not. Another factor that limited the results of this research was the small sample size consisting of male participants, namely out of sixteen participants only three of them were male. This could have an impact on the overall results of ranking tasks, as the diversity presented by an equal distribution of genders in groups could have yielded a different result in the frequency distribution of behaviours (Yuan et al., 2019).

Furthermore, another limitation that has an impact on the results is the fact that there was only one coder, and there was no second independent coder. This can have an impact on the accuracy of the coding of behaviours and the overall accuracy of frequencies of behaviours. However, it can be possible that having only one coder does not have a significant impact on the results of a study. For example, the study of O'Connor & Joffe (2020) offers a closer look at intercoder reliability in qualitative research. Their suggestion is that when a coding frame reaches high reliability, either quantitatively assessed, for example Cohen's kappa or qualitatively through coder consensus, a single trained coder can be enough to code the entire dataset. They support this suggestion by explaining that first, coders should initially test the coding frame through statistical methods or through iterative coding and then discuss. Secondly, once stability is demonstrated, the lead coder can start coding the remaining of the data. This scenario is not a perfect fit for this study, as this study implies a mixed methodology. Therefore, this could still have an impact on the overall results of the vide coded data, as a second conder could offer a different view on how to code the different scenes as well as the duration offered to each behaviour. Future research should use more than one coder as this will increase the reliability of the study (Church et al., 2019).

This study provided valuable information within the field of group-learning in group-based tasks. Future research can build upon this research and can potentially harness new results by incorporating a larger sample size, and more equally distributed variety of participants. Furthermore, a higher variation in age and gender between participants would also offer a more detailed view on how different knowledge can have an impact on how co-construction appears in a collaborative team task. For example, a study by Sun et al. (2021) focused on how specific collaborative problem solving (CPS) behaviours predict team performance in a structural digital environment. The study had a big sample size with a good distribution of participants and

showed that in order to have a successful collaborative environment it is necessary to have content knowledge as well as knowledge on how team members interact with each other.

## Conclusion

To conclude, the main aim of this study was to observe the influence of both co-construction and collaborative problem solving. The importance of both behaviours were highlighted in the results after observing the timelines. An important influence that has been observed in the frequency of each coded behaviour, the ones of the Group Flow category appeared to be the most influential for the survival activity. Given the study's limitations, such as small sample size, with uneven distribution of participants, and unequal distribution between genders. These findings require further development using a bigger sample size. Additionally, delving deeper into certain aspects, such as comparing a low and high performance team could harness interesting results. Furthermore, exploring the influence of knowing the majority of the participants in the experiment, could lead to additional insights in better understanding how the interaction would change between participants. This study contributes to the limited knowledge on the influence of both co-construction and collaborative problem solving in a collaborative team task. It serves as a foundation for future research to delve deeper into the complex influence of co-construction and collaborative problem solving.

## References

Alexander, R. (2005). *Towards dialogic teaching: Rethinking classroom talk* (3rd ed.). Dialogos.

Barron, B. (2000). Achieving coordination in collaborative Problem-Solving groups. *Journal Of The Learning Sciences*, *9*(4), 403–436. https://doi.org/10.1207/s15327809jls0904_2

Brandon, D. P., & Hollingshead, A. B. (2004). Transactive Memory Systems in Organizations: Matching Tasks, Expertise, and People. *Organization Science*, *15*(6), 633–644. https://doi.org/10.1287/orsc.1040.0069

Brundage, M. J., Malespina, A., & Singh, C. (2023). Peer interaction facilitates co-construction of knowledge in quantum mechanics. *Physical Review Physics Education Research*, *19*(2). https://doi.org/10.1103/physrevphyseducres.19.020133

Carletti, T., Guarino, A., Guazzini, A., & Stefanelli, F. (2020). Problem solving: when groups perform better than teammates. *Journal Of Artificial Societies And Social Simulation*, *23*(3). https://doi.org/10.18564/jasss.4292

Chiriac, E. H. (2014). Group work as an incentive for learning â€“ studentsâ€™ experiences of group work. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00558

Church, S. P., Dunn, M., & Prokopy, L. S. (2019). *Benefits to Qualitative Data Quality with Multiple Coders: Two Case Studies in Multi-coder Data Analysis*. eGrove. https://egrove.olemiss.edu/jrss/vol34/iss1/2/?utm_source=chatgpt.com

