The Effect of Metacognition in Cooperation on Team Behaviors

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***Abstract*—Teams and teamwork are indispensable, especially when tackling difficult and complex tasks that cannot be easily addressed by a single individual. Because breakdowns in team cooperation can cause accidents, much research attention has been devoted to studies on team cooperation, and many measurements and training of teamwork have been proposed. Traditional studies have often focused on observational teamwork behaviors to measure and enhance teamwork. In order to better measure and enhance teamwork, it is believed that it is necessary to focus on the cognitive mechanisms that underlie teamwork. This study focuses on metacognition in cooperation that underlies team cooperation, and aims to investigate the importance of metacognition in cooperation. The comparisons of metacognition in cooperation and team performance indexes suggest that an improvement of metacognition in cooperation will enhance team performance and that certain types of metacognition in cooperation are important for positive teamwork.**

Keywords - team cooperation, cognition, measurements, training.

I. INTRODUCTION

Team performance has been increasingly recognized as an indispensable foundation of difficult and complex tasks that cannot be easily addressed by a single individual, such as air traffic control and surgical care. The ability of an individual to contribute as the member of a team in a complex team task should be enhanced through training strategies that are aimed at providing competencies that facilitate teamwork. One of the prerequisites of team training is valid and reliable teamwork measurement, which underlies effective team performance. This is because it is necessary to identify the problems and characteristics of a team, provide constructive feedback, and evaluate the success of training for the training to be successful.

One of the typical measurements of teamwork is based on the behavioral marker system of teamwork. Mishra et al., for example, have developed a measurement of non-technical skills (NOTECHS), including teamwork [1]. They have divided NOTECHS into four behavioral dimensions (leadership and management, teamwork and cooperation, problem-solving and decision-making, and situation awareness) and defined the positive/negative behavioral modifiers of these dimensions. Based on these modifiers, trained experts evaluate NOTECHS using a four-point scale. Crew Resource Management (CRM) has been proposed and adopted as a procedure of teamwork training in different industries and organizations. CRM focuses on improving teamwork behaviors, including interpersonal communication, leadership, and decision-making [2].

The traditional research and methods described above have often focused on observational teamwork behaviors to measure and enhance teamwork. Explicit teamwork behaviors can be beneficial for the assessment of teamwork; however, it is additionally necessary to focus on both implicit teamwork and the cognitive aspects of teamwork in order to better measure teamwork. An improvement of the cognitive mechanisms underlying teamwork must effectively be able to enhance team performance. A recent study has implied that an important mechanism behind team cooperation is metacognition in cooperation [3]. This study aims to show the effect of metacognition on cooperation in effective team behaviors and to verify useful metacognition in cooperation for positive teamwork. The next Section introduces a team cognition model about metacognition in cooperation. In Section III, a team experiment and an analysis of the elicited reflection are described. In Section IV, the analysis and team performance indexes are compared. N Section V, we conclude this study.

II. A TEAM COGNITION MODEL

Cognition in teams has been receiving much research attention for more than a decade, and a variety of cognition models for teams have been proposed. Many of these models have aimed to present either the status of cognition in teams or the sum/overlap of individual cognition [4], instead of describing the cognitive factors underlying cooperation. We examined these factors through participants' reflections on cooperation, and proposed a team cognition model that describes and explains the cognitive processes of cooperation [3]. As a method to examine the underlying cognitive factors of cooperation, we analyzed participants' reflections on cooperation and elicited several important factors of cooperation. Subsequently, based on these factors, the findings of past studies by team researchers, and human cognitive abilities [5][6][7], we developed a team cognition model to capture a portion of the cognitive factors of team cooperation. The schematic of the proposed model is shown in Fig 1. The model consists of two levels—object-level and meta-level—with reference to a popular structure of metacognition that is defined as "cognition about cognition" [5]. The object-level is the ongoing progress or current status of a particular cognitive activity and is described by the combination of two categories—"Subjects" and "Contents". Object-level is monitored and controlled by meta-level, and the abilities for this process are defined as "Metacognitive skills". The details of each category are shown in Table I and are described in the following subsections.

