# A Laboratory Study on Distributed Problem Solving by Taking Different Viewpoints

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**Abstract**

In this study, we investigated effects of having different perspectives in solving collaborative tasks. A simple reasoning task was given to several pairs of participants, each of whom discussed their views with their partner. Protocol analysis was performed to reveal how people exchange information with a partner who has a different perspective to achieve successful collaboration. In the experiment, we controlled participants' perspectives, where the appearance of visual images was manipulated based on Gestalt psychological theory. Three conditions were set up: (1) the distributed-view condition, where one of two different perspectives was presented separately to each of the participants in a pair; (2) the dual-view condition, where two equivalent perspectives were presented together to both participants; and (3) the single-view condition, where only a single perspective was presented to both participants. The experimental results showed no significant differences in problem-solving performance between the distributed- and dual-view conditions; however, the participants in the distributed-view condition performed significantly better than those in the single-view condition. The protocol analysis also indicated that the participants in the distributed-view condition engaged in the task with their partner in complementary interactive ways, highlighting the nature of successful interaction style in collaboration.

**Keywords:** Problem solving; Distributed cognition; Collaboration

## Introduction

Several approaches have been used to investigate the nature of collaboration in cognitive science, such as field studies, psychological experiments, and computer simulations. These studies have indicated that obtaining different perspectives generally promotes effective interactions in human collaborative problem solving. For example, Dunbar (1995) and his colleagues investigated the usage of inductive reasoning in a scientific research group, and proposed a concept of distributed reasoning where the group members achieve their goals by taking charge of different types of inference. It was also found that getting different viewpoints and strategies is effective in promoting explanation activities (Okada & Simon, 1997; Miyake, 1986), leading reconstruction of the external representation (Shirouzu, Miyake, & Masukawa, 2002), and improving discovery performance by producing falsifying instances in scientific reasoning (Miwa, 2004).

Despite the positive effects shown by the brief summery above, there are general difficulties in interaction to be overcome when considering this kind of collaboration. These difficulties, such as perceptual and cognitive differences, are brought about by individuals' contextual and background knowledge, and the ambiguity of language expression and comprehension. For example, Hanson (1958) discussed a phenomenon of incommensurability between individuals where even when referring to the same physical reality, the individuals may construct different facts from an identical reality based on their different knowledge and contexts. Studies on discourse analysis have shown evidence that individuals' background and contextual knowledge invoke uncertainty when they transmit their intention during communication (Fodor, 1975). Keysar, Barr, Balin, and Brauner (2000) conducted an experiment in which participants' eye motions were analyzed, and demonstrated that people occasionally use an egocentric heuristic when they communicate. They argued that this egocentric heuristic may sometimes be successful in reducing ambiguities, though it could cause systematic errors.

To investigate how group members having different perspectives overcome difficulties in interaction, it is important to focus on how the individuals share information and reach consensus. In studies on group decision making, it has been suggested that information shared among group members is an important factor for successful decision making (Tindale, Kameda, & Hinsz, 2003). In studies on teamwork, Mathieu, Heffner, Goodwin, Cannon-Bowers, and Salas (2005) indicated that in teamwork the degree of agreement of members' mental models and tasks influences the team's performance; they pointed out the importance of information shared in collaborative activities. Thalemann and Strube (2004) focused on information shared during collaborative problem solving, and showed that sharing information on the initial and goal stages leads to better performance than does sharing information on operators. However, these studies have not focused on the nature of "how" information is shared during interaction.

In the field of ethnomethodology, it is said that people organize interaction through social customs called frames (Garfinkel, 1967). Using these frames, people come to know how to talk, observe, and behave during social interaction. For example, Sacks, Scheglioff, and Jefferson (1974) say that people use a turn-taking system during conversation. The concept of this turn-taking system suggests that there is an organized pattern that depends on a specific situation. Taking on this point of view, we hypothesize that there could be some type of association pattern extracted through conversation in collaborative problem solving by members having different perspectives. However, there have been no studies that focus on the information-sharing process and analyze the conversation pattern in controlled experimental settings. In this work, we therefore set up a situation in which two participants having different perspectives interact with each other, and analyze their conversation patterns through performing a protocol analysis.

