Title
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Abstract

In this study, we investigated the nature of establishing common ground during collaborative problem solving. Our goal was to investigate the following two points: (1) if the establishment of common ground leads to successful problem solving, and (2) how the two factors, communication experience and the richness of media, affect the establishment of common ground. We conducted a psychological experiment by constructing a situation where two participants engage in a rule discovery task with different perspectives. While solving the task, each of the participants confronts miscommunication about the other's perspective and has to manage to overcome this situation. The results show: (1) the establishment of common ground actually enhances successful problem solving, (2) communication experience between the members improves the establishment of common ground and as a result enhances successful problem solving, and (3) rich communication media also enhances the establishment of common ground and successful problem solving. The influences of the two factors, communication experience and richness of media are discussed both empirically and theoretically.

Keywords: Collaborative Problem solving; Common ground; Prior experience; Communication media

Introduction

In the field of cognitive science, several approaches have been used to investigate the nature of collaboration, 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) investigated the usage of inductive reasoning in a scientific research group. He 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 (Miyake, 1986; Okada & Simon, 1997), leading the reconstruction of the external representation (Shirouzu, Miyake, & Masukawa, 2002), and improving discovery performance by producing falsifying instances in scientific reasoning (Miwa, 2004).

However, there are general difficulties in such communication when people with different perspectives collaborate in problem solving (Hayashi, Miwa, & Morita, 2006). These difficulties are the problems of communication such as miscommunications, which often emerges in communication among different cultures. These miscommunications occur as a result of members' different knowledge and contexts, which are brought about by their different backgrounds. In the following, we discuss about establishing common ground as a crucial factor for overcoming the miscommunications.

Common ground

In linguistics, many studies have accumulated to investigate how speakers establish common ground during conversation. Recently, research has become active on the cognitive mechanisms involved in how people establish common ground during conversation (Richardson & Dale, 2005). Clark and Brennan (1991) uses a term called Grounding as an interactive process by which communicators exchange evidence in order to reach mutual understandings. It is important to establish common ground in collaborative problem solving and decision making, especially in a situation where members with different perspectives collaborate together.

Factors influencing common ground

Next, we discuss two important factors that may influence common ground. First, one of the important factors that influence the establishment of common ground is the familiarity of a partner.

For example, Fussell and Krauss (1992) investigated that the members' relationship influences their communication strategies. The result showed that the understandings of the messages they used differed depending on their relationship. Uhler and Clark (2001) investigated methods for enhancing group discussions. The result showed that group discussions preceded by interpersonal communication were more active than those without such communication. These studies imply that the establishment of common ground is influenced by whether members have communication experiences or no experiences.

As a second factor, it is pointed out that the establishment of common ground becomes difficult in computer mediated communication such as communication via telephone and electronic mail. According to Clark and Brennan (1991), the cost for establishing common ground is different depending on the types of media. For example, in face-to-face communication, people can understand the partner's intention by focusing on the tone of their voices or by watching their facial expressions and gestures. The cost for establishing common ground is relatively small in such a situation because they can refer to multiple types of information during communication. But in communication by e-mail and chatting through the Internet, non-verbal interaction is prohibited and symbolic information is also limited. In such a situation, the cost for establishing common ground becomes large because available information is limited. This view implies that communication media also influences the establishment of common ground.

In this study, we examine how these two factors affect common ground during collaborative problem solving.

Goal of our study and hypothesis

Our goal is to investigate the next two points:

1. If the establishment of common ground leads to successful problem solving,
2. How the two factors, communication experience between the members and the richness of media connecting them, affect the establishment of common ground.

Our hypotheses are as follows.

H1: The establishment of common ground enhances successful problem solving.

H2: Communication experience between the members enhances the establishment of common ground and, as a result, successful problem solving.

H3: Rich communication media enhances the establishment of common ground and successful problem solving.

Experiment paradigm

In our study, we use an experimental paradigm designed by Hayashi et al. (2006). In this paradigm, two participants engage in a rule discovery task, and each of them engages in the task with a different perspective. While solving the task, each of the participants confronts miscommunication about the other's perspective and has to manage to overcome this situation.