Decuyper, S., Dochy, F., & Van Den Bossche, P. (2010). Grasping the dynamic complexity of team learning: An integrative model for effective team learning in organisations. *Educational Research Review*, *5*(2), 111–133. https://doi.org/10.1016/j.edurev.2010.02.002

Endrejat, P., Meinecke, A., & Kauffeld, S. (2019). It All Starts with a Good Idea: A New Coding System for Analyzing Idea Finding Interactions (AIFI). *Proceedings of the . . . Annual*

*Hawaii International Conference on System Sciences/Proceedings of the Annual Hawaii International Conference on System Sciences*. https://doi.org/10.24251/hicss.2019.038

Fiore, S., Rosen, M.A., Smith-Jentsch, K.a., Salas, E., Letsky, M., & Warner, N., (2010). Toward an Understanding of Metacognition in Teams: Predicting Processes in Complex Collaborative Contexts. *Human factors*, 52, 203-224. Crossref. PubMed. Web of Science.

Forsyth, D.R. (2018). Group Dynamics, Cengage Learning

Graesser, A. C., Fiore, S. M., Greiff, S., Andrews-Todd, J., Foltz, P. W., & Hesse, F. W. (2018). Advancing the Science of Collaborative Problem Solving. *Psychological Science in The Public Interest*, *19*(2), 59–92. https://doi.org/10.1177/1529100618808244

Harvey, J., Cromwell, J. R., Johnson, K. J., & Edmondson, A. C. (2023). The Dynamics of Team Learning: Harmony and Rhythm in Teamwork Arrangements for Innovation. *Administrative Science Quarterly*, *68*(3), 601–647. https://doi.org/10.1177/00018392231166635

Horwitz, S. K., & Horwitz, I. B. (2007). The Effects of Team Diversity on Team Outcomes: A Meta-Analytic Review of Team Demography. *Journal of Management*, *33*(6), 987–1015. https://doi.org/10.1177/0149206307308587

Laughlin, P. R. (1999). Collective induction: twelve postulates. *Organizational Behavior and Human Decision Processes*, *80*(1), 50–69. https://doi.org/10.1006/obhd.1999.2854

Lehtinen, A., Kostiainen, E., & Näykki, P. (2023). Co-construction of knowledge and socioemotional interaction in pre-service teachers' video-based online collaborative learning. *Teaching and Teacher Education*, *133*, 104299. https://doi.org/10.1016/j.tate.2023.104299

Letsky, M.P., Warner N.W., Fiore. S., & Smith, C.A.P., (2008) *Macrocognition in Teams: Theories and Methodologies*. London, England: Ashgate

Mercer, N., & Howe, C. (2012). Explaining the dialogic processes of teaching and learning: The value and potential of sociocultural theory. *Learning Culture and Social Interaction*, *1*(1), 12–21. https://doi.org/10.1016/j.lcsi.2012.03.001

Näykki, P., Järvelä, S., Kirschner, P. A., & Järvenoja, H. (2014). Socio-emotional conflict in collaborative learning—A process-oriented case study in a higher education context. *International Journal of Educational Research*, *68*, 1–14. https://doi.org/10.1016/j.ijer.2014.07.001

Nemiroff, P.M., & Rasmore, L. (1975). Lost At Sea: A Consensus-Seeking Task. In W. Pfeiffer & J. Jones (Eds.), *Handbook for Group Facilitators* (pp. 28-34). University Associates.

Noël, R., Miranda, D., Cechinel, C., Riquelme, F., Primo, T. T., & Munoz, R. (2022). Visualizing Collaboration in Teamwork: a multimodal learning analytics platform for Non-Verbal communication. *Applied Sciences*, *12*(15), 7499. https://doi.org/10.3390/app12157499

O'Connor, C., & Joffe, H. (2020). Intercoder reliability in Qualitative Research: Debates and practical guidelines. *International Journal of Qualitative Methods*, *19*. https://doi.org/10.1177/1609406919899220

Organisation for Economic Co-operation and Development [OECD]. (2017). PISA 2015 Assessment and Analytical Framework. In *Programme for international student assessment/Internationale Schulleistungsstudie*, *P. 136.* https://doi.org/10.1787/9789264281820-en