## Purpose of Study

### Research framework

Figure 1 shows the situation of collaboration that we discuss in this study. In the figure, two problem solvers observe the same physical object. We call this object Data. The two problem solvers observe the Data based on their own context and background knowledge, which provide different perspectives. Therefore, each problem solver observes the Data through a different filter. The filters construct individuals' perceived reality to be different, and we call this perceived reality Fact. Any two problem solvers will construct different Facts from identical Data, communicating through interactions between the different Facts and thus facing a conflict. They must resolve this conflict to reach a solution.

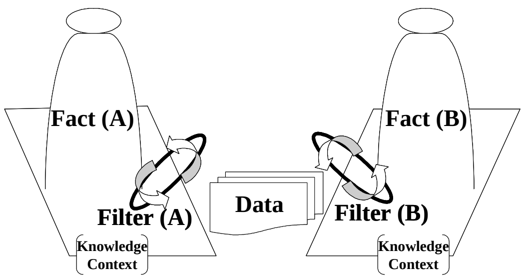


Figure 1: Data and Facts

### Aim of this study

We conduct a laboratory study to investigate the following two points based on the research framework presented above.

1. Understanding differences in interaction of collaborating pairs who have different perspectives and pairs who have the same perspectives.

2. Identifying factors for successful problem solving in interaction of collaborating pairs who have different perspectives.

## Method

### Materials

We propose the materials for setting up a situation in a laboratory where pairs who have different perspectives collaboratively solve a problem. We control the degree of tendency to focus on each of two different-colored surfaces to manipulate participants' perspectives by adopting Gestalt psychological principles (Koffka, 1935).

As shown in Fig. 2, we constructed stimuli where black and white unit squares are randomly arranged on a 6- by 6-grid. We call each surface comprising the black and white squares an "object ". In the example stimulus in Fig. 2, there are a total of ten objects comprising five black objects and five white ones. When constructing each stimulus, we assume the following two constraints: (1) the number of black and white unit squares is identical; and (2) half of the four corners of each stimulus are occupied by one of the two colors.

When presenting these stimuli on a black background, white objects pop out as a figure (black objects become a ground); therefore, participants have the perspective of focusing on the white objects. In addition, when presenting the stimulus on a gray background, participants are led to have two perspectives, focusing on both black and white objects.

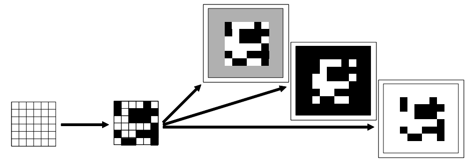

Figure 2: Example of Materials

### Procedures

Two participants collaborated through computer terminals and solved the problem. The participants were separated by a partition so that each could not see the other's display. Interaction through conversation only was permitted.

First, a square frame was presented for one second, then the stimulus was presented in the frame. The presentation of a frame and a stimulus was regarded as one trial (see Fig. 3). Basically, each stimulus was presented for thirty seconds; however, the participants were able to move on to the next trial by requesting it from the experimenter. The participants were required to find a target rule: regularity of a sequence of numbers of objects presented inside the frame as shown in Fig. 3. As described below, the regularity of the sequence was experimentally manipulated.

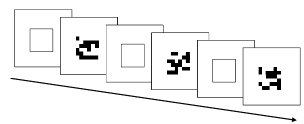

Figure 3: A series of presented stimuli

Participants started to solve the task after receiving their instructions from the experimenter. Participants who discovered the target rule were able to terminate the experiment whenever they decided. If participants could not discover the rule within thirty minutes, the experiment was terminated by the experimenter. When the experiment was terminated, participants were required to complete a questionnaire, in which an example stimulus being presented on the participants' display was shown. The participants were required to draw an arrangement of black and white objects on the partner's display when their own arrangement was the one in the presented stimulus.

### Conditions and Participants

We set up three experimental conditions to compare the characteristics of interaction of pairs having different perspectives and those having the same one (see Fig. 4).

- Distributed-view condition:

  In the distributed-view condition, to one subject the stimuli are presented on a black background whereas to the other one, the same stimuli are presented on a white background. Therefore, in this condition, two perspectives, focusing on the black and white objects, are distributed to the two participants.

