Analysis of Collaboration in Creative Problem Solving Based on Thinking Styles

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Abstract In this study, we analyze the process of collaborative problem solving from the viewpoint of thinking styles. Thinking styles are defined as a preferred way of thinking; here, we focused on three styles: Legislative, Executive, and Judicial. In this study, we created groups whose members displayed different thinking styles, and asked the groups to solve a creative task collaboratively. If thinking style were effective, we expected that distributed collaboration would be successful. The results are summarized as follows: (1) It was difficult to effect distributed collaboration based on thinking styles. Instead of that collaboration, dominative collaboration by Legislative thinking as the leader was observed. (2) Only with the Legislative style could we anticipate the degree of activity in Proposing. That is, Legislative thinkers actively participated in Proposing, whereas Executive and Judicial thinkers did not actively participate in Doing and Evaluating, respectively. (3) However, Executive and Judicial thinkers contributed to some subtasks following their thinking styles.

Key words: Role sharing, distributed collaboration, thinking styles

1. Introduction

Recently, collaboration has been increasingly recommended when solving problems. In previous research, it has been indicated that collaboration facilitates learning and problem solving [1], and particular factors for successful collaboration have also been indicated. For example, collaboration was well facilitated when learners clarified their own ideas, adopted other's ideas, and integrated these other ideas with their own [2]. Research also indicates that the visualization of ideas facilitates the clarification, adoption, and integration of ideas in collaborative learning [3]. In collaborative situations, role sharing appears within a group and the pattern of role sharing also influences problem solving and learning performance [4][5]. Our study focuses on role sharing.

Based on previous studies, we consider three types of collaboration: the first is equal collaboration, in which each learner contributes to all roles equally. The second type is distributed collaboration, in which each learner contributes to one role, and the task is completed with each learner's role complementing the others [4][5][6]. The third is dominative collaboration, where one particular learner contributes to all roles exclusively and the other learners do not contribute [2][7]. In this study, we focus on distributed collaboration.

Trials to encourage such collaboration have been conducted based on the control of group construction. In the Jigsaw method, groups consisted of learners, each of whom had acquired different knowledge in the initial learning phase; groups controlled in this way successfully enacted distributed collaboration [8][9]. Gabriele and Montecinos [10] also showed that when each peer-group consisted of an excellent learner and a poorer learner, distributed collaboration also occurred, and the collaboration provided positive effects, especially for the poorer learner. In this study, we consider thinking styles to be a factor that may lead to distributed collaboration.

2. Thinking Styles

Various theories of cognitive styles exist [11]. One example is field independent-dependent, proposed by Witkin and Goodenough [12]. This refers to the ability to separate an element from an embedded context. Individuals adept at separating elements are referred to as possessing field independence, while individuals who are not skilled at separating elements are referred to as being field dependent. Heath [13] also proposed four kinds of cognition in students confronting problems, and divided these into cognitive styles.

Generally, problems are solved through a process of three activities: Proposing, Doing, and Evaluating. In our study, we adopted the theory of mental-self government proposed by Sternberg [14] because this theory is the most suitable for understanding problem solving activities. This theory includes 13 thinking styles. Our research focuses on the three types of thinking styles mentioned in the theory of mental-self government: Legislative, Executive, and Judicial styles. According to this theory, a country is governed by three systems: the legislature, the administration, and the judiciary. Similarly, humans also govern themselves with Legislative, Executive, and Judicial styles. Legislative thinkers prefer situations that they have never experienced and like to solve problems in their own way. Therefore, they tend to prefer creating, planning, and making their own rules. In contrast, Executive thinkers prefer situations determined by other persons. Therefore, they prefer solving problems by following other's guidance. Judicial thinkers prefer to solve problems critically or analytically. Based on the theory of mental self-government, we hypothesize that in collaborative problem solving, Legislative thinkers are more active

in Proposing, Executive thinkers are more active in Doing, and Judicial thinkers are more active in Evaluating.

In studies on thinking styles, the relationship between thinking styles and other human factors such as intelligence, gender, culture, and development have been widely studied. For example, Grigorenko and Sternberg [15] demonstrated that college students in the United States who are Legislative thinkers achieve higher grades than those who are Executive thinkers. In Chinese universities, male students showed higher Legislative scores than females [16]. In Lin, Liu, and Yuan [17], learners were asked to assess whether or not others' actions were performed well in a learning operating system. As a result, when shown the assessment criteria in detail, Executive thinkers assessed the others' performance in a valid way. Furthermore, O'Hara, Linda, and Sternberg [18] examined the influence of instruction and thinking styles on works when writing essays. When Legislative thinkers were asked to write analytical essays their essays were poorly written, whereas Judicial thinkers wrote excellent essays no matter what kind of instruction they were given.

