Effects of Role Exchange between Task-doing and Observing Others on Insight Problem-Solving

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Abstract

We experimentally examined the effects of role exchange between task-doing and observing others on insight problem-solving. Sixty undergraduates were randomly assigned to one of the following three conditions: (1) *solo,* (2) *trial-and-other-observation pair,* (3) *and trial-and-self-observation*. In the first condition (15 individuals), the participants were asked to solve the T puzzle. In the second condition (15 pairs), each member of a pair was required to perform the task by alternating the roles of working with the pieces and of watching the partner's performance every 20 seconds. In the third condition, the participants were instructed to work alone and to alternate the same roles as those in the second condition. The results showed that the role exchange between task-doling and observing others had a facilitative effect on insight problem-solving, while the role exchange within an individual had a negative effect.

Keywords: collaboration; insight problem-solving; dynamic constraint relaxation theory; role exchange.

Introduction

Previous studies have shown that collaboration can facilitate problem-solving (e.g., Miyake, 1986; Okada and Simon, 1997; Ueda & Niwa, 1997; Kiyokawa, 2002; Shirouzu, Miyake, & Masukawa, 2002). Additionally, several studies have discussed the manner in which the facilitative effects emerged. Most studies focused on verbal interaction between collaborative group members and suggested that specific types of verbal interaction (e.g., explanatory activities; Okada and Simon, 1997) contributed to the facilitative effects. Although it appears to be one of the most important factors, there exist possibilities of other factors contributing to these effects. However, there exist fewer literatures that investigated processes other than verbal interaction during collaborative problem-solving.

Therefore, in this study, we focus on the role exchange between task-doing and observing the other's performance during collaborative problem-solving and investigate whether it can facilitate insight problem-solving.

What Processes Contribute to the Facilitative Effects of Collaboration on Problem-Solving?

Previous studies have examined the manner in which the facilitative effects of collaboration emerged in terms of verbal interaction between collaborators.

Based on interviews with members of R&D teams in leading Japanese companies, Ueda and Niwa (1997) identified a collaborative style in which a member actively engaged in problem-solving activities and his/her partner supported him/her by making metacognitive suggestions. According to Ueda and Niwa, metacognitive suggestions involve identifying any logical contradiction or inappropriateness of the partner's idea, clarifying the significance of the problem, and suggesting ways to discover solutions. In other words, metacognitive suggestions encourage the partner to reflect. They suggested that the metacognitive suggestions contributed to the invention of new products by the team.

Miyake (1986) pointed out that a collaborative group member often serves as a monitor and checks his/her partner's activities. As a result of interactions in the cases reported by her, each member of a pair deepened his/her understanding of a complex mechanical device such as a sewing machine. This type of interaction is similar to that identified by Ueda and Niwa. Specifically, it can be said that the person acting as a monitor plays the role of making metacognitive suggestions to his/her partner.

Using the experimental method, Kiyokawa (2002) attempted to determine whether collaboration, in which a member of a pair was encouraged to engage in metacognitive activities, could facilitate problem-solving. Participants, either individually or collaboratively, were asked to construct a map based on information presented as text. In the collaboration condition, a member of a pair was

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not allowed to text information independently or to express his/her ideas. These constraints led the member to engage in making metacognitive suggestions more actively than his/her partner. This type of collaboration led to higher performance on the task as compared with individuals.

In short, it can be said that all the previous studies mentioned above focused on verbal interaction as the key to the facilitative effects. Additionally, these studies indicated that two roles—Task-doer and Monitor—were important to facilitate problem-solving. This leads to the question of whether the facilitative effects of collaboration can be obtained without any verbal interaction.

Role Exchange between Task-Doing and Observing Others

As mentioned above, less attention has been paid thus far to nonverbal processes during collaborative problem-solving. Most researches in the field of cognitive science appear to implicitly hypothesize that verbal interaction is the key to the facilitative effects on problem-solving. Although it is one of the most important factors, there exist possibilities of other factors contributing to facilitating problem-solving. If we identify these factors, we can effectively collaborate with others in the setting where verbal interaction is restricted. Therefore, it appears helpful to address the question.