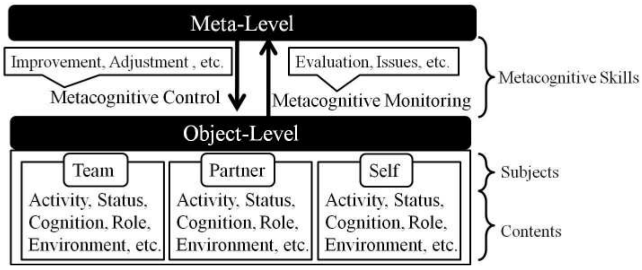

Figure 1. A Team Cognition Model

A. Subjects

Reviews and studies about group intention imply that humans use two modes of perspective in collective activities: reductive and non-reductive [8]. In the non-reductive perspective mode, one recognizes his or her group as having a mind of its own and this is distinct from individual members' intentions. The notion of "group mind" represents this mode [6]. In the reductive perspective mode, on the other hand, the individual infers or simulates the minds of others, consciously or subconsciously, and relates this to his or her own intention and the inference results. The notion of "mutual belief" represents this mode [7]. This category of the model presents the two modes of perspective in collective activities, and consists of three elements: "Self," "Partner," and "Team". "Self" and "Partner" represent the reductive perspective, and "Team" represents the non-reductive perspective.

B. Contents

This category represents content that relates to operations and consists of a variety of mental processes, actions, equipment conditions, situation awareness, mental status, knowledge, roles, tactics, etc. A set of one of the subcategories of this category and that of "Subject" comprises a basic element of the object-level. Non-cognitive elements such as equipment and roles were reported in introspections on team cooperation; thus, these elements are also included in this category.

C. Metacognitive Skills

Metacognitive skills are defined as monitoring and controlling the object-level (the set of "Subjects" and "Contents") through the meta-level. This category helps represent cognitive factors behind teamwork behaviors and teamwork behaviors themselves, in combination with the object-level. Examples are shown in the subsequent sections.

D. Characteristics

An advantage of the proposed model is that it describes the cognitive aspects of team cooperation and explains the reason behind popular teamwork as a set of "Metacognitive Skills," "Subjects," and "Contents". For example, mutual performance monitoring that is considered important teamwork behavior [9] can be described as applying "Evaluation (Good/Bad)/Issue" to "Activity/Status" of "Self/Partner/Team"; the shared mental model of role sharing can be described as applying "Compare (Match)" to the "Role" of "Team"; and behavior adjustments can be described as applying "Adjustment" to "Activity" of "Self".

Our previous study has implied that a wide scope of metacognition in cooperation will provoke metacognitive skills in both team members' activities and interactions; this could encourage team members to strive to improve their team performance. However, the importance of metacognition in cooperation, especially metacognitive skills for cooperation, has not completely been clarified.

TABLE I. THE CATEGORIES OF THE MODEL

Category	Subcategory	Explanation
Subjects	Self	The subject of content is oneself.
	Partner	The subject of content is a partner.
	Team	The subject of content is a team.
Contents	Activity	Actual actions, activities, decision-making activities, communication, etc.
	Cognition	Perception, comprehension, prediction, and thought.
	Tactics	Principle, operating procedures, tactics, etc.
	Role	Role sharing in a team.
	Status	Performance and workload.
	Environment	Environmental conditions regarding task accomplishment (e.g., equipment, positions of members).
Metacognitive Skills	Adjustment	Making modifications.
	Compare (Match/Mismatch)	Recognizing agreement/disagreement with the partner.
	Belief in Partner	Thinking about what his or her partner is thinking about.
	Improvement	Ideas for improving "Content."
	Issues	Pointing out problems.
	Clear/Not Clear	Content is clear/not clear.
	Evaluation (Good/Bad)	Giving some content a good/bad evaluation.
	Characteristics	Understanding characteristics of the team environment and task rules.

If metacognition in cooperation is important for positive teamwork, the reflection in cooperation by team members who demonstrate good team performance must include a variety of subjects, contents, and metacognitive skills. This study aims to test this hypothesis and investigate the importance of metacognition in cooperation.

III. Experiment and Data Analysis

In order to investigate the importance of metacognition in cooperation, we use the experiment data collected in [3] and analyze the relationship between the coded results of the reflection on cooperation and team performance in detail. First, the team experiment is introduced. Then, the coded results of the reflection on cooperation are shown. Finally, the reflection with the team performances to clarify the importance of metacognition in cooperation is compared.