- Dual-view condition:

  In the dual-view condition, the stimuli are presented on a gray background. Therefore, the participants simultane-

Table 1: Example of Sequences of the numbers of objects

| | Introductory phase | | | | | Conflict phase | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Numbers of white objects | ... | 3 | 4 | 5 | 6 | 2 | 2 | 6 | 5 | 2 | 5 | 6 | 7 | ... |
| Numbers of black objects | ... | 3 | 4 | 5 | 6 | 4 | 6 | 4 | 7 | 4 | 3 | 4 | 5 | ... |
| Total | ... | 6 | 8 | 10 | 12 | 6 | 8 | 10 | 12 | 6 | 8 | 10 | 12 | ... |

ously have two perspectives, focusing on both of the colored objects.

- Single-view condition:

  In the single-view condition, to both participants the stimuli are presented on the black (or white) background. Therefore, both participants have only one perspective, focusing on only one of the two colored objects.

Fifty undergraduate students, arranged into twenty-five pairs, participated in the experiment. Two pairs were excluded from the analysis because they knew the details of the experiment beforehand. Eleven pairs were assigned to the distributed-view condition, six pairs to the dual-view condition, and six pairs to the single-view condition.

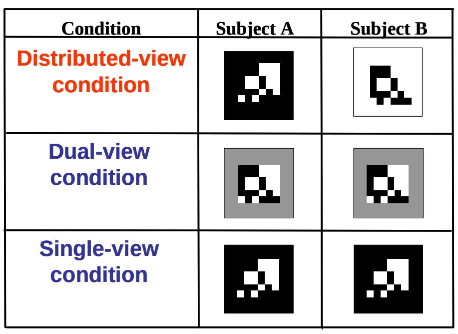


Figure 4: Experimental Conditions

## Target rule

Here, we explain how to manipulate a sequence of numbers of objects in the distributed-view condition. The manipulation is identical in the other two conditions. In the introductory phase, the participants are led to have one of the following distributed perspective separately: either a perspective focusing on black objects or one focusing on white ones. After this phase, a conflict phase follows in which the participants are required to integrate the two distributed perspectives to discover the target rule (See Table 1).

- Introductory phase

  The sum of the numbers of black and white objects is manipulated so that the sum will circulate, for example, 6, 8, 10, and 12. Under this constraint, each number of white (or black) objects also individually circulates (e.g., 3, 4, 5, and 6). In this phase, even though two participants have different perspectives, each of which focuses on one of either a black or white object, no conflict occurs between the two participants because each continuously reports identical numbers to the other. Additionally, in this phase it is not expected that they will notice they have different perspectives.

- Conflict phase

  After the seventeenth trial, the sum of the numbers of the two kinds of objects keeps circulating (such as 6, 8, 10, and 12); however, the regularity of the sequence of black objects is broken (such as 2, 2, 6, and 5). In this situation, the sequence of white objects has become 4, 6, 4, and 7 to maintain regularity. At this point, a conflict will occur during collaboration. To achieve the goal i.e., to discover the sequence of 6, 8, 10, and 12, as a target rule, the participants have to integrate the two distributed perspectives.

# Problem-Solving Performance

We estimate the problem-solving performance using the following two indices.

- Discovery ratio:

  The ratio of the number of pairs who discovered the target rule (the sequence of numbers of black and white objects) to the number of all pairs.

- Understanding ratio:

  The ratio of the number of participants who described an arrangement of objects on the partner's display correctly in the questionnaire to the number of all participants.

Table 2 shows the results of the analysis.

## Discovery ratio

We used Fisher's exact test to detect the difference in the discovery ratio between the distributed-view condition and the other two conditions. The difference was not significant between the distributed-view condition and the dual view condition ($p = 0.999$), whereas the difference between the distributed- and single-view conditions was significant ($p = 0.042$). This result indicates that there were no differences in the problem solving performance between the distributed-view condition and dual-view condition. In contrast, the problem solving in the distributed-view condition showed better performance than in the single-view condition. These results mean that the pairs having different perspectives showed the same or even better performance in problem solving than the pairs having the same perspectives. We will perform a protocol analysis to investigate whether the process of reaching the solution was also identical between the distributed- and dual-view conditions, where the problem-solving performance was almost the same.

