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A Sustainable Training Method of Metacognitive Skills in Daily Lab-activities

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Abstract: Metacognitive thinking skills that monitor and control one's thoughts, are an essential and important competency in various fields/domains. In order to promote learners' metacognitive activities, we have researched and confirmed that learner's and expert's eye-movement information during critical reading of the learner's own paper, contributes to enhancing the learner's metacognitive inference activities (MIA) and their metacognitive knowledge (Ogino et al., 2017). In this study, we embedded our metacognitive learning method into daily lab-activities in order to sustainably promote learners' MIA. This metacognitive learning design was continuously employed in our laboratory for three months. Experimental results showed that our proposed learning design was successfully adapted in learners' daily lab-activities.

Keywords: Metacognition, eye-movement information, long-term practice, research activity

1. Introduction

Metacognition is essential to successful learning because it enables individuals to better manage their cognitive skills, and to determine weaknesses that can be corrected by constructing new cognitive skills (Schraw, 1998). It has been pointed out that metacognitive skills are difficult to learn and execute, since thinking itself is invisible even by the subjects themselves and is difficult to control (Kayashima & Inaba, 2003). Writing activities offer an opportunity to develop such metacognitive skills (Hacker, 2009). By monitoring one's own sentences, which can be seen as visible expressions of one's own thoughts (Baker, 1989), one can recognize inconsistency or logical contradictions, in order to correct them. However, in many cases when writing academic documents, it is difficult for ordinary learners to be aware of logical inconsistencies or a lack of perspective, especially when monitoring their own documents. On the other hand, experts can demonstrate their metacognitive monitoring activities, during their critical reading processes.

In order to eliminate the difficulty and promote learners' metacognitive awareness, we have proposed a learning framework that focuses on writing opportunities of academic papers in which immature researchers (*learners*) and their supervisors (*experts*) collaboratively produce documents (Ogino et al., 2017). During metacognitive inferencing activities (MIA), learners try to infer experts' metacognitive knowledge based on eye-movement information during experts' critical readings of learners' documents, in order to produce their own metacognitive knowledge. From an initial experiment, we confirmed that learners' MIA were promoted by showing different types of eye-movement information, such as the difference in the total amount of gaze and the eye-movement process on the document.

In this paper, we propose a learning design for MIA by extending our proposed metacognitive learning framework to the daily lab-activities of both learners and experts. In addition, we report the results of continuous practice of MIA over three months in the context of daily lab-activities. To evaluate the learning design, we confirm the result in terms of two research questions: 1) whether our proposed learning design is suitable for learners' daily lab-activities in a way that does not hinder, but instead progresses, their research, and 2) whether the learning design promotes learners' metacognitive awareness through continuous practice of proactive MIA.

2. Metacognitive Learning in Daily Lab-activities

2.1 Learning Framework to promote Learners' Metacognitive Inference Activities

In our previous work, we proposed a learning framework for elaboration activities for academic papers, as an opportunity to foster learners' context-specific metacognitive knowledge construction (Ogino et al., 2017). The novel finding of this work is that the metacognitive activity of inferencing experts' metacognitive knowledge (MIA) is promoted by eye-movement information.

In order for learners to apply their metacognitive knowledge, it is desirable that they carefully consider learning materials in terms of their own thought contexts. Thus, in the previous study, we employed learners' document production activities, especially critical reading activities in writing their own academic papers. In comparison with reading activities of novels and essays, in which ordinary learners concentrate on understanding and enjoying the written contents, creating an academic paper requires critical reading (Suzuki et al., 2009). Learners need to critically read the paper contents to check whether there exists logical inconsistencies and gaps between what they wrote and what they intended to write, before they submit their paper to experts (supervisors). The experts also check the contents by applying their metacognitive monitoring activities.

A simple but promising idea of the framework is to focus on the differences in critical reading activities of learners and experts, which reflect the differences in their metacognitive activities. By providing eye-movement information as stimuli that can be interpreted in various ways, we propose that learners can be made aware of their immature metacognitive activities, so that they can attempt to improve their metacognitive knowledge on their own, without instructions. An early experiment was conducted, and we confirmed that eye-movement visualization tools (see Section 3) promoted learners' spontaneous MIA (Ogino et al., 2017).

2.2 Learning Materials of Metacognition in Daily Lab-activities

For this study, we designed sustainable learning activities to incorporate MIA into learners' daily lab-activities by extending our previous learning framework that focused on the specific opportunities such as academic paper elaboration activities. In order to provide sustainable metacognitive learning opportunities for learners in an authentic learning context, we needed to consider the appropriate learning materials and the suitable timing to capture eye-movement information in order to promote metacognitive awareness in learners.