A. Experiment

1) Task: An air traffic control simulator was used for a task (Fig. 2). The standard operating procedures of the task were as follows: (1) to select an aircraft with a mouse, and (2) to enter a command for the selected aircraft using a keyboard. Participants were asked to route arriving and departing aircraft both safely and accurately. During the session, the aircraft randomly appeared on the display. The participants were required to perform different sub-tasks simultaneously, such as understand commands that were given to aircraft, provide appropriate commands to control the altitudes and flight directions of aircraft, check distances between aircraft, make timely decisions about landings and takeoffs, monitor aircraft exiting from the airspace, etc. Each two-person team comprised a “Selector,” who had only a mouse, and a “Commander,” who had only a keyboard. The Selector selected the aircraft to which they would give a command with the mouse. Then, the Commander would enter a command for the selected aircraft using the keyboard. A team member could not complete these tasks by himself or herself and, thus, was required to cooperate with the partner. Because the number of aircraft increased in the second and third sets, team members had to reallocate team resources in the second and third sets; otherwise, they would fail to manage the aircraft.

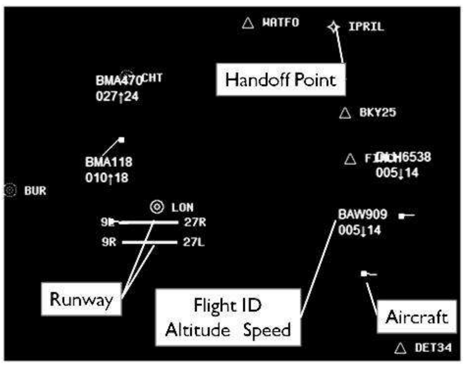

Figure 2. The simulator display

2) Participants: Twenty-six graduate/postgraduate students (13 teams) participated.

3) Instructions for reflection: Two-types of metacognitive instructions were designed and applied in order to investigate whether differences of metacognition in cooperation can affect team behaviors. The participants were asked to reflect on these instructions.

TABLE II. Metacognitive Instructions

Instruction	Description
Team-oriented instruction	How is this task being operated by your team?
Self-oriented instruction	How do you cooperate in this task?

4) Procedures: The participants practiced the operation until they could smoothly land and transfer an aircraft. The total trial duration was 15 min for all participants. The metacognitive instruction was presented every 7.5 minutes and the participants read it and wrote down their own cognitive status and beliefs twice in each set (Fig. 3). When the instruction was presented, the display turned blank and the simulation was suspended. The participants sat face-to-face, and communicated freely with each other, except when they were responding to the instructions. Some teams could not participate in the third set because of their schedules.

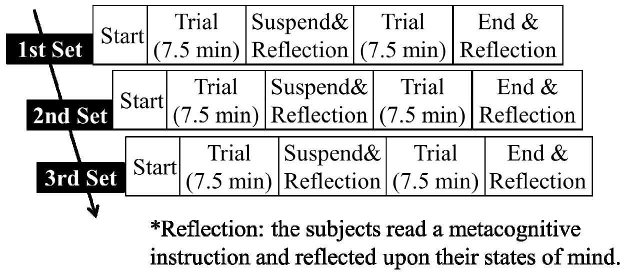

Figure 3. Procedure

5) Game scores: Two types of game score were used as team performance indexes: safety violation time and number of aircraft successfully processed. Safety violation time was the duration in seconds of when the distance between two different aircraft was less than 1,000 feet vertically and 3 miles laterally. The number of aircraft successfully processed was calculated by subtracting the number of failed landings or improper exits from the airspace from the number of successful landings or successful transfers to other airspaces at the handoff points.

B. Data analysis

The reflection data were coded by a collaborator (who was unaware of the research purpose), based on the categories of the proposed model. Initially, the reflection data were divided into two categories: related to cooperation and not related to cooperation. Subsequently, each reflection related to cooperation was represented as a set of subcategories of the three primary viewpoints. A subcategory "someone (self or partner)" was added in the "Subjects" category to code the reflection correctly. There were two types of sets of subcategories; a set of "Subject" and "Contents" and a set of "Subjects," "Contents," and "Metacognitive Skills". For example, the reflection "(I am) monitoring what my partner is not monitoring" was coded as "Self + Cognition + Adjustment," and the reflection "We demonstrate better performance than ever" was coded as "Team + Status + Evaluation (Good)". In addition, the reflection data that were not related to cooperation were represented as "Self" and "Contents" or a set of "Self," "Contents," and "Metacognitive Skills".