Controlling the participants' perspective

We controlled the degree of tendency of focusing on each of two different colored surfaces as an experimental stimulus to manipulate the participants' perspectives based on the Gestalt psychological principles (Koffka, 1935). As shown in Figure 1, we constructed stimuli where white and black unit squares are randomly arranged on a six $\times$ six grid.

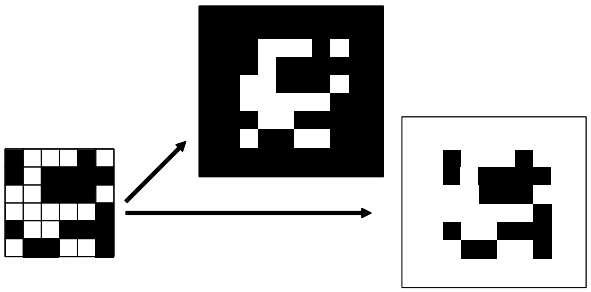

Figure 1: Example of stimuli

We call each surface comprising the white and black squares an Object. In an example stimulus in Figure 1, there is a total of ten Objects comprising five black Objects and five white Objects. This stimulus is displayed on either a black or white background. The participants acquire a single perspective focusing on Objects where the objects' color is the opposite from the background color.

Two participants, collaborating through computer terminals, were separated by a partition so that neither could see the partner's display (see Figure 2). First a square frame was presented for one second, and then the stimulus was presented in the frame. The presentation of a frame and a stimulus is regarded as one trial (see Figure 3). It was possible to move to the next trial by clicking on a button presented on the screen. The participants were required to find a target rule, i.e., the regularity of a sequence of the numbers of Objects presented inside the frame as shown in Figure 3. The participants were instructed to discuss the target rule and press the termination button presented on their screen when they reached the solution. In addition, the participants were required to examine at least 30 trials before they reached the solution. The instruction was stressed that the stimuli presented inside the frame are identical with each other.

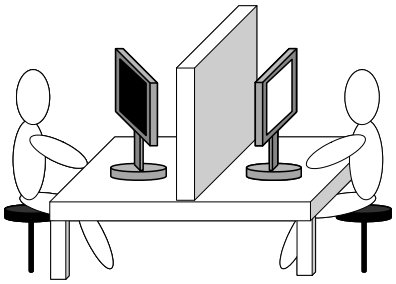

Figure 2: Experimental situation

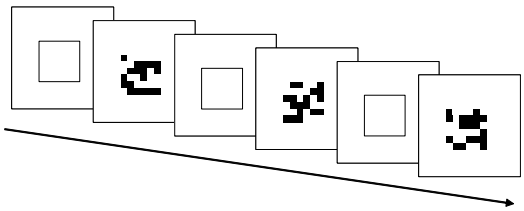

Figure 3: Series of presented stimuli

Manipulating miscommunication

Next, we explain how to manipulate a sequence of the numbers of Objects to create miscommunication. In the introductory phase, the participants are led to have one of the distributed perspectives: i.e., either a perspective focusing on black Objects or one focusing on white. After this phase, the conflict phase follows where 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 white and black Objects is manipulated to rotate, such as between 6, 8, 10, and 12. Under this constraint, each number of the white (or black) Objects also individually rotates such as between 3, 4, 5, and 6. In the introductory phase, even though the two participants have different perspectives (focusing on a black

or white Object), miscommunication does not occur between the two participants because each continuously reports the identical rotation of the numbers (i.e. 3, 4, 5, and 6) to the other. Additionally, in this phase they expect not to notice that they have different perspectives.