As an opportunity to externalize learners' thoughts about their research and daily lab-activities, we focus on reflective reports of the meetings that describe the contents of the discussion, written after the meeting. Research meetings are required for creative and collaborative discussion (Mori et al., 2017), and the meeting report should include not only discussion results, such as in minutes, but also discussion processes and the learners' own reflective observations towards their own research progress. It is also expected that learners write reflective descriptions, such as what kind of awareness about their own thought process they gained in the discussion. Therefore, we selected the reflective report of the research meeting (hereinafter called *reflective meeting report*), including the discussion among learners and their experts, and the thoughts and reflections of the learners, as an ideal learning material of metacognitive learning.

As for when to measure eye-movement information in learners, we focused on the time just before their submissions to experts, as in the previous study. This point in time can be regarded as the learners' final critical reading of their reports. As for experts, we selected the point in time when they critically read the report for the first time, i.e., just after submission. Based on both learners' and their expert's eye-movement information, the eye-movement visualization system (Section 3) provides two types of visualization data, each of which intends to continuously encourage learners' MIA in their daily research activity contexts.

2.3 MIA Learning Cycle in Daily Lab-activities

Based on the previous discussion, we designed learning activities to promote the metacognitive awareness of learners. The learning cycle consists of the following six phases:

P1 Research meeting: Learners report their progress and/or propose ideas of their research to experts and explicitly share their thinking processes through the discussion.
P2 Writing reflective meeting report: After the research meeting, learners reflect on the meeting and own thought process, and write them as a reflective meeting report in a logical manner based on the discussion. Since the reports reflect their thoughts on the research activities, they should write the contents with a deep understanding of their own research.
P3 Critical reading by learners: This phase corresponds to the point in time just before submission to experts. Learners critically read their own reflective meeting reports to verify whether there exists logical inconsistencies and gaps among what they intended to write, what they should report (reflect on) and what they wrote. During the critical reading, learners' eye-movement processes are measured by eye-tracking devices.
P4 Critical reading by experts: This phase occurs when experts read the meeting reports for the first time, just after the submission. As in P3, the experts' eye-movement processes are measured by eye-tracking devices. In this phase, experts need to check if they understand their own research and their own misunderstanding and they were properly written in addition to confirming the consistency between the contents of the report and the discussion. After the reading (eye-movement recording), feedback (voice recordings) from the experts is provided in order to foster learners' understanding.
P5 MIA of learner: Based on the eye-movement information measured in phases P3 and P4, learners concentrate on performing MIA using eye-movement visualization tools (see Section 3) so that they can attempt to improve their metacognitive knowledge on their own, without instructions. Through MIA, learners are required to infer the experts' metacognitive monitoring activities in their critical readings of learners' reports, such as *the words that the expert is paying attention to might have ambiguous meanings*, and *the part that the expert repeatedly reads might be different from the shared discussion contents or include my misunderstanding*.
P6 Proofing meeting report: Based on the MIA in P5, learners tackle proofing activities (i.e., performing metacognitive control activities) of their reflective meeting reports. During this process, they deepen their understanding of the report contents and reorganize their thoughts on their research. After the proofing activity, learners receive experts' feedback (i.e., the speech voice recorded in P4), and make a plan to improve their research for the next meeting.

3. Recording and Visualization Tools of Eye-movements Information

In this section, we first describe an eye-movement recording tool that measures and records gaze data when users critically read a reflective meeting report. Then, we present two types of visualization tools; *comparative heat map visualization tool* and *eye-movements visualization tool*, originally proposed in (Ogino et al., 2017).

Eye-movement Recording Tool: The eye-movement recording tool works with a screen-based eye-tracking device. The tool starts when a user inputs a target document (e.g., reflective meeting report) as text formatted in Japanese. It then divides the text into a set of minimal word units, each of which has a syntactic function, using a Japanese dependency parser. After processing, the tool automatically assigns area-of-interest (AOI) regions to respective word units and displays them. Based on the AOI regions, the tool detects if the eye-movements fall within AOI regions during each frame; it records the length of the user's gaze on the sentence-objects in milliseconds and their respective identification data, whereas AOIs are invisible to the user.
Comparative Heat Map Visualization Tool (C-View): This visualization tool is designed to help the learner become aware of the differences in the gaze time of respective sentence-objects between him/herself and the expert. The interface includes two heat maps, each of which statically represents the aggregations of gaze times of the learner (left side) and the expert (right side) for each sentence-object (Fig. 1). In the heat maps, the background color of each sentence-object becomes darker red proportionate to the gaze time. By contrasting and displaying each heat map, learners can compare and review the sections of their reports that experts paid attention to, but that learners did not.

