What are you talking about?: A Cognitive Task Analysis of how specificity in communication facilitates shared perspective in a confusing collaboration task

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Abstract

This study investigated how participant's specificity in sharing of information in collaborative problem solving was critical to them reaching a successful shared perspective. We analyzed participants' communication strategies in a collaborative task designed to make finding common ground challenging. We set out to better understand the difference between successful and unsuccessful collaborations by conducting a cognitive task analysis. From participants' utterances, we inferred cognitive processes associated with repeating communication moves and coded those processes as if-then production rules. We thereby specified the communication strategies used during interactions and developed a production-rule model to explain whether and how shared perspective developed or not. Our cognitive task analysis indicated that although all collaborating pairs described the objects they were seeing with a variety of features, the successful pairs were more specific in using combinations of features. Quantitatively, we found significant correlations between frequency of combined feature statements and success in sharing perspectives.

Keywords: Collaborative Problem Solving; Scientific Reasoning; Creativity; Coordination; Cognitive Task Analysis; Production Rules

Introduction

As discussed by cognitive scientists Herbert Simon and Allan Newell (Dasgupta, 2003), collaborative problem solving based on different perspectives helps generate new knowledge and scientific discoveries. Researchers in cognitive science have investigated the nature of collaborative problem solving (CPS), aiming to understand what kind of cognitive process underlie interactions (Okada & Simon, 1997; Salomon, 2001). Throughout these studies, it has been noted that CPS enables generation of meta-cognition, such as explanation activities (Chi, Leeuw, Chiu, & Lavancher, 1994), externalizing one's thoughts (Shirouzu, Miyake, & Masukawa, 2002), and receiving reflective responses from recipients of explanations (Miyake, 1986). Studies show that collaborating with partners with different types of knowledge and perspectives provides an opportunity to produce effective interactions (Greeno & de Sande, 2007). However, when conducting CPS research with individuals who hold different perspectives, it is important to consider constraints, such as interpersonal conflicts, which may occur due to the discrepancies among perspectives (Hayashi, 2018). Previous studies of dyads show that individuals work by role-sharing each other's different perspective (Hayashi, Miwa, & Morita, 2006). However, it is not fully understood what kind of communication processes underlie such activities, particularly regarding how dyads establish common ground by which to share their perspectives. To investigate this issue, this study reanalyzed data from Hayashi et al. (2006), by conducting cognitive-task analysis (Koedinger & Terao, 2002; Rittle-Johnson & Koedinger, 2001). We first review the CPS literatures, discuss the constraints on communication, and explain how common ground is achieved in our research paradigm (CPS based on different perspectives). We then state our specific goals and hypotheses.

CPS by taking different perspectives

Previous studies of scientific discovery in CPS showed scientists reason by taking different perspectives during interactions; this is termed distributed reasoning (Dunbar, 1995). Discussing different types of knowledge among individuals provides opportunities to generate conceptual changes (Roschelle, 1992), and is important for facilitating conceptual understanding (Greeno & de Sande, 2007). With this theoretical background, studies have shown that arguments and explanations within groups facilitate conceptual changes (Asterhan & Schwarz, 2009). Arguments made by group members by taking different perspectives are considered types of constructive and interactive joint collaborative activity (Chi, 2009); this is accomplished by coordinating individuals who hold different knowledge and perspectives. There exist group-based learning practices called jigsaw learning (Aronson & Patnoe, 1997), which focus on generating arguments by bringing together group members with different knowledge and asking them to discuss and integrate their knowledge. Throughout such studies, results show that cognitive bias and disagreements represent constraints on interaction; these factors should be considered when investigating CPS performance. Taking in these issues into consideration, Hayashi et al. (2006) conducted a laboratory based experiment using a simple reasoning task in which participants experienced difficulties on establishing common ground about each other's perspective. The results showed that when participants made substantive contributions to others by providing information by role sharing, they were able to generate broader perspectives by which to solve the problem. Moreover, successfully establishing coordination, such as correctly understanding others' perspectives, led to success in collaborations. Regarding the coordination process, recent studies of CPS have noted that collaborative problem-solving is composed of the following phases: (1) task work (problem solving), which builds internal knowledge, and (2) team work (coordination), during which internalized knowledge is exchanged and shared to build collective knowledge (Fiore, Rosen, Smith-Jentsch, Salas, & Letsky, 2010). However, it is not fully understood what kinds of knowledge and interaction strategies are used for coordination in team work, especially for CPS based on different perspectives, as considered in Hayashi et al. (2006).