There exists suggestive evidence to answer the question. Shirouzu et al. (2002) found that two roles (i.e., Task-doer and Monitor) differentiated naturally during collaborative problem-solving—these roles were frequently exchanged between members—and that role exchange contributed to strategy shifts and a more elegant task solution. It can be considered that the role exchange between Task-doer and Monitor per se can facilitate problem-solving. Since Shirouzu et al. did not control verbal interaction during collaborative problem-solving, it is necessary to experimentally examine whether the role exchange between task-doing and observing the partner per se can contribute to problem-solving.

Dynamic Constraint Relaxation Theory

To examine the effects of role exchange between task-doing and observing the partner, a theoretical framework is needed to analyze the processes when verbal interaction is restricted. In this study, we rely on the dynamic constraint relaxation theory on insight problem-solving (Hiraki and Suzuki, 1998).

The theory hypothesizes three types of constraints: object-level, relational, and goal constraints. The object-level constraint is our natural tendency to encode objects at a basic level, although there are numerous other ways of interpretations. The relational constraint is a tendency to choose specific relations among innumerable alternatives. The word "relation" is defined as the manner in which objects relate to each other and each object has a specific role. The goal constraint provides feedback to the other two constraints mentioned above by evaluating a match between present and desired states. A desired state and an evaluation function are based on the representation of a goal. Hiraki and Suzuki suggested that these constraints create an impasse and the incremental relaxation of the constraints driven by failures probabilistically causes qualitative transitions.

Purpose of the Study

In this study, we experimentally examine the effects of role exchange between task-doing and observing others on insight problem-solving and analyze the processes based on the dynamic constraint relaxation theory.

Method

Participants

Sixty undergraduates who were basically requested to bring a friend of the same sex were randomly assigned to one of the following three conditions: *solo, trial-and-other-observation pair, and trial-and-self-observation*.

Task

We used a T puzzle that comprised four wooden pieces (Figure 1). The goal was to arrange these pieces such that they formed a "T."

Procedures

In all the three conditions, before solving the problem, the participants were presented with a sheet of paper that had a 2/3-sized image of "T." They were then asked to silently arrange the four wooden pieces into a "T." Before beginning the experiment, they were informed that (1) a signal would be provided by the experimenter every 20 seconds, (2) the time limit for the experiment would be 20 minutes, and (3) the sheet of paper would be taken away before they began working on the puzzle. The entire experiment was videotaped for analysis. The procedures in each condition were as follows.

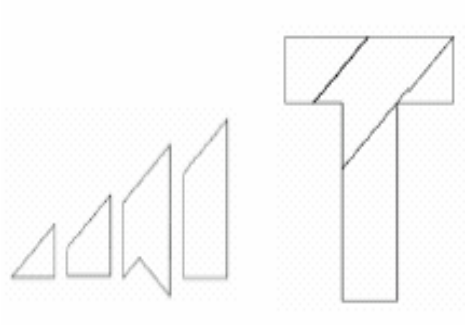

Figure 1: The T puzzle. As mentioned above, the goal was to arrange the four pieces such that they formed a "T."

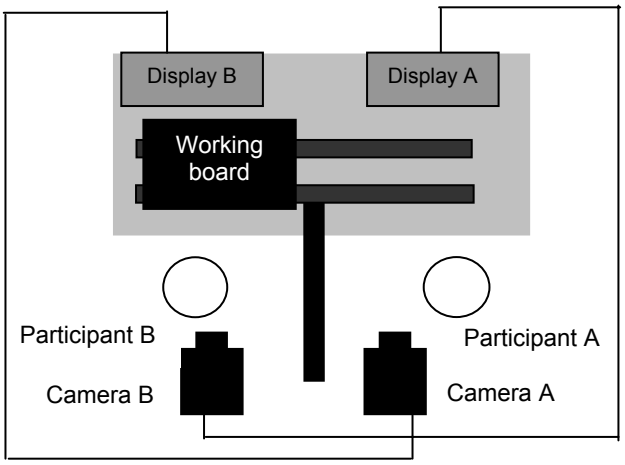

Figure 2: Experimental setting in the trial-and-other-observation pair condition.