Salas, E., Cooke, N.J., & Rosen, M.A., (2008). On Teams, Teamwork and Team Performance: Discoveries and Developments. *Human Factors, 50, 540-547.*

Smith, J. B. (1994). Collective intelligence in computer-based collaboration. In *L. Erlbaum Associates Inc. eBooks*. http://ci.nii.ac.jp/ncid/BA27014848

Sun, C., Shute, V. J., Stewart, A. E., Beck-White, Q., Reinhardt, C. R., Zhou, G., Duran, N., & D'Mello, S. K. (2021). The relationship between collaborative problem solving behaviors and solution outcomes in a game-based learning environment. *Computers in Human Behavior*, *128*, 107120. https://doi.org/10.1016/j.chb.2021.107120

Szuba, T. (2001). A formal definition of the phenomenon of collective intelligence and its IQ measure. *Future Generation Computer Systems*, *17*(4), 489–500. https://doi.org/10.1016/s0167-739x(99)00136-3

Van Den Bossche, P., Gijselaers, W., Segers, M., Woltjer, G., & Kirschner, P. (2010). Team learning: building shared mental models. *Instructional Science*, *39*(3), 283–301. https://doi.org/10.1007/s11251-010-9128-3

Van Voorhis, C. R. W., & Morgan, B. L. (2007b). Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology*, *3*(2), 43–50. https://doi.org/10.20982/tqmp.03.2.p043

Vogel, F., Weinberger, A., Hong, D., Wang, T., Glazewski, K., Hmelo-Silver, C. E., Uttamchandani, S., Mott, B., Lester, J., Oshima, J., Oshima, R., Yamashita, S., Lu, J., Brandl, L., Richters, C., Stadler, M., Fischer, F., Radkowitsch, A., Schmidmaier, R., . . . Noroozi, O. (2023b). Transactivity and knowledge Co-Construction in collaborative problem solving. *Computer-supported Collaborative Learning/the Computer-Supported Collaborative Learning Conference*. https://doi.org/10.22318/cscl2023.646214

Walker, C. J. (2021). Social flow. In *Springer eBooks* (pp. 263–286). https://doi.org/10.1007/978-3-030-53468-4_10

Wegner, D. M. (1987). Transactive Memory: A Contemporary Analysis of the Group Mind. In *Springer eBooks* (pp. 185–208). https://doi.org/10.1007/978-1-4612-4634-3_9

Wieman, C. E., & Holmes, N. G. (2015). Measuring the impact of introductory physics labs on learning and critical thinking. *2017 Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2015.pr.086

Wilson, K. J., Brickman, P., & Brame, C. J. (2018). Group work. *CBE—Life Sciences Education*, *17*(1), fe1. https://doi.org/10.1187/cbe.17-12-0258

Wiltshire, T. J., Butner, J. E., & Fiore, S. M. (2017). Problem-Solving phase transitions during team collaboration. *Cognitive Science*, *42*(1), 129–167. https://doi.org/10.1111/cogs.12482

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a Collective Intelligence Factor in the Performance of Human Groups. *Science*, *330*(6004), 686–688. https://doi.org/10.1126/science.1193147

Yuan, J., Xiao, Y., & Liu, H. (2019). Assessment of collaborative problem solving based on process stream data: a new paradigm for extracting indicators and modeling DYAD data. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.00369

Zahedi, M., Tessier, V., & Hawey, D. (2017). Understanding collaborative design through activity theory. *The Design Journal*, *20*(sup1), S4611–S4620. https://doi.org/10.1080/14606925.2017.1352958

Zhou, G., Moulder, R., Sun, C., & D'Mello, S. (2022). Investigating Temporal Dynamics Underlying Successful Collaborative Problem Solving Behaviors with Multilevel Vector

Autoregression. *Zenodo (CERN European Organization for Nuclear Research)*. https://doi.org/10.5281/zenodo.6853137

## Appendix A

## Lost at Sea Questionnaire

**Participant number: .....**

1. What is your age?

.....

2. What is your gender?

a) Female

b) Male

c) Other: .....

d) Not willing to say

3. What is your nationality?

a) African

b) Asian

c) European

d) North American

e) South American

f) Oceania/ Pacific Islander

g) Middle Eastern

4. What are you studying at the moment? Please mention the year that you are in, as well as if it is a Bachelor or a Master

.....