Grounding in CPS based on different perspectives

Communication studies in cognitive science have shown how speakers establish common ground during conversation (Richardson & Dale, 2005; Galantucci, 2005). Grounding is the interactive process by which communicators exchange evidence in order to reach mutual understanding (Clark, 1996; Clark & Brennan, 1991). Studies of group decision-making have indicated that information shared among group members is an important factor in successful decision-making (Tindale, Kameda, & Hinsz, 2003). Thalemann and Strube (2004) showed that sharing information in initial and goal stages leads to better performance during collaborative problem solving. In contrast, cognitive science studies of collaboration have shown that common ground is unnecessary in cooperative tasks, in some cases (Barr, 2004). Computer simulations using multi-agents showed that a population of egocentric agents can establish and maintain systematic conventions without sharing common knowledge. This observation is partially supported by empirical experimental results Hayashi et al. (2006), which indicated that some participants were able to complete a task (discovering a rule) by simply using the shared information without developing common ground. However, when generating correct mental models of others' perspective during CPS, developing common ground is necessary.

Then, what kinds of interaction processes can develop successful grounding in CPS? Communication studies in cognitive science show that individuals coordinate with each other by generating explicit sign signals, which are implicitly aware of each other (Galantucci, 2005). Garrod and Anderson (1987) investigated how dyads developed different languages associated with different mental models in a maze configuration task. Individuals with different perspectives established common ground by generating spatial descriptions to successfully coordinate with each other. Additionally, in the initial phase, speakers used detailed, concrete descriptions to specify situations. Individuals used abstract signs as they proceeded during the task. Analysis of communication in the study of Hayashi et al. (2006) also showed that individuals use spatial characteristics (called regions) regarding the presented stimuli. However, the aim of the dialog analysis in this previous study was to capture the degree of perspective bias; spatial expressions were analyzed based on which perspectives were mentioned. Therefore, further analysis of the types of detailed knowledge that were used to attain shared perspective and further establish common ground would be valuable.

Goals and Hypotheses

The present study focused on how individuals share perspectives while establishing common ground in CPS in which members interact based on different perspectives. Based on Hayashi et al. (2006), our first goal was to conduct a cognitive task analysis to determine what kind of communication strategies participants used to reach shared perspectives. The cognitive task analysis was based on the method of Rittle-Johnson and Koedinger (2001) and Koedinger and Terao (2002). According to Rittle-Johnson and Koedinger (2001), developing cognitive models during cognitive-task analysis enables one to specify unambiguous problem representations and thus detail comparisons of the problem-solving strategies. This is useful here in terms of specifying the types of featured knowledge that were used during conversations on sharing perspectives. We hypothesized that coding individuals' utterances based on production rules would provide knowledge regarding what types of featured knowledge are used to share perspectives. Then, based on this cognitive task analysis, our second goal was to investigate which type of knowledge helps dyads to successfully reach shared perspectives. We hypothesized that dyads who used more specific features, and combinations of knowledge of those features, would be more likely to reach a shared perspective.

Method

Participants

The present study reanalyzed the dataset of Hayashi et al. (2006) by analyzing dyads working with different perspectives (distributed view condition). The data of 22 Japanese university students (5 female, 17 male; *M*age: 20.73 years, SD: 2.27) who participated in dyads were reanalyzed.

Task

Controlling the participants' perspective

We reanalyzed data obtained from a simple rule-discovery task called the figure-ground reversal task, which was developed by (Hayashi et al., 2006) (for details, also see Hayashi (2018)). This task is similar to the story of "blind men and the elephant", where all individuals were touching an elephant but because they touched different parts they came to different conclusions about what they are touching. Pairs of participants collaborated through computer terminals that were separated by a partition so that neither could see the partner's display (see Fig 1). 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 was considered as one trial. The participants were instructed to find the sequence rule of the number of objects that are presented through the trials. The participants were told to discuss the target rule and press the termination button presented on their screen when