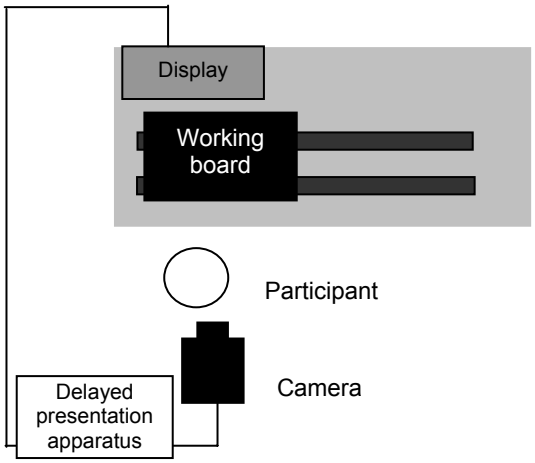

Figure 3: Experimental setting in the trial-and-self-observation pair condition.

Solo Condition In this condition, the participants were required to perform the task independently.

Trial-and-Other-Observation Pair Condition In this condition, the participants were asked to collaborate in the setting shown in Figure 2, which was designed such that they could not see their partners directly but on a display screen. This was done to avoid making the participants view their partners' trials from different angles.

Initially, participant A began working on the puzzle placed on a board in front of him/her. Participant B watched him/her on Display B, which was placed in front of him/her. The participants were asked to watch the display and think of ways to solve the puzzle. After 20 seconds, a signal was provided and participant A passed the board with the pieces to participant B without disturbing the form he/she constructed. Then, the latter began the task and the former watched his/her trial on Display A, which was placed in front of him/her. This procedure was repeated until they reached the solution.

Trial-and-Self-Observation Pair Condition In this condition, the participants were asked to work independently in the setting shown in Figure 3. The procedures in this condition were the same as those in the second condition, with the exception of what the participants observed. Since they worked independently, they were provided with a 20-second delayed feedback through a display placed before them and were asked to observe their own performance.

By comparing the second condition with the third one, we can clarify the effects of the target of observation.

Results

Initially, we examined the effects of role exchange between task-doing and observing the other on the performance of insight problem-solving. Then, we examined its effects on the process of insight problem-solving based on the dynamic constraint relaxation theory.

Performance Analysis

To examine the effect of role exchange on performance, the participants who could complete the task were classified into three groups, according to the time taken to solve the puzzle (Figure 4).

In the first condition, many participants were classified as "unsolved"; therefore, the peak solution time in this condition can be presumed to be more than 20 minutes. Meanwhile, in the second condition, the peak solution time was less than 400 seconds and the number of participants who could solve the puzzle decreased as the solution time increased. Conversely, in the third condition,[2] most of the participants were classified as "unsolved."

This difference in the distribution of solution time in each condition is verified by Fisher's exact test ($p < .001$). Residual analyses revealed that the rate of "unsolved" in the second condition was lower ($z = -3.20$, $p < .01$) and that of "solved (within 400 seconds)" was higher than the expected values ($z = 2.45$, $p < .05$). Conversely, the results showed that the rate of "unsolved" in the trial-and-self-observation pair third condition was higher than the expected value ($z = 2.59$, $p < .01$).

[2] The number of trials in the third condition was half of those in the first and second conditions. To control the number of trials, the performance in the hypothesized third condition was calculated as follows: (1) 105 (${}_{15}C_2$) pairs were made out of the total number of participants in the third condition; (2) the shorter solution time taken by a member of a pair was considered as the solution time for that pair; and (3) to control the degree of freedom, the frequencies were adjusted such that the sum of frequencies was 15.