5. Do you know another participant from today's study? If yes, how many?

.....

If possible mention if they are a best friend, friend or acquaintance.

.....

6. Have you participated in a similar study before? (such as the NASA moonbase alpha one)

.....

7. Would you like to be contacted by the researcher with the results of the video coding at the end of the data analysis?

.....

If yes, you would like to be contacted through this email address:

.....

**Appendix B**

Overview of the AIFI System

| Emergent state | Process | Behavioral codes |
|---|---|---|
| Group flow (+1) | Idea facilitation | Idea expression |
| | | Idea explanation |
| | | Idea development |
| | | Knowledge |
| | Team spirit facilitation | Support |
| | | Humor |
| Neutral (0) | | Process organization |
| | | Simultaneous talk |
| | | Other |
| Inertia momentum (-1) | Idea inhibition | Off-topic conversation |
| | | Loss in detail and repetition |
| | | Silence |
| | | Blocking |
| | Team spirit inhibition | Relationship conflict |
| | | Complaining |

## Appendix C

During the preparation of this work the author used ChatGPT in order to assist in programming and debugging Code in RStudio without using the actual data. After using this tool/service, the author reviewed and edited the content as needed and took full responsibility for the content of work.

```
##Bachelor Thesis###

library(tidyverse)
library(ggplot2)
install.packages ("psych")
library(psych)
library(readxl)
library(dplyr)
install.packages ("summarytools")
library(summarytools)
###Load data set##
participant_data <- read_excel("participants.xlsx", sheet = "Sheet1")

# Check your data
head(participant_data)
mean(participant_data$Age, na.rm = TRUE)
sd(participant_data$Age, na.rm = TRUE)
##Finding the gender
```

```
# Basic frequency table
gender_counts <- table(participant_data$Gender)

# Convert to percentages
gender_percentages <- prop.table(gender_counts) * 100

# Print the result
gender_percentages
##Demographics table
# This gives you a full summary of all variables
dfSummary(participant_data)
table(participant_data$Gender)
table(participant_data$Nationality)
table(participant_data$Knows_Others)
table(participant_data$Prior_Study)

install.packages("car")
library(car)
####TIMELINES###
library(readxl)
library(dplyr)
library(ggplot2)
```

```
# Load Excel file
df <- read_excel("noldus_participants.xlsx")
####Create performance category###
library(dplyr)
library(readxl)
demographics <- read_excel("participants_questionnaire.xlsx", sheet = "Sheet1")
demographics <- demographics %>%
  mutate(Performance_Category = case_when(
    Score_Activity >= 0 & Score_Activity <= 25 ~ "Excellent",
    Score_Activity >= 26 & Score_Activity <= 32 ~ "Good",
    Score_Activity >= 33 & Score_Activity <= 45 ~ "Average",
    Score_Activity >= 46 & Score_Activity <= 55 ~ "Fair",
    Score_Activity >= 56 & Score_Activity <= 70 ~ "Poor",
    Score_Activity >= 71              ~ "Very Poor",
    TRUE ~ NA_character_  # fallback for missing or invalid data
  ))
colnames(demographics)


colnames(df)
demographics <- read_excel("path/to/your/participants_questionnaire.xlsx", sheet = "Sheet1")
summary_table <- df %>%
  group_by(Performance_Category) %>%
  summarise(
```

```
    Mean_Age = mean(Age, na.rm = TRUE),
    SD_Age = sd(Age, na.rm = TRUE),
    Count = n()
  )
library(dplyr)

demographics <- demographics %>%
  mutate(Performance_Category = case_when(
    Score_Activity >= 0 & Score_Activity <= 25 ~ "Excellent",
    Score_Activity >= 26 & Score_Activity <= 32 ~ "Good",
    Score_Activity >= 33 & Score_Activity <= 45 ~ "Average",
    Score_Activity >= 46 & Score_Activity <= 55 ~ "Fair",
    Score_Activity >= 56 & Score_Activity <= 70 ~ "Poor",
    Score_Activity >= 71                        ~ "Very Poor",
    TRUE ~ NA_character_
  ))
table(demographics$Performance_Category)