However, almost all research on thinking styles has focused on individual activities; that is, examining the correlation between scores of thinking styles and scores of academic abilities or personality tests. This means that there are only few studies dealing with thinking styles in collaborative problem solving situations. In our research, we constructed groups based on thinking styles and analyzed the process of collaborative problem solving to examine the following two issues.

(1) Whether groups constructed by learners whose thinking styles differ lead to distributed collaboration. We consider that if each thinking style works well, distributed collaboration will occur successfully; however if each style does not work, equal or dominative collaboration will emerge.

(2) Whether thinking styles allow us to predict a learners' contribution to problem solving; that is, whether Legislative, Executive, and Judicial thinkers most actively engage in Proposing, Doing, and Evaluating, respectively.

Since this study was performed experimentally, in the following sections, learners are called 'subjects'.

3. Method
3.1 Experimental Task
We designated "Mindstorms", produced by the LEGO Co, as the tool subjects use to perform the given task. Mindstorms is a tool for designing robots, and it consists of a specific device with a computer that controls the robot's movement and other various normal blocks. The robot's motion is controlled by the program that the subjects construct. We felt Mindstorms was an appropriate material for our study because designing robots using Mindstorms involves three main activities: Proposing, Doing, and Evaluating. The subjects were instructed to collaboratively design a car with a unique physical design and motion.

3.2 Group Construction
3.2.1 Pre-examination of Thinking Styles
Before groups were constructed, we examined the thinking styles of 78 candidate subjects. The candidates were freshmen at a Japanese university with which one of the authors is affiliated. Based on the results, we selected suitable subjects and constructed groups of three subjects.

3.2.2 Task to Examine Thinking Styles
We adopted the scales of Legislative, Executive, and Judicial thinking styles proposed in Sternberg [14]. In each scale, we provided eight statements for evaluation. Table 1 shows sample statements. We asked the subjects to respond to each statement using a score from 1 to 7 (7: Extremely well; 6: Very well; 5: Well; 4: Somewhat well; 3: Slightly well; 2: Not very well; 1: Not at all), and used the average of scores of the eight statements as the degree of thinking style of each subject.

Table 1 Examples of Statements Used for Measuring Thinking Styles

Thinking styles scale	Questions
Legislative	When faced with a problem, I use my own ideas and strategy to solve it.
Executive	I enjoy working things that I can do by following directions.
Judicial	When discussing or writing down ideas, I like criticizing other's way of doing things.

3.2.3 Conditions of Group Construction
Groups were constructed based on results of the examination of thinking styles. The average scores of the candidate subjects' thinking styles (78 students) were 4.87 (Legislative), 4.50 (Executive), and 4.02 (Judicial) in male subjects, and 4.53 (Legislative), 4.68 (Executive), and 3.82 (Judicial) in female subjects. Since there was a variation of the average scores among the styles, we adopted relative scores to construct groups. Based on these scores, we defined a *factor* and a *style*.

First, we standardized the thinking style scores, where the average was zero and the standard deviation was 1.0. We stated that a subject has a *factor* X (X = Legislative, Executive, or Judicial) when the standardized score of thinking style X is equal to or more than 0.5. A *style* is defined as the pattern of the

factors possessed by each subject. Each group was then constructed based on the following rules. The first rule is that every subject should have one or two *factors*. The second rule is that all three *factors* should be complementary among the three subjects. The third rule is that every subject's *style* must differ from others in their group. The ideal was to ensure each group consisted of three subjects, each of whom has only one *factor*, that is, Legislative, Executive, or Judicial. However, since it was difficult to practically construct such groups, we used the above rules.

Variables other than thinking styles were also controlled. Each group consisted of subjects of the same sex. Moreover, a group was constructed so that all subjects were either good at collaborative activities, or poor at such activities. To estimate the degree of the ability, we adopted the Global scale proposed by Sternberg [14]. The Global scores for all subjects comprising a group were either greater than or equal to 0, or less than 0.

4. Experiment
4.1 Subjects

Four groups (Groups 1, 2, 3, and 4), were constructed based on the above rules. Although some subjects had previously used LEGO blocks, all were novices at Mindstorms. Table 2 shows the standardized scores for the subjects' thinking styles. The underlined numbers (those scores ≥ 0.5) show the *factors* of each subject. For example, in Group 1, Subject A exhibits positive Legislative and Judicial *factors*, Subject B displays a positive Executive *factor*, and Subject C shows a positive Judicial *factor*.

Although the experiment was a first meeting for almost all subjects, some knew other group members. We could not control this point completely. However we considered that this influence is not crucial.

Since candidate subjects who had two or three *factors* or did not have any *factor*s were relatively numerous, we were unable to construct more than four groups in our study. Thus, we did not construct control groups whose members display an identical *style*.