IV. Results and Discussion

To investigate the importance of metacognition in cooperation, we conducted two types of analysis. In the first analysis, we compared both the reflection and the transitions of the game scores between the team-oriented instruction and the self-oriented instruction (Analysis I). In the second analysis, we compared the coded results of the reflection with the mean scores of each team to clarify the effect of metacognition on the cooperation of members with relatively good performance across the sets (Analysis II).

A. The Scores

In order to compare the transitions of the scores of the teams that obtained similar scores in the first set between the two metacognitive instructions, the teams were classified into three groups according to the number of aircraft successfully processed in the first set: high (6~10), middle (3~5), and low (0~2). Because the simulator was accidently stopped during the experiment by one team for each instruction, their two values of performance data were excluded from the comparison on the scores. The teams that answered the team-oriented instruction and the self-oriented instruction were named T1~T6 and S1~S5, respectively.

Table III shows the transitions of the scores of the teams. T1 and S1 got the same degree of both the number of aircraft successfully processed and the safety violation time in the first set. Although T1 improved in both indexes in the second set, S1 deteriorated in the number of aircraft successfully processed. T2 and S2 got the same degree in both indexes in the first set. Both teams deteriorated in the safety violation time in the second set; the degree of deterioration in S2 was higher than that in T2. In the third set, both indexes of S2 improved. Both indexes of T3 and S3~S5 were similar in the first set; however, the safety violation time of T4 was longer that of T3 and S3~S5. Although the performance indexes of both T3 and T4 improved in the second and third set, respectively, those of S3~S5 worsened in the second (S5) or third (S3 and S4) set.

In addition, in order to highlight the teams that got relatively good scores in the experiment, we divided the teams into two groups according to their mean scores in the experiment sets. Fig. 4 shows the mean scores of all sets for each team. T1~T4, S2, and S4 were categorized as teams that relatively performed well. On the other hand, T5, T6, S1, S3, and S5 were categorized as teams that relatively performed badly. Because the number of the scores was too small to apply significance tests between the groups and between the sets, we could not discuss the significance of the differences.

TABLE III. The Scores

	Team	Scores	First	Second	Third
High	T1	Success aircraft*	9	13	--
		Safety violation time	647	189	--
	T2	Success aircraft	6	6	--
		Safety violation time	27	151	--
	S1	Success aircraft	10	3	--
		Safety violation time	779	192	--
	S2	Success aircraft	7	7	10
		Safety violation time	140	400	190
Middle	T3	Success aircraft	3	7	8
		Safety violation time	57	269	73
	T4	Success aircraft	4	11	15
		Safety violation time	475	435	414
	S3	Success aircraft	4	8	-1
		Safety violation time	140	400	190
	S4	Success aircraft	5	9	3
		Safety violation time	0	0	76
	S5	Success aircraft	3	3	8
		Safety violation time	27	879	170
Low	T5	Success aircraft	0	4	--
		Safety violation time	85	150	--
	T6	Success aircraft	0	4	2
		Safety violation time	293	138	125

* "Success aircraft" implies "number of aircraft successfully processed".

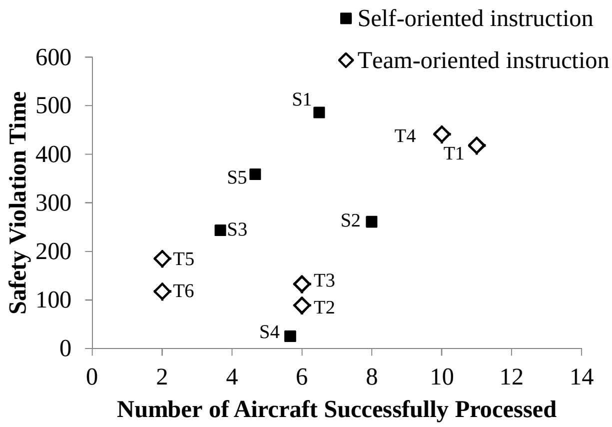

Figure 4. The mean scores

B. Analysis I

We statistically compared the two groups of the reflection to investigate the effects of the two types of metacognitive instructions on the viewpoint of metacognition pertaining to cooperation. Then, the game scores that were regarded as team performance indexes were compared.