Conflict phase After the seventeenth trial, the sum of the numbers of black and white Objects keeps rotating; however, the number of individual colored Objects is controlled so that when the participants focus on only one of the two colors, they do not report the same numbers and miscommunication occurs. For example, in Table 1, the regularity of the sequence of black Objects has ceased, such as with 2, 2, 6, and 5; and the sequence of white Objects has become 4, 6, 4 and 7. Although in the conflict phase, the circulation of the sum of the numbers of Objects remains as 6, 8, 10, and 12, the rotation of the numbers of both black and white Objects irregularly changes against the sequence of 3, 4, 5, and 6. To discover the sequence of 6, 8, 10, and 12, as the target rule, the participants have to integrate the two distributed perspectives.

Table 1: Example of sequences of the numbers of objects

	Introductory phase					Conflict phase						
# black objects	…	3	4	5	6	2	2	6	5	2	5	…
# white objects	…	3	4	5	6	4	6	4	7	4	3	…
Sum of objects	…	6	8	10	12	6	8	10	12	6	8	…

Experiment design

Controlled factors

The experiment has a two $\times$ two between-subjects factorial design. The two factors, communication experience between the participants and the richness of media, were experimentally manipulated. The first factor was controlled by manipulating whether or not the participants had communication experience prior to the rule discovery task explained above. In the following, we call this factor the experience factor. The condition with communication experience is called the experience condition, and the condition without communication experience is called the no experience condition. The second factor was controlled by manipulating whether the participants engaged in the task with oral conversation or chatting via computer terminals. In the following, we call this factor the media factor. The condition of communication with conversation is called the conversation condition and the condition of chatting is called the chat condition.

Participants

Eighty-eight undergraduates participated in the experiment (males = 37, females = 51, *M* age = 18.47 years). All participants were randomly assigned to each condition. Table 2 shows the number of participants assigned to each condition.

Procedure

The experiment is composed of three phases.

Table 2: Experimental conditions and participants

		Experience	
		Experience	No Experience
Media	Conversation	22	22
	Chat	22	22

Phase one In this phase, we controlled the experience factor. We used a tangram task where the participants were instructed to create several types of tangram figures by combining different, small pieces within 20 minutes. In the experience condition, the participants created the tangram figures together while conversing with the partner via computer terminals. On the other hand, conversation was prohibited in the no experience condition, and the participants created the tangram figures independently.

Phase two In this phase, we controlled the media factor. In the conversation condition, the participants were able to talk with the partner while they engaged in the task. On the other hand, in the chat condition, the participants engaged in the task while using the chat system implemented on the experimental system. This chat system was set up so that the participants were able to exchange their messages alternatively. The time limit of this phase was 40 minutes.

After the task, in order to examine the performance of problem solving, i.e., finding the target rule, the experimenter asked the participants their inferred rule individually. For protocol analysis, we recorded the participants' conversation in the conversation condition, and recorded the dialogs in the system in the chat condition.

Phase three In this phase, we conducted a questionnaire to investigate the establishment of common ground. In this questionnaire, the participants' understanding was tested on how precisely they understood the arrangement of Objects on their partner's screen. In particular, to the participants an arrangement of Objects on their own screen was presented to the participants on the questionnaire sheet, and an arrangement of Objects on the partner's screen was required to be drawn. When the participants drew the partner's screen precisely, we conclude that they established common ground.

Criterion of problem solving and common ground

In our task, successful problem solving means to discover the target rule; in other words, the participants answered the target rule correctly at the final stage of Phase Two. On the other hand, the establishment of common ground means that the participants understood their partner's perspective correctly; more concretely, the participants drew the partner's screen precisely in Phase Three. Therefore, from this criterion, we examine hypothesis H1, that the establishment of common ground enhances successful problem solving.

Results

Analysis was performed for each individual, not in pairs.

Establishment of common ground and successful problem solving

Figure 4 indicates the relationship between the establishment of common ground and successful problem solving.

Here, we divided the participants into two groups: the participants who established common ground and those who did not; in each group of the participants, we calculated the ratio of successful problem solving. Fisher's exact test shows a statistical difference in the ratio of successful problem solving depending on the establishment of common ground ($p < .01$). This indicates that there was a correlation between the achievement of common ground and success in problem solving. This result supports our hypothesis H1.