Table 2 Subjects' Factors in Each Group

(a) Group 1

Subjects	Legislative	Executive	Judicial
A	2.47	-0.90	2.58
B	-0.1	1.53	-1.37
C	-0.37	0.45	0.55

(b) Group 2

Subjects	Legislative	Executive	Judicial
D	1.53	0.99	0.43
E	0.44	1.40	-0.65
F	-0.10	0.45	1.14

(c) Group 3

Subjects	Legislative	Executive	Judicial
G	1.26	-0.36	0.19
H	-0.1	0.72	0.19
I	0.99	-1.44	0.79

(d) Group 4

Subjects	Legislative	Executive	Judicial
J	1.12	-0.49	0.43
K	-2.26	1.26	-1.37
L	0.71	-1.17	1.86

4.2 Procedure

In the initial stage of the experiment, subjects were given basic instructions on Mindstorms and the requirements for solving the task. The main instructions were as follows: arrangement of the parts neatly on the table, method of using those parts that are difficult to understand, and method of creating a program to control the car that they design. We stressed the following requirements; that all three members in the group design one car collaboratively; that all members actively discuss any problems they face; and that they continue to engage in the task right up to the designated time limit (one hour and 50 minutes). After receiving these instructions, the subjects started to collaboratively design a car.

The three subjects worked at a rectangular desk during problem solving upon which Mindstorms parts and a personal computer for programming were provided; group members shared one computer. The subjects' activities were recorded by video cameras and MD recorders to collect verbal and behavioral data. We used four video cameras. Three cameras were set to record the subjects' problem solving from fixed locations, and one camera was used by an experimenter to record specific situations that needed to be focused on from various viewpoints. Each subject was given an MD recorder. Since the subjects were novices, we also gave them a Mindstorms instruction manual and a basic car component as a sample product. They were also given a pencil and a piece of paper to share their ideas.

4.3 Analysis

We analyzed the experimental data from the viewpoint of Proposing, Doing, and Evaluating. We proposed this categorization based on the hypothesis

that each of these actions respectively corresponds to Legislative, Executive, and Judicial thinking styles. Doing was analyzed based on the subjects' filmed behavioral data, while Proposing and Evaluating were based on verbal data.

4.3.1 Coding Doing

First, we define Mediated Products (MPs) according to the structure of a final product and the process of producing that product. Each MP is an isolated part of a final product, and is constructed by a series of behaviors. Figure 1 shows a sample structure of a final product. Each box shows an MP. This figure shows a four-wheeled car, with a main body consisting of two power reactors. A power reactor is also created through a series of behaviors, such as making both the front and back parts of the power reactor and combining these components with a motor. We assigned the label Doing to the series of behaviors that produce each MP.

4.3.2 Coding Proposing and Evaluating

The subjects' dialogs relating only to MPs were coded as Proposing or Evaluating. Examples of other dialogs include comments urging referral to a manual or to the sample, comments related to programming, emotional utterances, laughing, and jokes. Since we are focusing on design processes, we analyzed only those dialogs relating to MPs.

Because it was difficult to analyze the process based on single dialogs, units that consisted of a series of dialogs were used for analysis. Proposing is a unit that suggests what should be done. Examples of the Proposing units include suggesting what parts should be used, proposing a way to combine components, and deciding on the next MP to be made. Units labeled as Evaluating include questioning, explaining a situation, and estimating whether the current state is acceptable.

Table 3 shows some sample dialogs from the subjects in Group 1. The left column shows the unit numbers, the middle column shows the subjects, and the right column shows the dialogs. Units 119, 123, and 321 in table 3(a) show Proposing. In Units 119 and 123, the subjects propose using smaller wheels, and in unit 321 they propose changing a gear. On the other hand, Unit 11 in table 3(b) shows Evaluating where the subjects evaluate the physical design of the vehicle's wheels. Unit 126 also shows Evaluating where they evaluate the parts they produced.