summary_table <- demographics %>%
  group_by(Performance_Category) %>%
  summarise(
    Mean_Age = mean(Age, na.rm = TRUE),
    SD_Age = sd(Age, na.rm = TRUE),
    Count = n()
```

```
  )
install.packages("gt")  # Only once
library(gt)
install.packages("rlang")
install.packages("gt")
library(gt)
ls("package:gt")



summary_table %>%
  gt() %>%
  tab_header(
    title = "Summary of Participant Demographics by Performance Category"
  ) %>%
  fmt_number(
    columns = c(Mean_Age, SD_Age, Mean_Known, SD_Known),
    decimals = 2
  ) %>%
  cols_label(
    Performance_Category = "Performance Level",
    Mean_Age = "Mean Age",
    SD_Age = "SD Age",
    Mean_Known = "Mean Known People",
```

```
    SD_Known = "SD Known People",
    Count = "N"
  )
remove.packages("gt")
remove.packages("rlang")


install.packages("rlang", dependencies = TRUE)
install.packages("gt", dependencies = TRUE)
library(gt)
gt::gt
summary_table %>%
  gt() %>%
  tab_header(
    title = "Summary of Participant Demographics by Performance Category"
  ) %>%
  fmt_number(
    columns = c(Mean_Age, SD_Age, Mean_Known, SD_Known),
    decimals = 2
  ) %>%
  cols_label(
    Performance_Category = "Performance Level",
    Mean_Age = "Mean Age",
    SD_Age = "SD Age",
```

```
    Mean_Known = "Mean Known People",
    SD_Known = "SD Known People",
    Count = "N"
  )
library(gt)


summary_table %>%
  gt() %>%
  tab_header(
    title = "Summary of Participant Demographics by Performance Category"
  ) %>%
  fmt_number(
    columns = c(Mean_Age, SD_Age),
    decimals = 2
  ) %>%
  cols_label(
    Performance_Category = "Performance Level",
    Mean_Age = "Mean Age",
    SD_Age = "SD Age",
    Count = "N"
  )
###Behavioral timeline###
# Load libraries
```

```
library(tidyverse)
library(readxl)

# Load the Noldus data
noldus_data <- read_excel("noldus_participants.xlsx", sheet = "Sheet1")

# Inspect column names if needed
colnames(noldus_data)

# Prepare the data: calculate end time
noldus_timeline <- noldus_data %>%
  mutate(
    Start = as.numeric(Time_Relative_sf),
    End = Start + as.numeric(Duration_sf),
    Group = as.factor(Observation),
    AIFI_Category = Subject  # flow, inertia, neutral
  )

# Plot the behavioral timeline
# Load required packages
library(tidyverse)
library(readxl)
```

```
# Read the Excel file
noldus_data <- read_excel("noldus_participants.xlsx", sheet = "Sheet1")


# Clean and prepare the data
noldus_timeline <- noldus_data %>%
  mutate(
    Start = as.numeric(Time_Relative_sf),
    End = Start + as.numeric(Duration_sf),
    Group = as.factor(Observation),
    AIFI_Category = Subject  # flow, inertia, neutral
  )


# Create the behavioral timeline plot
ggplot(noldus_timeline) +
  geom_segment(aes(
    x = Start, xend = End,
    y = Group, yend = Group,
    color = AIFI_Category
  ),
  size = 4) +
  labs(
    title = "Behavioral Timeline per Group (AIFI System)",
    x = "Time (seconds)",
```

```
    y = "Group (Observation)",
    color = "AIFI Category"
  ) +
  scale_color_manual(values = c("flow" = "#66C2A5", "inertia" = "#FC8D62", "neutral" =
"#8DA0CB")) +
  theme_minimal() +
  theme(axis.text.y = element_text(size = 10))
library(tidyverse)
library(readxl)
ggplot(noldus_data, aes(
  x = Time_Relative_f,
  y = Observation,
  fill = Subject  # now should reflect AIFI categories
)) +
  geom_bar(stat = "identity") +
  labs(
    title = "Behavioral Timeline per Group (AIFI System)",
    x = "Time (seconds)",
    y = "Group (Observation)",
    fill = "AIFI Category"
  ) +
  theme_minimal()
# Basic participant scores table
```

```
participant_data %>%
  select(Participant_ID, Score_Activity) %>%
  arrange(desc(Score_Activity))  # Optional: sort by highest score
library(knitr)

# Simple table of participant scores
participant_data %>%
  select(Participant_ID, Score_Activity) %>%