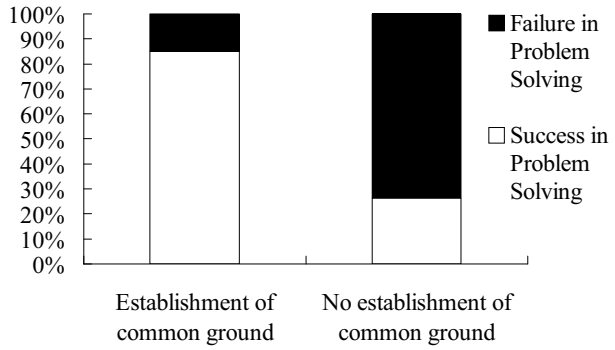

Figure 4: Relationship between establishment of common ground and successful problem solving

Performance on problem solving

Figure 5 indicates the performance of problem solving. The vertical axis represents the ratio of the participants who succeeded in problem solving, and the horizontal axis represents each experimental condition. Our interest is to investigate how the two factors, experience and media, influence the performance. Therefore, we conducted an ANOVA using the χ^2 distribution based on the arcsine transformation method. This method enables detecting both the main effects and interaction of the two experimental factors.

The analysis was performed by a two $\times$ two ANOVA with the factor of experience (experience condition vs. no experience condition) and the factor of media (conversation condition vs. chat condition) as a between-subject factor. There was a main effect in both the factor of experience and media ($\chi^2(1) = 13.72$, $p < .01$; $\chi^2(1) = 34.52$, $p < .01$). The performance in the experience condition was better than that in the no experience condition, and the performance in the conversation condition was also better than that in the chat condition. In addition, there was a marginal interaction between the two factors ($\chi^2(1) = 3.68$, $p = .055$).

The main effects of the two factors indicate that the communication experience between the participants and the richness of media actually contribute to successful problem solving.

Performance on establishment of common ground

We analyzed the ratio of the participants who successfully established common ground. Figure 6 indicates the result of the establishment of common ground. The vertical axis represents the ratio of the participants who established common ground, i.e., correctly answered the questionnaire conducted in Phase Three, and the horizontal axis represents each experimental condition.

Here, we conducted the same ANOVA using the χ^2 distribution. There was a significant main effect in both the factor of experience and media ($\chi^2(1) = 9.045$, $p < .01$; $\chi^2(1) = 2.26$, $p < .01$). The ratio of successful common ground in the experience condition was higher than that in the no experience condition, and the ratio in the conversation was also higher than that in the chat condition. In addition, there was a marginal interaction between the two factors ($\chi^2(1) = 2.73$, $p = .09$). The main effects of the two factors indicate that both the communication experience between the participants and the richness of media improve the establishment of common ground. The results of performance on problem solving and the establishment of common ground support our hypotheses H2 and H3.

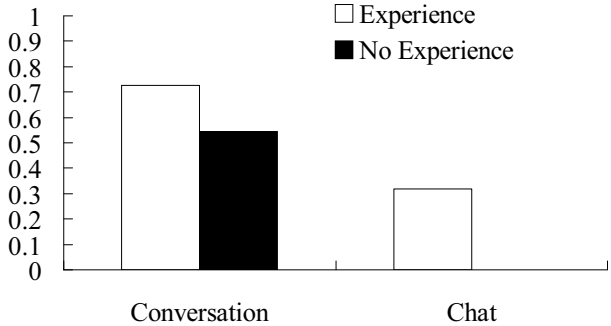

Figure 5: Performance of problem solving

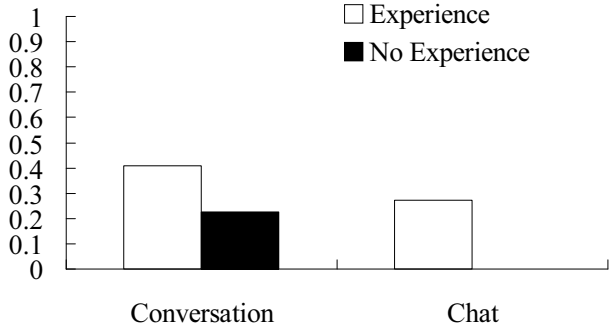

Figure 6: Establishment of common ground

Discussion and conclusions

Our goal was to investigate the following two points: (1) if the establishment of common ground leads to successful problem solving, and (2) how the two factors, communication experience and richness of media, affect the establishment of common ground.