4.3.3 Proposer, Doer, and Evaluator

In general, since a unit and a series of behaviors are generated by multiple subjects, we need to identify a primary contributor. The primary contributor for Doing was identified by pin-pointing the subject who actually enacted a series of behaviors related to constructing a specific MP in a video, where we focused on utterances relating to completion and the action of putting a final product on the table as identifying cue information. We call this contributor
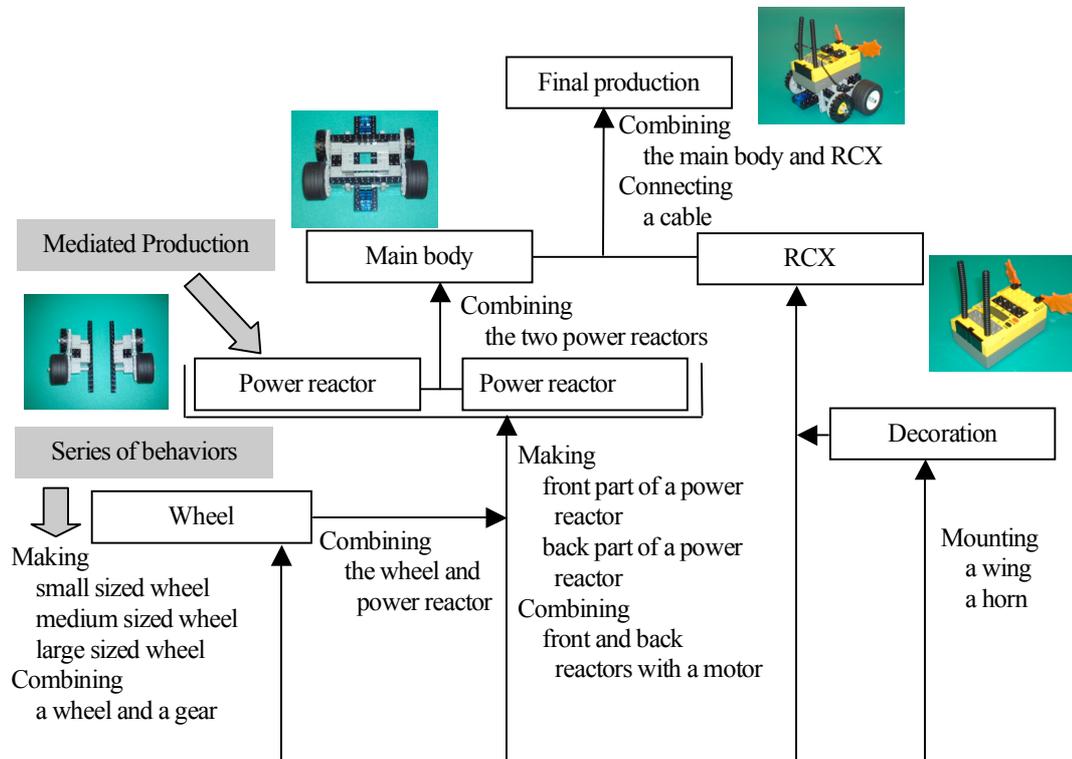

Figure 1 Structure of a Final Production

the Doer.

We define the subject who initially verbalizes a proposal as the primary contributor for Proposing, and we call this contributor the Proposer. A subject who repeats the same dialogs and reacts in a simple manner such as nodding or saying just only "yes" or "no" is not regarded as a primary contributor for Proposing.

Table 3(a) Example of Proposing Units

Units	Subjects	Dialogs
119	B	Do you think this will fit?
	C	Yeah.
	B	Probably.
	C	Want to try?
	B	Shall we use a smaller one?
	B	How do we know?
123	A	Use a very small wheel.
	C	This one?
	A	Sure.
321	A	Let's change the gear.
	B	O.K. let's change the gear.

Table 3(b) Example of Evaluating Units

Units	Subjects	Dialogs
11	A	It looks strong.
	B	The physical design is unique.
	C	It looks cool!
126	A	This doesn't fit either.
	C	This, this is…
	B	It doesn't fit?
	C	This has nothing to do with it? Because it moves.
	A	Then, using this wheel isn't important.

All subjects who relate to evaluating activities are regarded as primary contributors to Evaluating, and we call them Evaluators. Since multiple subjects constructed Evaluating units while commenting from diverse perspectives, it was difficult to identify a primary Evaluator. Thus we regarded all subjects who contributed to evaluation as Evaluators. The criterion for Evaluators is somewhat different from that for Proposers. However, since we did not compare the occurrence numbers of Proposing and Evaluating, we consider that there are no major concerns in this regard.

However, a subject who gave only simple reactions such as nodding was not regarded as a primary contributor to Evaluating. For example, in Table 3, in Units 119 and 123, since Subject C shows simple reactions, only Subject A is a Proposer in Unit 123 and Subject B in Unit 119. In Unit 321, Subject A is also a Proposer because Subject B merely repeats Subjects A's dialog.

While all subjects contributed to Evaluating in Unit 11, in Unit 126 Subjects A and C are Evaluators because Subject B just repeats Subjects A's utterance.

4.4 Rating
4.4.1 Types of Collaboration

We compared the number of cases where each subject was identified as a Proposer, Doer, and Evaluator based on a χ^2-test and Ryan's procedure, and the significantly larger number was regarded as representing an active contribution. If no significant difference appeared, active contribution was rejected. Significant differences occurred in every activity, Proposing, Doing, and Evaluating, and the three types of activity were performed in a complementary way; thus we consider distributed collaboration to have emerged.