  arrange(desc(Score_Activity)) %>%
  kable(
    caption = "Table: Individual Participant Scores for the Collaborative Task",
    digits = 2,
    align = "lc"
  )
library(ggplot2)

ggplot(participant_data, aes(x = reorder(Participant_ID, -Score_Activity), y = Score_Activity)) +
  geom_col(fill = "#4E79A7") +
  labs(
    title = "Participant Task Scores",
    x = "Participant ID",
    y = "Score"
  ) +
```

```
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
library(tidyverse)
library(readxl)

# Load updated data
participant_data <- read_excel("participants_questionnaire.xlsx", sheet = "Sheet1")  # or
whichever sheet has the column

# Check that the column exists
colnames(participants_questionnaire)

# Plot
ggplot(participants_questionnaire, aes(x = reorder(Participant_ID, Score_Activity), y =
Score_Activity, fill = Coast_Guard)) +
  geom_col() +
  geom_hline(yintercept = 0, linetype = "dashed", color = "black") +
  labs(
    title = "Participant Task Scores Categorized by Coast Guard Evaluation",
    x = "Participant ID",
    y = "Score (Lower = Better)",
    fill = "Performance Category"
  ) +
```

```
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
##Extra###
library(readxl)

#  This line loads the data and stores it as `participants_questionnaire`
participants_questionnaire <- read_excel("participants_questionnaire.xlsx", sheet = "Sheet1")
colnames(participants_questionnaire)

library(dplyr)
library(knitr)
participants_questionnaire2 <- read_excel("participants_questionnaire2.xlsx", sheet = "Sheet1")
colnames(participants_questionnaire2)
participants_questionnaire2 %>%
  select(Group_ID, Group_Score, G_Coast_Guard) %>%
  distinct() %>%
  arrange(Group_Score) %>%
  kable(
    caption = "Group Scores and Coast Guard Categories on the Lost at Sea Task",
    digits = 2,
    align = "lcc"
  )
library(ggplot2)
```

```
participants_questionnaire2 %>%
  distinct(Group_ID, Group_Score, G_Coast_Guard) %>%
  ggplot(aes(x = reorder(Group_ID, -Group_Score), y = Group_Score, fill = G_Coast_Guard)) +
  geom_col() +
  geom_hline(yintercept = 0, linetype = "dashed", color = "black") +
  labs(
    title = "Group Task Scores Categorized by Coast Guard Evaluation",
    x = "Group",
    y = "Score (Lower = Better)",
    fill = "Performance Level"
  ) +
  theme_minimal() +
  theme(axis.text.x = element_text(size = 12),
        legend.title = element_text(size = 10),
        legend.text = element_text(size = 10))
###Group Values divided by each participant##
library(ggplot2)
library(dplyr)

# Ensure the Group_Score is distinct per group
group_scores <- participants_questionnaire2 %>%
  select(Group_ID, Group_Score, G_Coast_Guard) %>%
```

```
  distinct()


# Plot
ggplot() +
  # Group bars
  geom_col(
    data = group_scores,
    aes(x = Group_ID, y = Group_Score, fill = G_Coast_Guard),
    width = 0.6,
    alpha = 0.6
  ) +
  # Participant dots
  geom_jitter(
    data = participants_questionnaire2,
    aes(x = Group_ID, y = Score_Activity, color = Coast_Guard),
    width = 0.15, size = 3
  ) +
  labs(
    title = "Group Scores and Individual Participant Scores",
    x = "Group",
    y = "Score (Lower = Better)",
    fill = "Group Performance",
    color = "Participant Performance"
```

```
  ) +
  theme_minimal() +
  theme(
    axis.text.x = element_text(size = 12),
    legend.title = element_text(size = 10),
    legend.text = element_text(size = 10)
  )
###Frequency Tables###
# Load libraries
library(dplyr)
library(readxl)

# Load your data (update the path as needed)
data <- read_excel("four_groups.xlsx")

# Filter for 'State start' events only
start_events <- data %>%
  filter(Event_Type == "State start")

# Function to create summary per group
summarize_group <- function(group_name) {
  group_data <- start_events %>% filter(Observation == group_name)
```

```
  total_duration <- sum(group_data$Duration_sf, na.rm = TRUE)