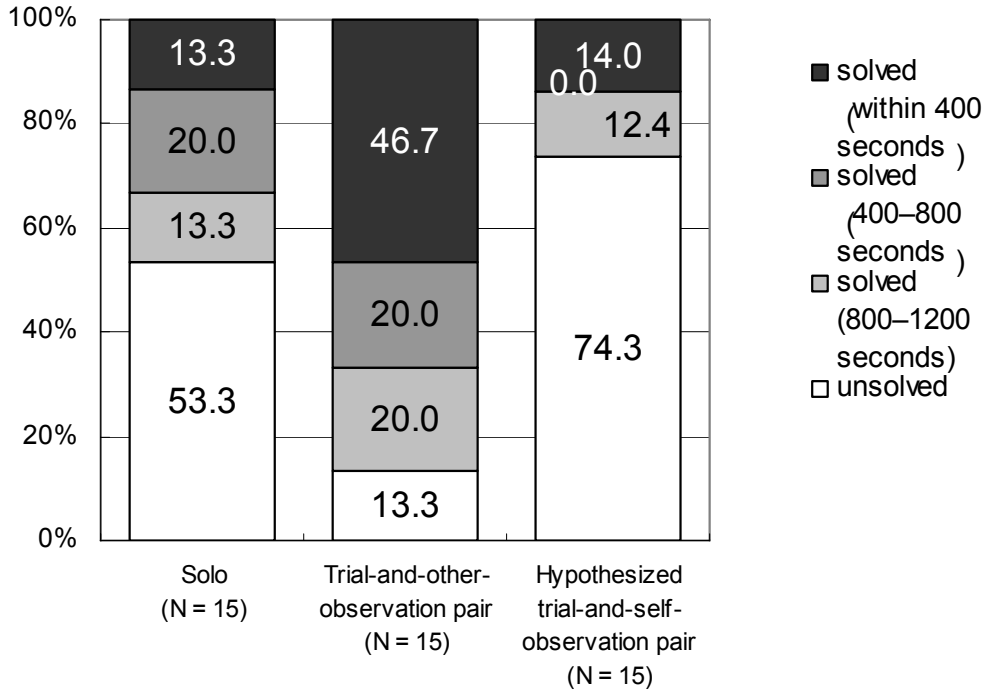

Figure 4: Distribution of solution time in each condition.

In short, the role exchange between task-doing and observing others has a facilitative effect, while that within an individual has a negative effect on insight problem-solving.

Process Analysis

According to the dynamic constraint relaxation theory, we examined the effects of role exchange on the processes of insight problem-solving.

As mentioned above, this theory hypothesizes object-level, relational, and goal constraints and indicates that these constraints result in an impasse. Further, the incremental relaxation of these constraints, which is largely due to failures, probabilistically causes qualitative transitions. Therefore, we can regard insight problem-solving as the process of constraint relaxation. More specifically, it can be said that the more frequently one deviates from these constraints, the more likely is it that he/she will obtain the solution.

Since Suzuki and Hiraki (1997) found that people have a strong tendency to place the pentagon either vertically or horizontally, with regard to the T puzzle, placing the pentagon diagonally was regarded as a violation of the object-level constraint.

With regard to the relational constraint, people tend to connect pieces in order to fill notches. Therefore, the index of the relaxation of the relational constraint was defined as connecting the pentagon with other puzzle pieces at the central part of "T." The central part indicates that the pentagon is placed at the intersection of two bars of "T."

Further, the number of times that the participants "placed the pentagon diagonally (including the placement at right angle)" and simultaneously "joined the pentagon with another piece as the central part" was counted as the index of the strong relaxation of the constraints since these factors were related not only to object-level and relational constraints but also to a goal constraint.

In this study, *term* was used as a unit of analysis and. A term was operationally defined as every 20 seconds between signals. We calculated the rates of violation from each constraint, dividing the number of terms in which some abovementioned violation occurred by term taken.

Figures 5–7 show the mean violation rates calculated from each constraint in each condition in each half. The rate of constraint violation in each condition was submitted to an analysis of variance (ANOVA) along with condition (solo, trial-and-other-observation pair, or the hypothesized trial-and-self-observation pair: between participants) and time (the first or second half: within participants) as the independent variables.

The results revealed that with respect to the object-level constraint, the main effect of condition and of time were significant ($F(2, 117) = 7.50$, $p < .01$; $F(1, 117) = 4.75$, $p < .05$, respectively—see Figure 5). In addition, the interaction between condition and time was marginally significant ($F(1, 118) = 2.64$, $p = .08$). Multiple comparisons showed that those in the first condition deviated less than those in the other two conditions (comparing with both the second condition—$t(117) = 3.26$—and the third condition—$t(117) = 2.54$, $p < .05$).

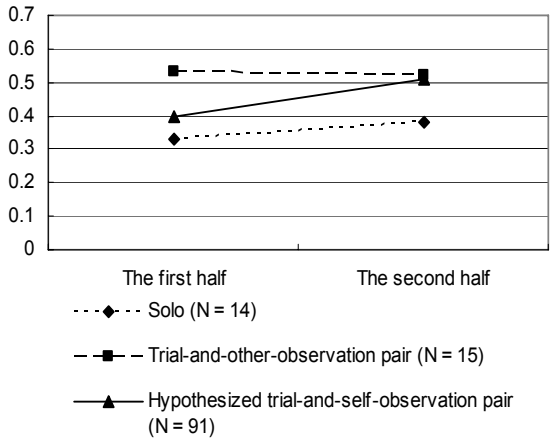

Figure 5: Mean violation rates of the object-level constraint in each condition in each half.