4.4.2 Prediction of Contribution Based on Thinking Styles

Next, we discuss to what degree contribution to a specific activity can be predicted based on thinking styles. Let us consider the relationship between Legislative thinking and Proposing. When a subject who has a positive Legislative *factor* exhibits active contribution to Proposing, we consider that thinking style predicates their contribution. When a group consists of two subjects, both of whom have a positive Legislative *factor*, we consider that thinking style predicates a contribution when at least one of them shows an active contribution to Proposing. The relationship between Executive thinking and Doing and between Judicial thinking and Evaluating are also estimated based on the criteria outlined above.

5. Results
5.1 Types of Collaboration and Prediction of Contribution Based on Thinking Styles

First, we examined whether distributed collaboration occurs in a group comprising subjects whose thinking styles are different. Table 4 shows the analysis results. Letters A to L indicate subjects (n=12); L, E, and J in the headings show Legislative, Executive, and Judicial factors, respectively. The single values in the top row represent the frequency at which each subject was identified as a Proposer, Doer, and Evaluator; underlined numbers indicated active contributions. In each group, there were two subjects who contributed actively to at least one activity

(Subjects A and B in Group 1, Subjects D and E in Group 2, Subjects G and I in Group 3, and Subjects J and L in Group 4) and one subject who did not (Subject C in Group 1, Subject F in Group 2, Subject H in Group 3, and Subject K in Group 4). The former is called an *active contributor* and the latter is called an *inactive participant*. These results indicate that it was difficult to effect distributed collaboration by specifically constructing groups based on thinking styles in these cases; in fact, dominative collaboration emerged.

Table 4 Contribution Frequencies in Each Group.

(a) Group 1

	A (L/J)	B (E)	C (J)
Proposing	81 (57, 24, 7)	86 (83, 3, 11)	39 (33, 6, 5)
Doing	15 (9, 6, 3)	40 (40, 0, 4)	7 (6, 1, 5)
Evaluating	91 (64, 27, 17)	119 (117, 2, 27)	75 (60, 15, 23)

(b) Group 2

	D (L/E)	E (E)	F (J)
Proposing	95 (83, 12, 20)	109 (92, 17, 26)	35 (34, 1, 6)
Doing	18 (16, 2, 0)	28 (23, 5, 13)	16 (14, 2, 5)
Evaluating	98 (77, 21, 18)	95 (72, 23, 27)	26 (25, 1, 3)

c) Group 3

	G (L)	H (E)	I (L/J)
Proposing	64 (54, 10, 4)	42 (30, 12, 7)	111 (64, 47, 7)
Doing	25 (22, 3, 8)	17 (13, 4, 14)	18 (10, 8, 1)
Evaluating	111 (98, 13, 26)	71 (49, 22, 20)	138 (89, 49, 23)

(d) Group 4

	J (L)	K (E)	L (L/J)
Proposing	22 (20, 2, 5)	47 (41, 6, 8)	115 (110, 5, 19)
Doing	21 (21, -, 15)	9 (9, -, 4)	20 (20, -, 0)
Evaluating	46 (46, 0, 8)	78 (76, 2, 28)	120 (117, 3, 28)

Additionally, regarding subjects' *factors*, all participants who have a Legislative *factor* were one of two *active contributors* in each group. Another way of

saying, all subjects that exhibited a positive Legislative *factor* were *active contributors*. We should note that, in Groups 2, 3, and 4, the most active participant was a Legislative thinker (Subject D in Group 2, Subject I in Group 3, and Subject L in Group 4). In contrast, in Group 1, the most active participant was an Executive thinker, Subject B. However, a Legislative thinker, subject A, was one of two *active contributors*. These indicate that, generally speaking, Legislative thinkers made major contributions to cause dominative collaboration. We call this collaboration "dominative collaboration with Legislative thinkers acting as leaders."

Next, we discuss whether thinking styles predicate contribution to a specific activity. First, let us examine the relationship between Legislative thinking and Proposing. All groups showed significant differences in Proposing. In Groups 1 and 2, those subjects with a positive Legislative *factor* actively contributed to Proposing. Meanwhile, in both Groups 3 and 4, which comprised two subjects with a Legislative *factor*, at least one of them actively contributed to Proposing. In terms of Doing, in Groups 1 and 4, there was a significant difference in Doing, whereas in Groups 2 and 3 there was not. In Group 1, the subject with a positive Executive *factor* actively contributed to Doing, whereas the subject in Group 4 did not. Finally, in terms of Evaluating, there was a significant difference in Evaluating among all groups. A subject with a Judicial *factor* was judged as contributing actively in both Group 3 and 4. However, in Groups 1 and 2, the subjects having a Judicial *factor* did not actively contribute to Evaluating. These results indicate that being a Legislative thinking certainly predicated the frequency of Proposing, though neither Executive nor Judicial thinking predicated the frequency of Doing and Evaluating, respectively.