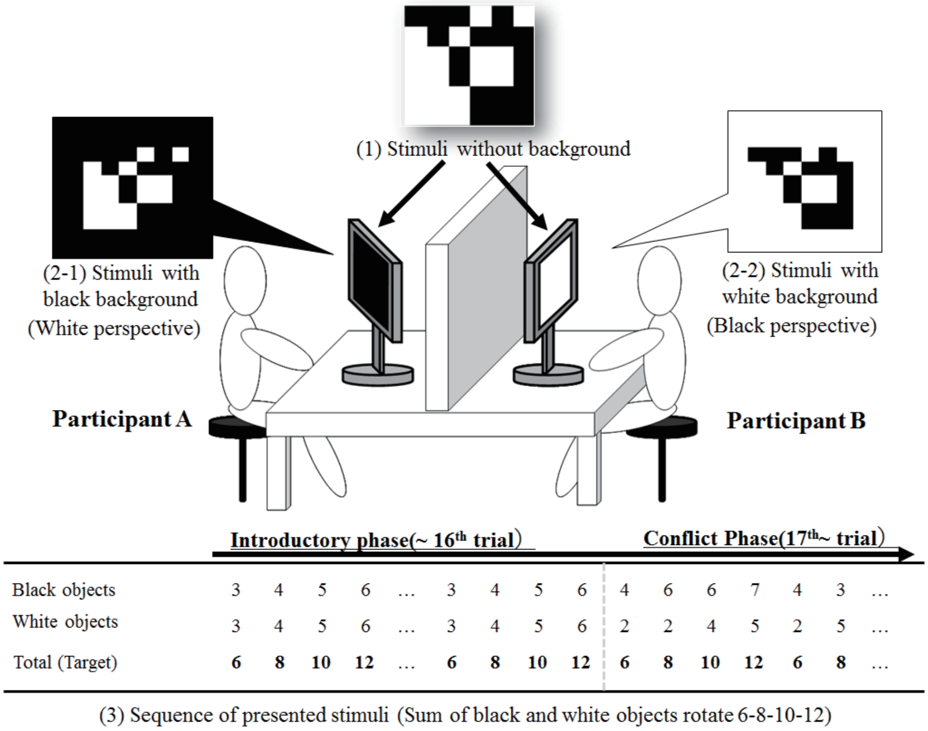

Figure 1: Experimental situation and task.

they reached the solution. The target rule was set to as the sequence of the sum of the black and white objects, i.e. the sum of the numbers of white and black objects rotating between 6, 8, 10, and 12. To manipulate a situation where the dyads were interacting based on different perspectives, principles from Gestalt psychology (Koffka, 1935), were used where the number of objects were fixed to change from figure to ground based on the background color. By putting the objects in different background, participants are led to have one of the distributed perspectives: i.e., either a perspective focusing on black objects or one focusing on white. In an example stimulus in Fig 1, there is a total of eight objects comprising three black objects and five white objects. This stimulus is displayed on either a black or white background and the participants have distributed perspective focusing on either one color as figure. The instructions stressed that the stimuli presented to each participant within the square frame were identical to each other, but the information about the background color was not mentioned.

Controlling disagreement about each other's perspectives

To control how the dyads incorporated different perspectives, the number of objects was adjusted to generate discrepancies when participants reported the numbers. In the initial stage (Introductory Phase), participants observed different colored objects (figure color) but reported the same number of objects (see Fig 1). Previous results using this task showed that participants reported the same number of objects in the Introductory Phase and therefore believed that they were looking at objects of the same color. As shown in (3) in Fig 1, participants simply reported varying numbers of objects (such as 3, 4, 5, or 6) in the Introductory Phase and thus generated misconceptions regarding the target rule. On the seventeenth trial (Conflict Phase), the number of the objects rotated by 3, 4, 5, or 6 and was scrambled. The number of objects was arranged so that only the sum of the number of objects would represent a valid response. After the Conflict Phase, participants needed to modify their misconceived initial hypothesis and instead count both black and white objects to discover the rule. It should be noted that, the participants have to discover the rule across observing the trials within the single task conducted in this experiment.

Data collection

Task Analysis

This task could proceed by two different types of interaction: (1) each participant reported only the number of figure objects (non-shared perspective method), or (2) each participant counted figure and ground objects (shared perspective method). To proceed with method (2), participants need to set a sub-goal, which was to develop mutual understanding of why they were reporting different numbers after the 17th trial. To develop a concrete shared perspective, they needed to discuss details of the display and understand how to count both figure- and ground-colored objects. Taking these issues into consideration, we provide an overview flowchart for representative dyads working on the task by establishing common ground in Fig 2.

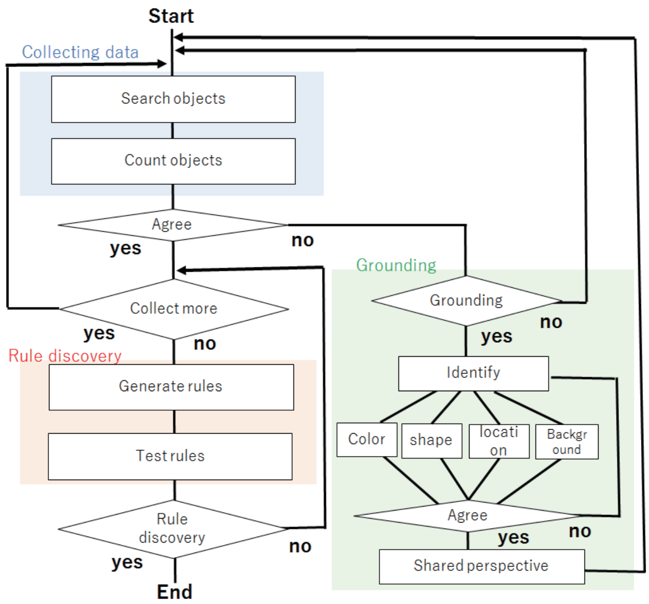

Figure 2: Flow of problem solving based on task analysis.