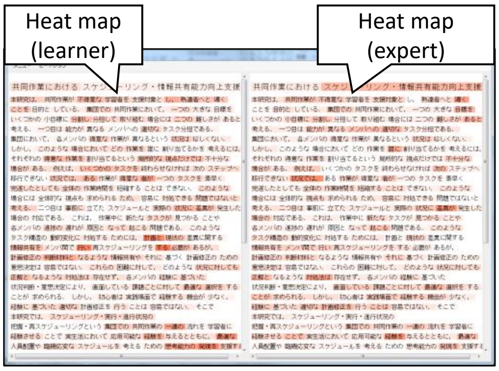

Figure 1. Interface of Comparative Heat Map Visualization Tool

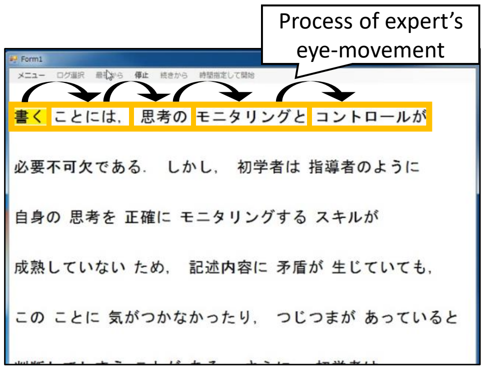

Figure 2. Interface of Eye-movements Visualization Tool

<u>*Eye-movements Visualization Tool (EM-View)*</u>: This tool shows the untouched 'processes' of eye-movements during reading activities according to the timing data of the expert's gaze at statement-objects. Figure 2 shows the interface. By observing the EM-view, a learner can follow the expert's reading processes, in which his/her metacognitive activities are reflected. In the interface, the gazed at statement-object is highlighted at each point in time. While this visualization method might be quite straightforward, we expect that it could help the learner infer the expert's metacognitive monitoring processes.

4. Practicing Metacognitive Inference Activities in Daily Lab-activities

Study participants conducted three months' practice to confirm the usefulness of our proposed metacognitive learning activities discussed in Section 2, and whether the learning design could be sustainably incorporated into authentic lab-activities.

4.1 Setting

We practiced our proposed metacognitive learning cycle, in which learners tackled the above series of tasks, from mid-October 2017 to mid-January 2018.
Participants: 10 researchers (four undergraduate students and six graduate students) in the same laboratory were selected as learners. Their professor was selected as an expert. In addition, another professor was selected as an evaluator in the same laboratory, who joined in the all research meetings, to evaluate the quality of learners' reflective meeting reports.
Learning opportunities: we selected the time at which each learner writes down his/her reflective meeting report after his/her research meeting. Learners continually practiced according to the learning cycle in the daily lab-activities (Section 2.3).
Learners' tasks: learners were asked to tackle three types of tasks shown in Table 1. Q1 and Q2 correspond to the MIA task through the interfaces of C-view (Fig. 1) and EM-view (Fig. 2). Q3 is to clarify the reasons for correction (if any) after their proofing reflective meeting report phase (P6).
Evaluator's tasks: Table 2 shows tasks for the evaluator. In Q4, we set two reports for each learner, submitted report and report after correction in P6, at random as report α and report β. The evaluator was asked to conduct a blind evaluation of them. Q5 was designed to confirm whether learners' corrections of their reflective meeting reports (i.e., learners' metacognitive controls) were meaningful or not.

4.2 Results and Discussion

The total number of practices was 48 and the average number of practices per learner was 4.8. The range in the number of characters written in each meeting report was 500 to 3,500 characters.

<u>*Feasibility of the Learning Design*</u>: While the time taken to write a reflective meeting report depends on the discussed contents, the average time required for the learner was about three hours (P1:

Table 1

Questions for Learners

	Timing	Question
Q1	P5	Infer and list what the expert was thinking about during his/her critical reading of your report by referring to *C-view*.
Q2	P5	Infer and list what the expert was thinking about during his/her critical reading of your report by referring to *EM-view*.
Q3	P6	Write down the reasons for your correction of your report contents.

Table 2

Questions for the Evaluator

	Question
Q4	Rate report α and report β respectively on a scale of one to ten (0.5 point intervals).
	Write down the reasons for your scores if there is a difference between the scores.
Q5	Check the correction reasons of learner (Q3) and whether each of them is rational or not.