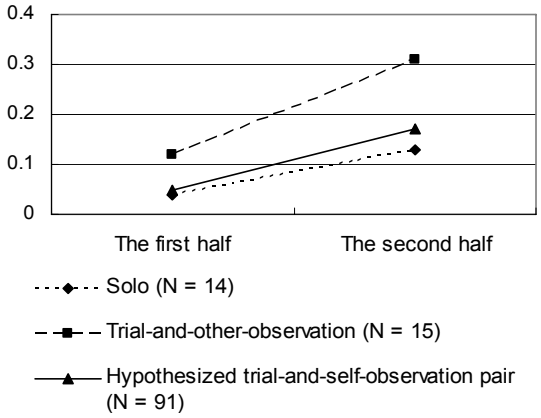

Figure 6: Mean violation rates of the relational constraint in each condition in each half.

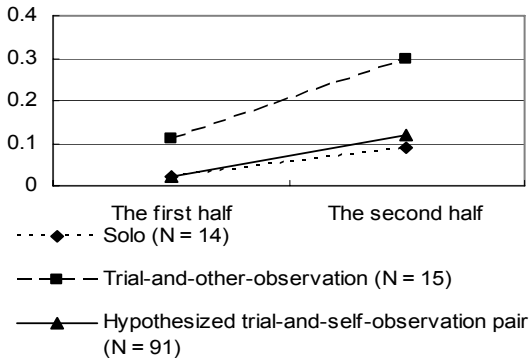

Figure 7: Mean violation rates of both constraints at the same time in each condition in each half.

With regard to the relational constraint, the interaction between condition and time was significant ($F(2, 117) = 3.57$, $p < .05$).

The interaction indicates that there were no significant differences in the violation rates among conditions in the first half, whereas those in the second condition deviated more frequently than those in the other two conditions in the second half (comparing with the first condition—$t(234) = 4.48$—and the third condition—$t(234) = 4.86$, $p < .05$).

Additionally, with simultaneous violation from both the constraints, the interaction between condition and time was significant ($F(2, 117) = 6.01$, $p < .01$). The interaction indicates that the participants in the second condition deviated simultaneously from both the constraints more often than those in the other two conditions in both the halves; the differences increased with time (comparing with the first condition—$t(234) = 2.19$—and with the third condition—$t(234) = 2.84$—in the first half; and with the first condition—$t(234) = 5.49$—and with the third condition—$t(234) = 6.49$—in the second half; $p < .05$).

In short, it can be said that the role exchange between task-doing and observing others can facilitate constraint relaxation, particularly with respect to the relational constraint.

Discussion

The present study aimed to investigate the effect of the role exchange between task-doing and observing others on insight problem-solving. The results showed that the role exchange between task-doing and observing others has a facilitative effect, while that within an individual has a negative effect on insight problem-solving. Moreover, the participants in the trial-and-other-observation pair condition placed the pieces in ways that deviated from the constraints more frequently than those in the other conditions.

The difference between the trial-and-other-observation pair condition and the solo one laid in whether or not the role exchange existed. Thus, the facilitative effect found in the former condition could be attributed to the effect of role exchange. Moreover, it has to be noted that the facilitative effect was obtained only in the trial-and-other-observation pair condition but not in the hypothesized trial-and-self-observation pair condition. The result implies that the emergence of the effects of role exchange depends on what one observes.

Why Is Role Exchange between Task-doing and Observing Others Effective?

Some interpretations are provided in an attempt to answer the question "Why different effects are obtained between the trial-and-other-observation pair and hypothesized trial-and-self-observation conditions?"

One is the effect of diverse patterns during observation. When observing others, the participants can view patterns that are different from those that they employ during task-doing. Conversely, when observing self-trials, the same patterns viewed in the previous trial occur repeatedly. The more various the patterns are, the more likely is it that a deviation from the constraints would occur. Therefore the

facilitative effect was obtained only in the trial-and-other-observation pair condition.