We conducted a psychological experiment to investigate the above points. The results indicate as follows: (1) the establishment of common ground enhances successful problem solving, (2) communication experience between the members improves the establishment of common ground and as a result enhances successful problem solving, and (3) rich communication media enhances the establishment of common ground and successful problem solving. We discuss the results in the following.

Establishment of common ground and success in problem solving

The results indicated that there was a correlation between the establishment of common ground and success in problem solving; that is, the establishment of common ground led to successful problem solving.

An interesting point is that, just to solve this task rationally, the establishment common ground is not an essential qualification. The most important information to solve the task is the numbers of Objects. It is not necessarily required to understand the partner's perspective because it is possible to solve the problem by exchanging only information about the numbers of Objects. In spite of this, the participants tried to resolve miscommunication and to understand the partner's perspective, and eventually they established common ground and succeeded in problem solving.

Now, we discuss why the establishment of common ground enhanced successful problem solving. It is assumed that efforts to establish common ground aroused an intention to bring in the partner's perspective, and as a result the participants integrated the two perspectives, focusing on information given from the partner. The credibility of statements of the partner decreased in the initial stage of the conflict phase because miscommunication occurred. But as the participants deepened their understandings of the partner's perspective through establishing common ground, the credibility of the partner's statements increased. As a result, the participants focused on both colors and eventually found the target rule. On the other hand, when the participants could not understand the partner's perspective, the credibility of statements of the partner remained low. This may inhibit the attitude of trying to consider information from the partner. As a result, the participants could not find the target rule because they did not integrate the black and white Objects considering information from the partner.

Media

The main effect of the media factor indicates that it was difficult to establish common ground in the chat condition compared to the conversation condition. The chat system was designed so that the turn taking during conversation was permitted only alternatively. Therefore, the participants' turn taking in the chat condition was more enforced and communication was difficult compared to the conversation condition. It is pointed out that turn taking is an essential factor that organizes human conversation (Sacks, Scheglioff, & Jefferson, 1974). We assume that the enforcement of this turn taking influenced the failure in establishment of common ground.

In addition, the marginal interaction of the two factors, experience and media, implies that the performance in the chat situation without prior communication experience decreases remarkably compared to the other conditions. To investigate this in detail, we analyzed the process of the establishment of common ground by conducting the protocol analysis. In particular, we focus on the protocols mentioning the color of Objects and the background color of the display. The protocols about the numbers directly relate to communication for solving the problem, i.e., finding the target rule. On the other hand, the protocols about the colors are interpreted as the efforts for establishing common ground, i.e., understanding the partner's situation.

Figure 7 indicates the efforts for establishing common ground. The vertical axis represents the ratio of sentences referring to the colors to all sentences. The horizontal axis represents each experimental condition.

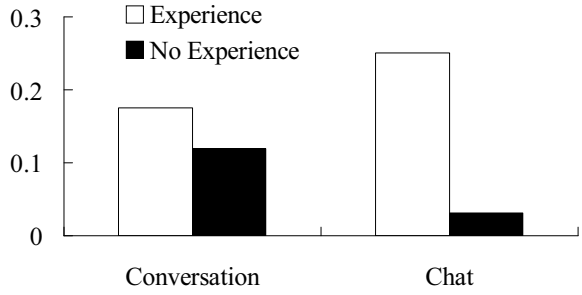

Figure 7: Efforts for establishing common ground

The analysis was performed by a two $\times$ two ANOVA with the factor of experience (experience condition vs. no experience condition) and the factor of media (conversation condition vs. chat condition) as a between-subject factor. The interaction between the two factors, experience and media, was significant ($F(1,84) = 7.16$, $p < .01$). An analysis of the simple main effect was conducted in each level of the media factor. In the conversation condition, the ratio of protocols mentioning the colors between the experience and no experience conditions was not significantly different ($F(1,84) = 1.68$, $p = .2$). On the other hand, in the chat condition, the ratio was significantly higher in the experience condition than that in the no experience condition ($F(1,84) = 25.8$, $p < .01$).