5.2 Contribution to Proposing Key Concepts

Above, we clarified that Legislative thinking predicates the frequency of Proposing. However, the type of Proposing dealt with in the above analysis was related to Mediated Products. There is another important type of Proposing: proposals to decide a key concept. An example of a key concept is deciding on the type of a car such as a four-wheeled, three-wheeled, or caterpillar-wheeled car. Since deciding the key concepts significantly influences the structure of products and design processes, this type of proposal is crucial. Next, we examined whether Legislative thinkers actively contributed to deciding key concepts. Table 5 shows the results of our analysis. Here "O" means that the subject contributed to proposing a key concept. For example, in Group 1, the subjects first produced a four-wheeled car, and then they changed it to a caterpillar-wheeled car as the final product. Table 5 shows that six of the eight key concepts that emerged

from the four groups were proposed by subjects who displayed a positive Legislative *factor*. These results indicate that Legislative thinkers also actively contributed to Proposing a key concept.

Table 5 Proposals Related to Key Concepts in Each Group

(a) Group 1

	A (L /J)	B (E)	C (J)
Four-wheeled car	O		O
Caterpillar-wheeled car	O	O	

(b) Group 2

	D (L /E)	E (E)	F (J)
Four-wheeled car		O	

(c) Group 3

	G (L)	H (E)	I (L / J)
Caterpillar-wheeled car			O
Four-wheeled car		O	

(d) Group 4

	J(L)	K(E)	L(L / J)
Caterpillar-wheeled car			O
Four-wheeled car			O
Caterpillar-wheeled car		O	O

5.3 Contribution When Performing a Divided Task

The results of the previous section indicate that there were two *active contributors* who participated in at least one of three activities (Proposing, Doing, and Evaluating), and one *inactive participant* in each group. The task used in this study can be subdivided into three subtasks. If we examine the subjects' activities from the perspective of performing the subtasks, we can observe that *inactive participants* also contribute to solving some of the subtasks. The first subtask, regarded as a central task, was to produce the main body of the car, and the second subtask, a secondary task, was decorating the car's exterior. These two subtasks are related to MPs, which were analyzed in the previous section. These subtasks were mainly performed by dealing with blocks or parts; in contrast, the third subtask was to program and control the car's movement. We also labeled the subjects' dialogs relating to programming as Proposing and Evaluating using the procedure identical to that used in the above sections. In contrast, we regarded subjects that contribute to constructing a program for a test run as Doers, judged based on their mouse operation. Since the programming task is different from the central and secondary tasks in the procedure to identify a Doer, we addressed this task separately in **Section 5.1**.

The lower three numbers in each cell of Table 4 show the frequency of cases where each subject was identified as a Proposer, Doer, and Evaluator in the central task (left column), in the secondary task (middle column), and the programming task (right column), respectively. Since both the central task and secondary task relate to producing MPs, the sum of the numbers in the left and middle columns corresponds to the upper number. In addition, "-" indicates that the subjects did not perform the specific activities. The underlined numbers denote active contribution.

First of all, an *inactive participant*, Subject C in Group 1, who has a positive Judicial *factor*, actively contributed to the decorating subtask as an Evaluator. Another *inactive participant*, Subject F in Group 2, who has a Judicial *factor*, did not actively contribute to any subtasks. Subject H in Group 3, as an *inactive participant* with an Executive *factor*, actively contributed to the programming subtask as a Doer. Finally, Subject K in Group 4 with an Executive *factor*, actively contributed to the programming subtask, but this contribution was performed as an Evaluator. These results show that even if *inactive participants* did not actively contribute to performing a central task, they contributed to a secondary task or a programming task, and several did so following their thinking styles.

6. Discussion

Summarizing the main results, we found it difficult to effect distributed collaboration by constructing groups based on thinking styles; instead, it caused dominative collaboration with Legislative thinkers acting as the leader. However, a detailed analysis based on task division indicated that *inactive participants* also actively contributed to some subtasks, and some of them did so by following their thinking styles.

It is considered that Legislative thinkers are good at Proposing, Executive thinkers are good at Doing, and Judicial thinkers are good at Evaluating from the definition of thinking styles adopted in our study. Therefore, we consider that constructing groups based on thinking styles is an important strategy to encourage subjects to play an appropriate role in collaborative problem solving. However, almost all preceding studies on thinking styles have examined only correlation between scores of thinking styles and scores of academic abilities or personality tests. No studies have examined interaction generated by group members with different thinking styles and focusing on the process of interaction. Thus, we consider that these findings are of importance, providing novel contributions to studies on human collaboration.