  summary_table <- group_data %>%
    group_by(Behavior) %>%
    summarise(
      Frequency = n(),
      Total_Duration = sum(Duration_sf, na.rm = TRUE)
    ) %>%
    mutate(
      Percentage = round((Total_Duration / total_duration) * 100, 2)
    ) %>%
    arrange(desc(Percentage))

  return(summary_table)
}

# Get summaries for Group 2, 3, and 4
group1_summary <- summarize_group("Group 1")
group2_summary <- summarize_group("Group 2")
group3_summary <- summarize_group("Group 3")
group4_summary <- summarize_group("Group 4")

# View the tables
```

```
print("Group 1:")

print(group1_summary)


print("Group 2:")

print(group2_summary)


print("Group 3:")

print(group3_summary)


print("Group 4:")

print(group4_summary)

# Load ggplot2

library(ggplot2)


# Function to plot summary for each group

plot_group_summary <- function(summary_table, group_name) {

  ggplot(summary_table, aes(x = reorder(Behavior, -Percentage), y = Percentage)) +

    geom_bar(stat = "identity", fill = "skyblue") +

    geom_text(aes(label = paste0(Percentage, "%")), vjust = -0.5, size = 3.5) +

    labs(

      title = paste("Behavior Duration % -", group_name),

      x = "Behavior",

      y = "Percentage of Total Time"
```

```
  ) +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
}

# Plot each group's summary
plot_group_summary(group1_summary, "Group 1")
plot_group_summary(group2_summary, "Group 2")
plot_group_summary(group3_summary, "Group 3")
plot_group_summary(group4_summary, "Group 4")
###SINGLE TABLE##
# Load libraries
library(dplyr)
library(readxl)
library(tidyr)

# Load your dataset (update the file path if needed)
data <- read_excel("four_groups.xlsx")

# Keep only 'State start' events
start_events <- data %>%
  filter(Event_Type == "State start")
```

```
# Function to get frequency per behavior for a group
frequency_summary <- function(group_name) {
  start_events %>%
    filter(Observation == group_name) %>%
    count(Behavior, name = paste0("Frequency_", group_name))
}

# Generate frequency tables for all groups
group1 <- frequency_summary("Group 1")
group2 <- frequency_summary("Group 2")
group3 <- frequency_summary("Group 3")
group4 <- frequency_summary("Group 4")

# Combine into one wide table
combined_frequencies <- full_join(group1, group2, by = "Behavior") %>%
  full_join(group3, by = "Behavior") %>%
  full_join(group4, by = "Behavior") %>%
  arrange(Behavior)

# View the result
print(combined_frequencies, n = Inf)
###Behavior Percentages for Group 1###
# Load required packages
```

```
library(dplyr)
library(readxl)

# Load your dataset (update file path if needed)
data <- read_excel("four_groups.xlsx")

# Filter for 'State start' events only
start_events <- data %>%
  filter(Event_Type == "State start")

# Filter only Group 1
group1_data <- start_events %>%
  filter(Observation == "Group 1")

# Calculate total duration for Group 1
total_duration_group1 <- sum(group1_data$Duration_sf, na.rm = TRUE)

# Summarize behavior durations and calculate percentages
group1_summary <- group1_data %>%
  group_by(Behavior) %>%
  summarise(
    Frequency = n(),
    Total_Duration = sum(Duration_sf, na.rm = TRUE),
```

```
    .groups = "drop"
  ) %>%
  mutate(
    Percentage = round((Total_Duration / total_duration_group1) * 100, 2)
  ) %>%
  arrange(desc(Percentage))

# View the result
print(group1_summary)
# Load ggplot2 for visualization
library(ggplot2)

# Plot behavior percentages for Group 1
ggplot(group1_summary, aes(x = reorder(Behavior, -Percentage), y = Percentage)) +
  geom_bar(stat = "identity", fill = "steelblue") +
  geom_text(aes(label = paste0(Percentage, "%")), vjust = -0.5, size = 3.5) +
  labs(
    title = "Behavior Time Percentage – Group 1",
    x = "Behavior",
    y = "Percentage of Total Time"
  ) +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```