Table IV shows the results of coding the reflection data by a collaborator who was unaware of the research purpose. We compared the mean number of each subcategory that was used to code the reflection elicited from the team-oriented instruction with that of the self-oriented one, using t-test per answer sheet for each member in each interval. Although the mean number of the reflection that does not relate to cooperation in the self-oriented instruction was significantly higher than that in the team-oriented instruction, the mean number of the reflection that relates to cooperation in the self-oriented instruction was significantly lower than that in the team-oriented instruction. The mean numbers of "Partner," "Team," "Role," and "Environment + Characteristics" in the team-oriented instruction were greater than those in the self-oriented instruction were. The coding pattern of "Role + Improvement" only existed when coding the reflection data that were derived from the team-oriented instruction. These results suggest that the team-oriented instruction induced metacognitive skills for cooperation more than the self-oriented instruction did.

Although the scores in the second and third set of the team-oriented instruction team improved, those of the self-oriented scores instruction team remained the same or worsened. The performance indexes after the team-oriented instruction may have improved because three teams (T2, T3, and T5) talked about their teamwork (e.g., role sharing) just after the team-oriented instruction. The team-oriented instruction induced team members to think about not only their own cooperation but also that of their partner and their team. This wide scope of metacognition in cooperation is expected to provoke metacognitive skills in both their activities and interactions; thus, it probably encourages team members to find problems in their teamwork and strive to improve their team performance.

C. *Analysis II*

Table V shows the coded results of the reflection for each member. The number in each cell represents the sum of subcategories that were used for coding the reflection through all the sets. Because the differences between the metacognitive instructions affected the viewpoint of metacognition pertaining to cooperation, we compared the coded results of the reflection with the scores for each team within the teams that answered the same instruction.

Among the team-oriented instruction teams, T1~T4 were categorized as better-performing teams. On the other hand, T5 and T6 were categorized as teams that performed relatively badly. The fact that the reflections of T1 and T2 were coded using more "Self" and "Partner" values implies that the members of both T1 and T2 tended to reflect their cooperation in terms of the reductive perspective. Their reflection, which included "Self/Partner + Equipment + Characteristics," "Compare," and "Adjustment," implied that the members applied metacognitive skills that were derived from the metacognition of their partner. Although the

TABLE IV. COMPARISION OF THE REFLECTION

	Team-oriented Instruction	Self-oriented Instruction	*p*
Not related to cooperation	0.98	1.88	$t(100) = 2.60, p < .05$
Related to cooperation	4.48	2.60	$t(95) = 2.89, p < .01$
Self	1.57	1.27	*ns*
Partner	1.04	0.46	$t(78) = 2.43, p < .05$
Team	1.68	0.88	$t(98) = 2.67, p < .01$
Role + Improvement	0.71	0.00	—
Environment + Characteristics	0.55	0.17	$t(87) = 2.20, p < .05$

TABLE V. THE CODED RESULTS OF THE REFLECTIONS

	Team-oriented instruction												Self-oriented instruction									
Team	T1		T2		T3		T4		T5		T6		S1		S2		S3		S4		S5	
Members	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
Related to cooperation	18	26	20	33	14	20	18	2	36	21	10	16	14	19	35	10	29	17	26	7	3	3
+ Self	5	4	4	14	5	9	8	1	18	3	0	2	6	10	20	4	8	9	9	6	3	1
+ Partner	6	3	6	9	2	3	1	1	16	4	0	2	3	4	6	0	4	1	7	1	0	0
+ Team	3	13	10	10	5	8	9	0	2	14	10	12	5	5	9	6	17	7	10	0	0	2
+ Adjustment	0	1	0	0	0	0	1	0	0	0	1	1	0	0	5	0	1	0	2	1	0	0
+ Compare	0	3	2	2	0	1	0	0	0	0	0	0	1	0	2	0	4	0	0	0	0	0
+ Belief in Partner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0
+ Improvement	0	0	2	2	4	4	2	0	0	5	2	0	4	2	1	1	0	1	3	1	0	0
+ Evaluation, Issue, Clear/Unclear	0	2	2	6	2	5	4	0	4	2	2	2	3	9	13	6	10	2	15	0	2	3
+ Self/Partner + Equipment + Characteristics	1	1	3	9	0	2	2	1	1	0	0	0	2	0	0	1	0	1	1	0	0	0
Not related to cooperation	0	1	4	0	18	2	10	22	3	9	0	0	8	12	7	25	3	6	3	4	10	6
+ Improvement	0	0	2	0	3	0	0	4	0	1	0	0	0	0	0	8	0	0	0	0	0	0
+ Evaluation, Issue, Clear/Unclear	0	1	1	0	3	1	10	6	1	3	0	0	6	8	5	13	0	2	2	0	3	1