Table 2: Discovery and Understanding ratios. Numbers inside parentheses represent the number of successful and unsuccessful participants.

| | Distributed view | Dual view | Single view |
|---|---|---|---|
| Discovery | 0.54(6/5) | 0.5(3/3) | 0(0/6) |
| Understanding | 0.45(10/12) | 0.92(11/1) | 0.92(11/1) |

### Understanding ratio

Using Fisher's exact test, we detected statistically significant differences in the understanding ratio between the distributed-view condition and the dual-view condition ($p$ = 0.011). The difference between the distributed- and single-view conditions was also statistically significant ($p$ = 0.011). As Table 2 shows, misunderstanding occurs more often when the participants have different perspectives. These results seem to be reflected by the experimental setting where conflicts of interaction occur only in the distributed view condition. Therefore, the participants in that condition were unable to describe an arrangement of objects on the partner's display correctly because of the conflicts that occurred during the task.

## Protocol analysis

As mentioned in the explanation of our research framework described in Fig. 1, conversation between two participants occurs through interaction of their Facts constructed from the Data. In the protocol analysis, we have to detect which object, black or white, as Data each verbalization as Facts refers to. In the following we represent verbal data mapped with the black and white objects as BLACK and WHITE.

### Coding

All participants' dialogs were transcribed and segmented into unit sentences as the participants' verbal protocols. Words related to color, number, and region of objects were extracted from the protocols. Then, the words were coded as either BLACK or WHITE in reference to the stimulus presented when the words had been verbalized during the task. The coding procedure is indicated as follows, using example protocols and stimuli indicated in Table 3 and Fig. 5.

Each number verbalized was coded based on the number of each black or white object that was actually presented on the display. For example, one participant said, "I see three objects on the screen." We coded this verbalization as BLACK because there were actually three black objects on the screen (See Fig. 5). When the numbers of two kinds of objects were identical in a stimulus, verbalization for the numbers was coded as "undetected" because we could not map the verbal data to either BLACK or WHITE. Verbalization related to the color of objects was coded simply based on the verbalization itself. For example, one paticipant said "Oh! I was looking at the white color." This was coded as WHITE. Verbalization related to the region of objects was coded based on the stimulus presented when the words were verbalized. For example, one paticipant said, "I see a tetrazoid in the lower-right corner.". This was coded as BLACK because the black tetrazoid was actually observed in the stimulus.

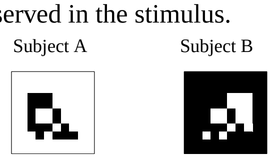


Figure 5: Stimuli used in Table 3.

### Indices for evaluation

The frequencies of BLACK and WHITE labels were analyzed to detect which perspective, focusing on black or white objects, the participants had. We adopt the following two indices for the analysis.

Table 3: Example of coding

| | | Fact | Data |
|---|---|---|---|
| Number | Subject A | "I see three objects on the screen." | BLACK |
| | Subject B | "Really, aren't there five objects?" | WHITE |
| Color | Subject A | "I'm looking at the black one." | BLACK |
| | Subject B | "Oh! I was looking at the white color." | WHITE |
| Reigion | Subject A | "I see a tetrazoid in the lower-right corner." | BLACK |

**Individual activities** First, we analyze a bias of perspective in individuals by using an index *Bias* defined in the following. In Table 4, $n_1$ indicates the frequency of BLACK and $n_2$ indicates the frequency of WHITE, where *Bias* is defined in the following formula.

$$Bias = \frac{|n_1 - n_2|}{n_1 + n_2}$$

Table 4: BLACK and WHITE tendency

| | BLACK | WHITE |
|---|---|---|
| Subject A | $n_1$ | $n_2$ |

*Bias* ranges from zero to one, where a value closer to one indicates that the subject is fixed to have one partial perspective focusing on either black or white objects. A value closer to zero, on the other hand, indicates that the subject has two perspectives, focusing on both black and white objects.

**Group activities** Next, we analyze the correlation of perspectives in pairs by using an index $\phi$ defined in the following. Table 5 shows an example pattern of the frequencies of BLACK and WHITE in a pair of participants, where the index $\phi$ is defined by the following formula.

$$\phi = 0 (n_{1.} = 0, n_{2.} = 0, n_{.1} = 0, n_{.2} = 0)$$

$$\phi = \frac{|n_{11}n_{22} - n_{12}n_{21}|}{\sqrt{n_{1.}n_{2.}n_{.1}n_{.2}}}$$

(other than those listed above)