Additionally, although our results proved contrary to our expectation of the appearance of

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distributed collaboration, we quantitatively indicated Legislative thinkers' contribution as a factor in dominative collaboration. Similar to Johnson, Johnson, and Holubec's [1] recognition of differences of ability as a factor that causes dominative collaboration, we identify a new factor for domination.

While we hypothesized that distributed collaboration emerges by groups comprising members with different thinking styles, if distributed collaboration had occurred in these groups, it might have been significant to confirm whether or not equal collaboration or dominative collaboration emerges in control groups comprising members with an identical thinking style. However, since dominative collaboration emerged, the hypothesis was rejected. Thus we did not pursue further investigation by constructing control groups.

6.1 Why Do Legislative Thinkers Dominate and Why are There Inactive Participants?

In our research, all subjects were Mindstorms novices. Thus, the situation that we set up in our study was unusual for these subjects. In an unusual situation like this, it is important to propose how problems should be solved. Since Legislative thinkers prefer unusual situations [14], they actually actively contributed to Proposing as we predicted based on the theory of mental-self government. However, Legislative thinkers also contributed to the roles that should have been performed by Executive or Judicial thinkers. In particular, the definition of Doing was "to construct Mps" and the definition of an Executive style was "to follow plans proposed by other persons." We considered that both (i.e., doing and following) co-occurred on the assumption that MPs are constructed following a plan previously proposed in the experimental situation. However Executive thinkers were not active for Doing. This means that Proposals generated by Legislative thinkers did not function well for Executive and Judicial thinkers. We must examine why Legislative thinkers dominated almost all roles.

6.1.1 Achievement Goals

First, we discuss the results from the view-point of the nature of the goals that subjects were required to archive. Generally, goals can be divided into two types: learning and performance [10] [19] [20]. A performance goal is a concrete goal that subjects should complete. For example, when subjects are asked to design a product, the performance goal is designing and producing it. Meanwhile, a learning goal is the acquisition of learning contents such as knowledge, strategies, and skills through performing a task. In this study, the performance goal was to design and produce a car with a unique physical design and motion. As Mindstorms is an educational tool, so learners are expected to acquire various types of basic engineering

knowledge such as ways to combine gears and computer programming [21]. However, the subjects seemed only to focus on the performance goal because we did not stress the learning goal. When only the performance goal is stressed, the dominative contribution of one particular subject may be permitted to obtain a high level product. This may cause dominative collaboration.

6.1.2 Social Loafing and Structure of the Task

When one particular subject causes dominative collaboration, the other subjects may forfeit their roles and fail to contribute to achieving the goal. Such a situation is called social loafing. According to Latane, Williams, and Harkins [22], since collaborative activities often generate a situation where each member's degree of contribution and effort is not clear, some members find it easy to loaf. However, the subjects in this study knew that their activities were being recorded by MD recorders and video cameras. This implies that the possibility of subjects' loafing is relatively low.

Mindstorms includes numerous very small and similar parts, although the ways of combining these components are relatively complex. Therefore, it was difficult for a Proposer to express their ideas to other collaborators. This constraint may bring about a situation in which Proposers not only proposed their ideas but also acted on these proposals by themselves as a Doer.

From the viewpoint of these task structures above, Legislative thinkers might prevent the other participants from actively contributing. Actually, some of the *inactive participants* took a central role in performing some of the subtasks, indicating that they were not loafing.

6.2 Instruction and Tutors' Contributions

Instruction plays an important part in collaborative learning [23]. For example, Johnson, Johnson, and Holubec [1] indicated that instruction on social skills and roles for learners facilitated their collaboration. The aim of our study was to construct a group in which the members' different thinking styles function effectively, and to understand the interactions that emerge from this situation. Thus, we gave the subjects minimal instruction such as 'for all three members in a group to design one product collaboratively', or 'for all members to actively discuss any problems they face', and we did not instruct the subjects in role sharing. If we gave them any instructions about role sharing, it might have caused distributed collaboration.

Additionally, in the learning sciences, the way tutors contribute to students' learning activities is a key issue [23] [24]. If tutors successfully assign roles to learners, distributed collaboration may emerge. However, our study also focused on the process of

voluntary collaborative problem solving, therefore the subjects solved problems without tutors. The contribution of instruction and tutors is a subject of future investigation.

6.3 Subjects with Two Factors, Including being a Legislative Thinker

In our study, in each group there was one subject who had two factors. Subjects A, I, and L, in Groups 1, 3, and 4 had both Legislative and Judicial factors. In addition, Subject D in Group 2 had both Legislative and Executive fac*tors*. Previous research has indicated a positive relationship between Legislative and Judicial thinking [16][25][26][27]. In our study, the Legislative score for all candidates did not relate to the Executive score (r=0.05, n.s); on the whole, the Legislative score significantly related to the Judicial score (r=0.70, p<0.01). This made it difficult to construct groups where each subject has only one *factor* exclusively.