To establish common ground, featural knowledge, such as (a) color, (b) shape, (c) location, and (d) background, was essential. We conducted cognitive task analysis based on the type of these features, as explained in the next section.

Production-rule model for shared perspective

Production rules in this study consisted of declarative and procedural knowledge, as in ACT-R (Anderson, Corbett, Koedinger, & Pelletier, 1995). The production rules were stated in IF-THEN format, which consisted of declarative chunks. In our task, we focused on the four types of information shown, namely (1) location of the object: ?E[“location”’], (2) shape of the object: ?F[“shape”’], (3) color of the object: ?G[“color”’], and (4) background of the object: ?H[“background”’]. Using these variables, a declarative knowledge “chunk” can be defined. For example, a chunk associated with mentioning a particular object can be defined in the following way.

#Location-shape
-color(3-way)

isa	object
trial	1
number	1
location	?E[upper left]
shape	?F[tetra-zoid]
color	?G[white]
background	null

In this analysis, we only focused on combinations with color(?G[]) and other knowledge for the 2-way and 3-way, because color information was considered key for perspective-taking in this task. Next, we examined associations between the number of dyads who used specific featural knowledge (using more feature combinations) and success in sharing perspectives. Utilizing shared perspectives was defined based on the following evidence: (1) explicitly mentioning that they can see the partner’s perspective (opposite color to the background) during their grounding process, or (2) counting both black and white colored shapes after their grounding process. For example, evidence for (1) could be ”I understand what you mean and I can see the tetra-zoid in the black”, whereas (2) could be ”Now I know your perspective I will count both and I see four in black and six in white.”

Results: Association between # of featural knowledge types and shared perspective

For all 11 dyads, we conducted Fisher’s exact test to compare 2 (Featural knowledge: Mentioned vs. Not mentioned) × 2 (Shared perspective: Successful vs. Unsuccessful).

one-way strategy The results revealed no significant differences between establishing shared perspective and feature type, i.e., location (p = 0.49, FET), shape (p = 0.15, FET), color (p = 0.27, FET), or background (p = 0.06, FET). This indicates that sharing only one feature did not facilitate success in sharing perspectives.

two-way strategy Results revealed significant differences in establishing shared perspective by combinations of feature types, namely according to color & location (p = 0.02, FET) and the combination of color & shape (p = 0.02, FET). However, there was no relationship between establishing shared perspective and the combination of color & background (p = 0.18, FET). Comparing these results with the one-way strategy, we can see that the more features were mentioned during the conversations, the more likely it was that participants successfully shared perspectives.

three-way strategy There were also significant differences between establishing shared perspective and three-way combination of features, namely color & location & shape(p = 0.02, FET). This also supports the hypothesis that the more features are used, the more participants are able to share perspectives. Table 2, 3, 4 shows a summary of the results. F/S stands for feature mentioned/shared perspective, F/N stands for feature mentioned/not shared perspective, N/S stands for not feature mentioned/shared perspective, N/N strands for not feature mentioned/not shared perspective.

Discussion and Conclusions

Our first goal was to conduct cognitive task analysis to understand the types of featural knowledge that were used during interactions during the grounding process. Based on Rittle-Johnson and Koedinger (2001), we developed production rule models for knowledge regarding features of the images pre-

Table 1: Example dialog coded by production rules and types of chunks.