30min., P2:120min., P3:5min., P5&P6: 40min.). The expert took about 40 minutes for each research meeting and critical reading of the report (P1:30min., P4:10min.). Many of the learners commented that, *although the workload of preparing the reflective meeting report is not low, there is no trouble in carrying out the research and it is meaningful in organizing the content of the discussion and my research itself*. In addition, the expert commented that, *it is meaningful to review their reflective meeting reports, in terms of grasping learners' level of understanding of their research, and there is very little workload accompanying the critical reading (measurement of gaze information)*. These results and comments support that our proposed learning activities can be successfully and sustainably integrated into the daily lab-activities both of learners and their expert.

Effectiveness of MIA by C-view and EM-view: The average numbers of comments in Q1 and Q2 were 3.27 and 2.81, respectively. During the practice, both Q1 and Q2 were always completed by learners. These results indicated that learners' metacognitive activities of inferencing expert's metacognitive knowledge were activated by observing eye-movement information, as displayed in C-view and EM-view. In this practice, we employed the learning design, in which learners first conducted MIA with C-view, and then they tackled MIA with EM-view. It is an interesting result that C-view and EM-view increasingly promote learners' MIA even for reports that the learner had critically checked before submission.

The average number of comments in Q3 was 2.57. All of learners made some correction to their reflective meeting report during each practice and wrote down the reasons for them. This result suggests that learners' MIA contribute to their correction activities, i.e., metacognitive control activities in P6, even though the meeting reports had been thoroughly reviewed before the submission.

Quality of Learners' Correction Through the Long-term Practice: Figure 3 shows the evaluation results of the meeting reports from Q4. After the correction, the average scores of nine learners out of ten were higher than before. The number of times the evaluator judged the corrected ones higher, and was 33 out of 48 reports (about 69%). In order to investigate whether there was a difference between the evaluation scores before and after the correction of meeting reports, a paired t-test was calculated. Based on this test, the score after correction was significantly higher than before correction ($t(47)=6.75$, $p<.01$). In addition, we also confirmed there were significant differences in report scores before and after, in all three months (left side of Fig. 3). Thus, we confirmed short-term and long-term improvement in the quality of learners' reflective meeting reports. Through this long-term practice, the evaluator judged 83 reasons as rational out of 126 reasons given (about 66%) in Q5. In addition, we confirmed that more than two of each kind of reason were produced by each learner.

According to the above results, we indicated that our proposed learning design encourages MIA, and can be successfully incorporated into an authentic lab context in a sustainable way. This is one of the research contributions of this study. In addition, we confirmed the effectiveness of activating learners' MIA continuously, and indicated that MIA contributed to learners' awareness of

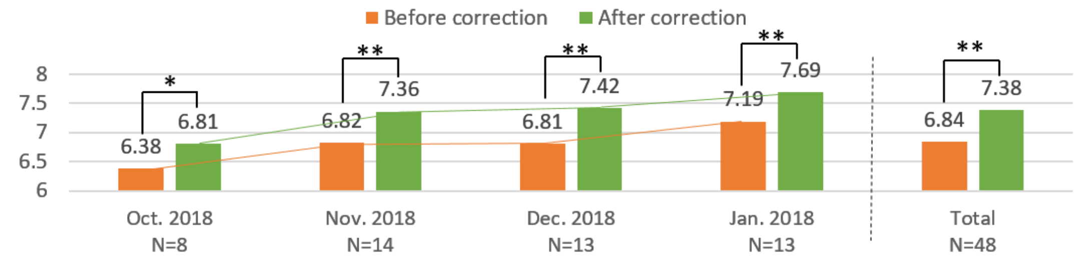

Figure 3. Evaluation Results of Learners' Meeting Reports

metacognition, which led to the correction activities of their meeting reports. These results are supported by the increase in evaluations of the reflective meeting reports. To summarize, it is suggested that our proposed learning design in daily lab-activities could contribute to improving learners' metacognitive awareness.

5. Conclusion

In this study, we proposed sustainable learning activities to promote learners' MIA by extending our previous learning framework. As learning materials, we focused on eye-movement information during reading of reflective meeting reports in daily lab-activities as opportunities to externalize learners' thoughts about their research. Based on the designed learning cycle, we conducted a long-term practice program with ten learners. The results showed that our proposed research activities were successfully incorporated into learners' daily lab-activities for three months, and that the visualization tools contributed to continuously promoting learners' metacognitive awareness by MIA.

In the context of authentic research activities, there are many factors that may affect the improvement of metacognitive awareness. Thus, we cannot conclude that all the results presented in this study are due to the proposed learning activities. However, it is notable that the learning framework makes it possible to produce opportunities where learners become aware of cultivating own metacognitive skills in daily lab-activities in a sustainable manner. For the future work, we plan to investigate what kind of stimuli were effective in promoting learners' metacognition, taking into account the characteristics of learners in more detail.

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