The results indicate that in the chat condition the participants' protocols about the colors definitely decreased when they did not experience prior communication. Based on the above discussion, it is assumed that the reason the performance decreased in the chat without communication experience may be because the process for establishing common ground did not emerge in such a situation.

Communication experience

The main effect of the experience factor indicates that communication experience enhances the establishment of com-

mon ground. When no verbal communication was experienced, the establishment of common ground was difficult because inadequate recognition of the partner's situation appeared due to the lack of communication experience between the participants.

In CMC (Computer Mediated Communication), we often face opportunities to communicate with someone we don't know. It has been pointed out that discussion in CMC sometimes degenerates into defamatory exchanges. This phenomenon is called Framing (Sproull & Kiesler, 1991). We assume that this is an example phenomenon that occurs by inadequate recognition of the partner due to the lack of communication experience. This false recognition about the partner in such a situation leads to preconceived impressions that are not based on facts. Based on this view, in our experiment we examine which types of inadequate recognition about the partner's situation appear especially in the no verbal communication condition. To do so, we analyzed the pictures drawn in the questionnaire sheet by the participants who were not able to establish common ground.

As a result, we found the typical incorrect figures shown in Figure 8. In the pictures, the colors of Objects, which are supposed to be physically identical, changed oppositely. This picture contradicts the instruction that each stimulus inside the frame for one participant is identical to the other stimulus for the partner. This drawing is interpreted as the deviation from the instruction. Figure 9 indicates the ratio of the participants who drew such an incorrect picture indicated in Figure 8. The vertical axis represents the ratio of the participants who drew the incorrect picture. The horizontal axis represents each experimental condition.

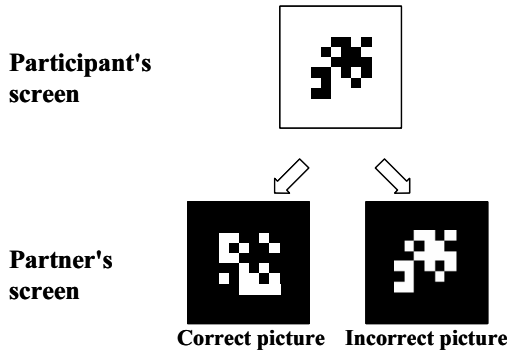

Figure 8: Example of typical incorrect figures

We conducted an ANOVA by using the χ^2 distribution. The ANOVA indicates that neither the interaction nor the main effect of the media factor was significant ($\chi^2(1) = 0.2$, $p = .65$; $\chi^2(1) = 0.001$, $p = .98$). On the other hand, there was a main effect of the experience factor. This indicates that more incorrect drawings emerged in the no experience condition than in the experience condition ($\chi^2(1) = 4.81$, $p < .05$). The result shows that the lack of prior communication experience brings about this kind of serious inadequate recognition of the partner's situation, and this eventually leads to the difficulties for establishing common ground.

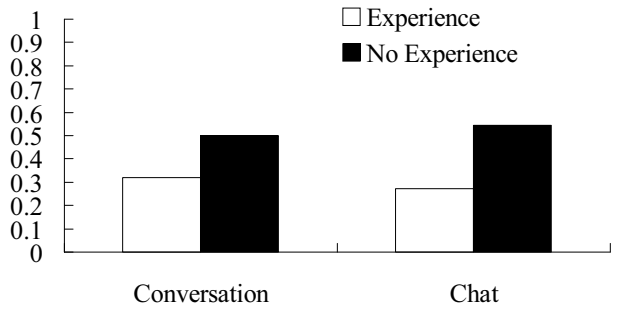

Figure 9: Typical incorrect figures

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