* "C" means "Commander" and "S" means "Selector".

reflection of T5 included more “Self” and “Partner” values, the metacognitive skills of “Compare/Adjustment” were not included. The reflection of T5 included relatively fewer descriptions of cooperative relationships than those of “Self/Partner + Equipment + Characteristics,” and a variety of metacognitive skills including “Evaluation, Issue, Clear/Unclear,” and “Improvement”. The reflection of T3 included relatively more “Evaluation, Issue, Clear/Unclear,” and “Improvement” values. The number of reflections of T6 was relatively lower. Members of T6 tended to describe themselves in terms of “Team,” and there are few descriptions that included metacognitive skills. Among the self-oriented instruction teams, S2 and S4 were categorized as better-performing teams. On the other hand, S1, S3, and S5 were categorized as relatively bad. The reflection of S2 included more descriptions of metacognitive skills. Specifically, the commander’s description in S2 included a variety of metacognitive skills that were probably derived from belief in the partner, including “Adjustment,” “Compare,” and “Belief in Partner”. The reflection of S4, whose team performance indexes improved in the second set, but worsened in the third set, included descriptions of the characteristics of the equipment and “Adjustment”. Although the reflection of the commander in S4 included metacognitive skills through all the sets, the number of reflections that included metacognitive skills gradually decreased in the reflection of the selector. Although the reflection of S1 included more descriptions about cooperation and metacognitive skills such as “Compare,” there were no descriptions coded as “Adjustment” and “Belief in Partner”. There was a reflection coded as “Self/Partner + Equipment + Characteristics”; however, it was included by the final reflection. The reflection of S3 included more descriptions in terms of “Team”. Although the commander of S3 applied metacognitive skills in team cooperation, the selector did not. There were fewer reflections of S5.

These results imply the following four characteristics of the reflection in teams that had good cooperation: (1) members can easily understand the characteristics of their equipment; (2) members can describe their cooperation activities in terms of “Self” and “Partner,” rather than “Team”; (3) both members applied metacognitive skills in cooperation; and (4) metacognitive skills that can be derived from belief in partner, such as “Compare,” “Adjustment,” and “Belief in Partner,” can be important for positive teamwork. These four characteristics mentioned above may be compatible with past findings from research on teams: (1) can correspond to system monitoring, or can understand environmental characteristics in teams [9]; both (2) and (3) can correspond to mutual performance monitoring; and (4) can correspond to shared mental models and backup behaviors [10]. Observational marker systems for teamwork are probably not suited to evaluating these implicit teamwork behaviors. The reflection on cooperation and its analysis can be applied as a teamwork measurement for implicit teamwork and can be expected to give us good insights on some problems of team cooperation that cannot be identified through observation.

The team task used in the present study demanded team resource management, such as building effective cooperation patterns and adjusting behaviors, to not interfere with the partner, but to help the partner. It was necessary for the management to monitor the members’ status and to identify problems with their team cooperation. In addition, understanding the characteristics of members’ equipment in the task was necessary for building an effective cooperation style in this task. These are probably the reasons why teams whose reflections included more metacognitive skills and richer descriptions of cooperation could show and maintain good performances. If this is true, a metacognitive instruction that induces a wide range of metacognition in cooperation can be applied as effective team training in tasks that have the same characteristics as those in this experiment.

V. CONCLUSION

This study aimed to examine the importance of metacognition in cooperation. The comparisons of both the reflection and the transition of the game scores between the team-oriented instruction and the self-oriented instruction suggested that a wide range of metacognition in cooperation could enhance team performance. In addition, the comparisons between the coded results of the reflection and the scores for each team suggested that the reflection of teams that had relatively good performances through the sets included metacognitive skills that were derived from belief in the partner’s cognition and activities. These two comparisons suggested that for positive teamwork, it is important that team members apply metacognitive skills to a variety of “Subjects” and “Contents” with each other.

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