Table 5: 2 × 2 cross matrix

| | BLACK | WHITE | Sum |
|---|---|---|---|
| Subject A | $n_{11}$ | $n_{12}$ | $n_{1.}$ |
| Subject B | $n_{21}$ | $n_{22}$ | $n_{2.}$ |
| Sum | $n_{.1}$ | $n_{.2}$ | $N$ |

Furthermore, $\phi$ also ranges from zero to one. For example, $\phi$ becomes large when a subject A verbalizes many BLACKs, i.e., $n_{11}$ is large and $n_{12}$ is small, and a subject B verbalizes many WHITEs, i.e., $n_{22}$ is large and $n_{21}$ is small. On the other hand, $\phi$ becomes small when both participants verbalize one of two colored objects in a one-sided manner such as BLACKs where $n_{11}$ and $n_{21}$ are large and $n_{12}$ and $n_{22}$ are small; or each subject verbalizes both colored objects where both $n_{11}$ and $n_{12}$(and/or $n_{21}$ and $n_{22}$) are nearly identical. This means a value closer to one indicates that the perspectives of the pair of participants are distributed and correlated, and role sharing of the pair of participants emerges in the interaction. On the other hand, a value closer to zero indicates that the participants are fixed to have one perspective, focusing on either black or white objects, or two perspectives, on both black and white objects, but role sharing does not occur.

## Results

The participants were divided into successful pairs who found the target rule, and unsuccessful pairs who did not. The two indices defined above were estimated for each of the two groups

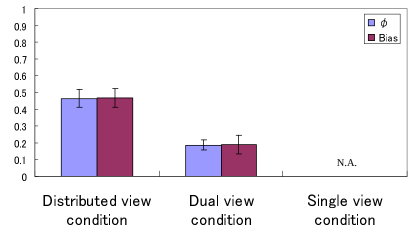


Figure 6: $\phi$ and *Bias* for the participants who discovered the rule. The bars indicate standard deviations.

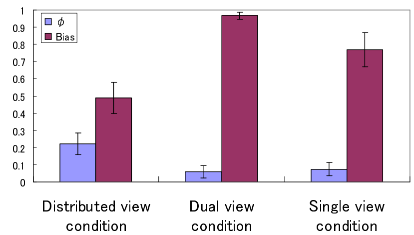


Figure 7: $\phi$ and *Bias* for the participants who did not discover the rule. The bars indicate standard deviations.

**Successful pairs** The result for the successful pairs is shown in Fig. 6. There were no successful pairs in the single-view condition. A 2 (indices: $\phi$ and *Bias*) × 2 (conditions: distributed and dual) ANOVA was conducted, revealing that the main effect of the conditions was significant ($F(1,16) = 11.192, p < .01$), but neither the main effect of the evaluated indices ($F(1,16) = 0.007, n.s.$) nor the interaction between the two factors was significant ($F(1,16) = 0.006, n.s.$). This result shows that the scores of both indices, $\phi$ and *Bias*, in the distributed-view condition were greater than those in the dual-view condition. This means that problem solving in the distributed- and dual-view conditions showed almost the same performance; however, the quality of the interaction between pair participants was different. That is, in the distributed view-condition, each of a pair of participants had one partial perspective with respects to individual problem-solving activities. From the viewpoint of group activities, however role sharing where each of pair participants compensates for the other emerged. On the other hand, in the dual-view condition, each of pair participants had two perspectives, focusing on both kinds of objects; role sharing did not appear.

**Unsuccessful pairs** The result for the unsuccessful pairs is shown in Fig. 7. A 2 (indices: $\phi$ and *Bias*) × 3 (conditions: distributed, dual, and single) ANOVA was conducted, revealing that the interaction between the two factors was significant ($F(1,25) = 7.086, p < .01$). The main effect of the indices reached significance ($F(1,25) = 79.192, p < .01$) but the main effect of the conditions was not significant ($F(1,25) = 2.127, n.s.$). Analysis of the simple main effect showed that the score of *Bias* was higher than that of $\phi$ in every condition. [In the Distributed-view condition ($F(1,9) = 7.596, p < .05$); in the dual-view condition ($F(1,5) = 366.084, p < .01$); In Single view condition ($F(1,11) = 28.362, p < .01$)] These results show that, in every experimental condition, the individuals were fixated to have one partial perspective. Moreover, in group activities both members tended to be drawn into one partial perspective, either black or white, and role sharing did not emerge. In the single-view condition, both members were forced to focus on one figure, and found it difficult to notice another ground perspective. In the dual-view condition, even though each participant seemed able to perceive both black and white objects, why did a similar interaction to the one in the single-view condition emerge? In these cases, during the early stage of problem solving, one subject proposed counting the numbers of black objects while ignoring white ones, and the other accepted it. Once this agreement was concluded, it was very difficult for them to change this assumption throughout the task. In the distributed-view condition, both participants communicated with each other while sharing one partial perspective, focusing on one of two kinds of objects. This means that one subject grasped the ground perspective, even though it was difficult to perceive the ground objects, and communicated with the other while taking the ground perspective.