The second interpretation is the effect of "perspective." Several studies have suggested that other-generated hypotheses have facilitative effects on inductive reasoning, e.g., Schunn and Klahr (1993). They showed that the other-generated hypotheses led participants to investigate the plausibility of those hypotheses more thoroughly and yielded less false terminations with incorrect solutions. Kiyokawa, Ueda, and Okada (2004) experimentally clarified whether assessing other-generated hypotheses could facilitate a revision of hypotheses using a rule-discovery task. The results showed that the participants who assessed the other-generated hypotheses before generating and assessing their own hypotheses performed better than those who generated their own hypotheses and assessed them thoroughly. Although the task used in these studies is different from that used in this study, it appears that the task demand—changing initial representation to reach the solution—is common among the tasks. Therefore, it is possible that the effects seen in Schunn and Klahr and Kiyokawa et al. also emerged in this study.

The third is the effect of cognitive resources. A similar effect is known as the worked-example effect (e.g., Atkinson, Renkl, Derry, & Wortham, 2000). In other words, worked examples are superior to learning than doing. It is interpreted that this work-example effect may be caused by observers' more cognitive resources for reflecting on a task.

Future Directions

In the future, it is necessary to answer the question "What happens when the roles are fixed?" In this study, the participants in the trial-and-other-observation pair condition were asked to alternate between two roles every 20 seconds. Strictly speaking, to assert that role exchange is effective in facilitating insight problem-solving, it is necessary to compare this condition with the one in which the same roles were set but not alternated. Additionally, it is necessary to examine whether the timing of alternating the roles will affect the facilitative effect of role exchanges obtained in this experiment.

Second, it is necessary to examine whether the facilitative effects of role exchange can be generalized. In this study, the facilitative effects were obtained without any verbal interaction. It is possible that the effects are restricted to the T puzzle because verbal processes appear unnecessary for solving the puzzle. It is important to determine the extent to which role exchanges per se can be effective in facilitating problem-solving.

Third, the effects of sociomotivational factor should be examined. In the trial-and-self-observation pair condition in particular, with regard to a frustrating task that one cannot find a solution for, watching oneself fail at it might lead to greater frustration and self-consciousness. However, watching the other fail as well may have a positive effect on the motivation to perform the task. In addition to the abovementioned cognitive factors, these sociomotivational factors should be examined.

Finally, it is necessary to determine the mechanism by which role exchange facilitates constraint relaxation during insight problem-solving.

Conclusion

In this study, by controlling verbal interaction, it was revealed that the role exchange between task-doing and observing others per se can facilitate insight problem-solving. Additionally, it was revealed that the positive effect is not obtained when alternating the roles within an individual. It can be said that this research suggests a new positive effect of collaboration on insight problem-solving.

References

Atkinson, R. K., Derry, S. J., Renkl, A., & Wortham, D. (2000). Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research*, 70, 181–214.

Hiraki, K., & Suzuki, H. (1997). Constraints and their relaxation in the processes of insight. *ETL Technical Report*, TR-97-13.

Hiraki, K., & Suzuki, H. (1998). Dynamic constraint relaxation as a theory of insight. *Cognitive Studies: Bulletin of the Japanese Cognitive Science Society*, 5, 69–79. [in Japanese]

Kiyokawa, S. (2002). The interdependence structure facilitating representational change: Collaborative problem solving dividing activities into a task level and a meta-task level. *Cognitive Studies: Bulletin of the Japanese Cognitive Science Society*, 9, 450–458. [in Japanese]

Kiyokawa, S., Ueda, K., & Okada, T. (2004). The effects of other-generated hypotheses on scientific reasoning. *Cognitive Studies: Bulletin of the Japanese Cognitive Science Society*, 11, 228–238. [in Japanese]

Miyake, N. (1986). The constructive interaction and the iterative process of understanding. *Cognitive Science*, 10, 151–177.

Okada, T., & Simon, H. A. (1997). Collaborative discovery in a scientific domain. *Cognitive Science*, 21, 109–146.

Schunn, C. D., & Klahr, D. (1993). Self- vs. other-generated hypothesis in scientific discovery. *Proceedings of the 15th Annual Conference of the Cognitive Science Society* (pp. 900–905). Hillsdale, NJ: Lawrence Erlbaum Associates.

Shirouzu, H., Miyake, N., & Masukawa, H. (2002). Cognitively active externalization for situated reflection. *Cognitive Science*, 26, 469–501.

Ueda, K., & Niwa, K. (1997). Cognitive analysis of collaborative knowledge creation in R&D teams. *Proceedings of Portland International Conference on Management of Engineering and Technology (PICMET'97)* (pp. 524–527).