Speaker	Example Dialog	Productions rules	Chunk Type
B	”I see a tetra-zoid on the upper left corner”	If goal is to grounding and there is an object ?E[upper left] with feature ?F[tetra-zoid] Then express ”the object is ?F[tetra-zoid]”	#Location-shape (2-way)
A	”(tetra-zoid)On the upper left? I don’t see such thing”	If goal is to grounding and If partner says object has feature ?F[tetra-zoid] and object does not have feature ?F[tetra-zoid] in ?E[upper left] Then express ”NO ” and search new feature	#Location-shape (2-way)
B	”What about a shape “T” on the upper right?”	If goal is to grounding and there is an object ?L[upper right] with feature ?F[T] Then express ”the object is ?F[T] at ?E[upper right]”	#Location-shape (2-way)
A	”You mean (upper right T) in black? Not in white?”	If goal is to grounding and partner mentions a new feature perspective ?F[T] and the object ?E[upper right] being is discussed is ?G [Black] Then confirm ?F[T] is ?G[Black] not ?G[White]	#Location-shape -color(3-way)
A	”Oh! I see it(upper right T) in black!”	If goal is to grounding and there is an object ?L[upper right] that matches the feature ?F[T] from partner in color ?G[Black] Then say ?G[Black] and ”yes”	#Location-shape -color(3-way)

Table 2: Summary of association between knowledge types and shared perspective: 1-way feature.

1-way feature	F/S	F/N	N/S	N/N
color	8	2	0	1
shape	7	1	1	2
location	6	1	2	2
background	6	0	2	3

Table 3: Summary of association between knowledge types and shared perspective: 2-way feature. * indicates statistical significance.

2-way feature	F/S	F/N	N/S	N/N
color & shape*	7	0	1	3
color & location*	7	0	1	3
color & background	5	0	3	3

sented in the experiment. The conversations within the dyads were transcribed into production rules, defined by declarative features of knowledge, which consisted of shape, location, color, and background. Through this cognitive task analysis, we discovered that dyads used combinations of featural knowledge when developing mutual understanding of each

Table 4: Summary of association between knowledge types and shared perspective: 3-way feature. * indicates statistical significance.

3-way feature	F/S	F/N	N/S	N/N
color & shape & location*	7	0	1	3

other’s different perspectives. Simply put, collaborators who were more specific about what they were talking about were more likely to reach shared perspective. More precisely, our cognitive task analysis indicated that although all collaborating pairs described the objects they were seeing with a variety of features (e.g., color, shape, location), the successful pairs were more specific in using combinations of features (e.g., ”the white T in the upper right” rather than ”the white one” or the ”the T”). Returning to the blind men and the elephant example introduced earlier, our results suggest that might, eventually, individuals reach agreement if they are more specific – describing as much as they can, the shape, texture, smell, relative location of their observations, etc. Past studies of communication showed that speakers use combinations of detailed spatial information to establish common ground (Garrod & Anderson, 1987); the current results are consistent with those studies. Moreover, once the participants established common ground, they tended to use simple phrases when counting shared perspectives such as "two-four"' and "four-four". These can be considered as types of conceptual packs (Brennan & Clark, 1996), which are used when common ground is established during conversations.

In our study, we used quantitative analysis to investigate whether use of specific combinations of knowledge yielded higher performance in sharing perspectives. As hypothesized, dyads who were more specific in their grounding, i.e., mentioned more combinations of features, were more likely to reach a shared perspective. More specifically, participants who mentioned color and shape (2-way strategy), or color, shape, and location (3-way strategy) performed relatively well in sharing perspectives. Thus, specifying spatial information facilitates success in shared perspectives. There may be general critiques such as, "can common ground achieved by simply describing what is relevant?" To answer this question, we must first consider the point how did the participants determine what's relevant. In trying to achieve common ground with another, it seems possible, even likely, that one cannot fully anticipate the ambiguities that the other person may be experiencing or anticipate the alternative view of the world that they are seeing and perceiving. As mentioned previously, from the example of the story of the "blind men and the elephant", what features to focus on may be unclear and therefore, one cannot figure out what's relevant. One can simply try to be as specific as possible about in describing what they are seeing and perceiving.

Another important point that should be stressed from this study is the type of expressions that the speakers were using after they recognized about their conflicts. In natural conversations it is more efficient in most settings to not be specific(Grice, 1975). However, in a situation such as in this task, where participants have become aware of confusions and discrepancies, one must work hard to avoid our natural tendencies to be more efficient (less redundant) in our speech. Speakers need to strive for more redundancy and explicitness. Apparently, this switch is not easy to make as many of our participants do not seem to make the switch and continue to speak in natural, efficient but less specific and redundant ways. As future work, we will further investigate these points to uncover the conversational dynamics and discover the mechanisms of shared understanding in collaborative tasks.

This paper provides new implications regarding the methods one may use to capture the collaborative process in a systematic way. Although, there are limitations to the current study, primary among which is the small number of dyads used. As mentioned above, one of the next steps is to conduct a more focused experiment on how participants establish common ground. Specific analysis using eye movements and conversational data will likely be useful to elucidate the nature of coordination, too. Another possible future directions of this study is to further conduct simulations using the production-rules to further confirm our results on how the individual establish common ground.

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