## Discussion

### Successful Pairs in the Distributed-View Condition

The protocols of the successful pairs in the distributed-view condition indicated that they interacted with each other through role sharing. Even though the participants provided information based on an egocentric strategy for individual activities, this method of interaction resulted in well-organized group activities where one compensates for the other's lack of information.

We discuss these results based on a teamwork study conducted in a natural setting and another study using computer simulations based on a multi-agent system. The well-organized group activities performed by the successful participants could be understood based on the theory of the distributed cognitive system, proposed by Hutchins (1995), who carefully observed teamwork activities in a marine vessel. The distributed cognitive system is an inductive bottom-up system where a set of local interactions creates a global structural order. The analysis based on the two indices defined in the study indicated that each of the participants in a pair interacted with the other from his/her own point of view, meaning that he/she had a particular local perspective. There was little difference in the bias of the individuals' perspective between the successful and unsuccessful pairs. However, role sharing in group activities emerged only in the successful pairs. This indicates that the interactions in the successful pairs are characterized by the following two aspects: to provide his/her egocentric perspective in local activities, and to generate structured role sharing in global activities created from the local activities.

This result is also consistent with the study of Barr (2004), where multi-agent computer simulations were conducted, showing that a population of egocentric agents can establish and maintain systematic conventions without sharing common knowledge. The simulation results agree with our experimental results where egocentric interactions, in which information was shared based on a local partial perspective, may provide a successful solution. Since our experiment was conducted in a closed-ended situation, the ecological validity is not high. Therefore, in future work investigation in more natural settings is needed.

### Unsuccessful Pairs in the Distributed-View Condition

The protocols of the unsuccessful pairs indicated that one subject in a pair interacted with the other focusing on the ground colored objects that were difficult to perceive. This means the perspective of this subject was shifted toward the partner's figure perspective. We attempt to understand this phenomenon based on two explanations presented below.

One explanation is conformity phenomena appearing when individuals are required to decide something in a majority. We consider this phenomenon, observed in our experiment, by adopting the theory of Deutsch and Gerard (1955), two types of social influence were assumed. They divided social influence into two types: normative influence and informative influence. Normative influence is brought about by social pressures applied by other group members. On the other hand, informative influence arises from usage of one partner's behavior as information to adjust his/her own behavior.

The participants who participated in our experiment were acquaintances; therefore, we expected no socially biased relationships to exist among them. Therefore, it is impossible to assume that the participants experienced social pressure from their partners. It appears the participants shifted their perspective because they did not understand which type of objects, black or white, should have been focused on. Consequently they tried to determine how to count the number of objects based on information given by the partner. This ivestigation implies that the informative influence is predominant over the normative influence.

The other possibility is that the participants intentionally took the opposite perspective to solve the contradiction. This could be interpreted as an adaptive process implemented while the participants were developing their communication system. When a contradiction occurred in the conflict phase, the participants needed to change communication style that had been used so far and construct a new communication system. The behavior of the participants whose perspective shifted toward the partner's could be interpreted as an adaptive behavior that occurred in order to construct a new communication system, as pointed out by Galantucci (2005).

## Conclusion

In this study, we analyzed the characteristics of paired problem solvers who have different perspectives, compared with those who have the same perspectives. The protocol analysis showed that the successful pairs holding different perspectives constructed a mutually complementary interactive pattern such as role sharing, even though each of them locally took his/her partial perspective. On the other hand, in the unsuccessful pairs, one of the participants shifted his/her perspective to the partner's perspective, meaning that this subject interacted with the partner while holding the ground perspective.

In future work, we will analyze the structures of distributed cognition in collaborative problem solving by using more sophisticated methods of analysis, such as eye-motion analysis.

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