The purpose of our study is to examine the interaction among Legislative, Executive, and Judicial thinkers. However, due to the difficulties of group constructions mentioned above, there was at least one subject with two *factors*, and there were two subjects who have the same *factor* in a group. For example, Groups 3 and 4 consist of two subjects, both of whom had a Legislative *factor*. In the groups, one member (Subject I in Group 3 and Subject L in Group 4) actively contributed to Proposing whereas the others (Subjects G and J) did not. However, the Legislative subjects who were not active in Proposing contributed to other activities such as Doing and Evaluating; as a result, this caused the dominative collaboration of Legislative subjects. Based on these cases in Groups 3 and 4, we hypothesize that if two Legislative thinkers compete in the same group, one of them would become active in Proposing and the other may actively engage in another type of activity to avoid a conflict between the two Legislative thinkers. This may cause dominative collaboration by the legislative thinkers. In such a situation, a more complex interaction may emerge among the three subjects.

6.4   Future Work

Individual differences are complex phenomena caused by a number of variables, and collaborative activities are influenced by many factors. With this in mind, prior to the experiment, we hypothesized variables that might influence collaborative activities and attempted to control these variables. First, novices at Mindstorms were selected as subjects. Each group also consisted of subjects of the same sex, and attitudes to collaborative activities were controlled based on the investigation (see **Section 3.2.3**).

Meanwhile, problems were generally solved through a process of three activities: Proposing, Doing, and Evaluating. According to the definition of thinking styles adopted in our study, it is considered that Legislative thinkers are good at Proposing, Executive thinkers are good at Doing, and Judicial thinkers are good at Evaluating. In spite of the assumption that thinking styles closely relate to role sharing of problem solving, dominative collaboration by Legislative thinkers as leaders emerged in the collaboration.

Thus, the next step of our investigation is to identify situations where distributed collaboration is effected by groups constructed based on thinking styles. With this mind, we propose the following experiments based on our findings.

(1) Group Construction Based on More Detailed Examination

In our study, it was difficult to construct groups consisting of three subjects each of whom has only one *facto*r based on the preceding investigation of 78 candidate subjects. Further more, although the threshold amount of the standard deviation score determining a *factor* was a somewhat low (0.5), subjects who had two or three *factors* and subjects who did not have any *factors* were overwhelmingly represented.

Consequently, we consider that it is important to construct groups more precisely, based on the investigation of a large number of candidate subjects, and to carry out additional experiments. Moreover, there are various methods to examine thinking styles other than those adopted in our study [14]. If we give candidate subjects a task similar to the problem adopted in our study and identify their thinking styles based on analysis of their performance or activities in the task, more appropriate groups might be constructed.

(2) Effects of Instruction

It might be possible to examine whether effective instructions cause distributed collaboration in groups. In the experiment, we instruct to subjects the roles of Proposer, Doer and Evaluator, and explain that a problem is effectively solved while these three roles work complementarily. The instruction did not include the definition of each thinking style. Thus, in future studies, we could examine whether such an instruction makes Legislative, Executive, and Judicial thinkers engage in problem solving following their styles.

(3) Effect of Goals

In **Section 6.1.1**, we pointed out a possibility that assigning only a performance goal to subjects is one of factors that cause dominative collaboration. In this regard, we could investigate the effects of assigning a learning goal in future studies.

6.5 Contribution to Class and Curriculum Design

According to Sternberg [14], thinking styles contribute to class and curriculum design. In this study, we hypothesize the following principles based on the results of the present study.

(1) Legislative learners should be carefully organized as key people when constructing a group because they take a central role in collaboration.

(2) Tasks used in a class must be carefully considered in order to ensure that Executive and Judicial thinkers actively contribute to performing the task.

(3) Devise instruction to participants and tutors' contribution.

Since the third principle has not been examined in this current study, future investigation is warranted. If our hypothesis is well supported by further research, more desirable collaborations, such as distributed collaboration, may emerge based on the active contribution by Executive and Judicial thinkers. The above hypotheses should be empirically tested, and will be an important focus of our future research.

7. Conclusion

We investigated on Legislative, Executive, and Judicial thinking styles and constructed groups comprising members with different thinking styles. We analyzed the process of their collaborative problem solving, with the following results:

(1) It was difficult to effect distributed collaboration through group construction based on thinking styles. Instead, we observed that dominative collaboration by Legislative thinkers emerged.

(2) Only Legislative thinking could be applied to predict the frequency of Proposing, whereas Executive and Judicial thinking was unable to do so.

In the future, we need to investigate a situation in which Executive and Judicial thinkers can contribute actively with Legislative thinkers who act as leaders.

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