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Enhancing Metacognitive Inference Activities Using Eye-movements on One's Academic Paper

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Abstract: Metacognitive thinking skills are essential for learning. Performing writing activities with experts is a great opportunity for learners to construct metacognitive knowledge by inferring experts' critical reading processes. In this study, we refer to "metacognitive inference activities" as learners' inferring activities of experts' metacognitive knowledge in their critical readings. In order to promote such learners' metacognitive inference activities, we first discuss about learning processes using learners' own academic paper and eye-movements during their critical reading to find metacognitive knowledge without instructions. Then, we propose a system featuring three types of visualization based on learners' and experts' eye-movements information. Experimental results showed that the visualized information of comparative heat map (C-view) and experts' eye-movement processes (EM-view) promote learners' metacognitive inference activities. More specifically, EM-view increasingly promotes their reflections toward being aware of metacognitive knowledge without instructions.

Keywords: Metacognitive inference activity, metacognitive knowledge, eye-movements, critical reading processes

1. Introduction

Metacognitive thinking skills for performing monitoring and control of one's own thought are an essential and important competency/ability in various fields/domains such as business activities, problem-solving, reading and learning (Flavell, 1979; Schraw and Dennison, 1994). Since thinking itself is unobservable even by the subjects themselves and chaotically behaves, we are often faced with situations in which we cannot exert our metacognitive skills appropriately. It is therefore a good chance for learners to perform writing activities so that they develop such metacognitive skills (Hacker, Keener and Kircher, 2009). By monitoring one's own sentences seen as visible expressions of own thought (Baker, 1989), one can realize the inconsistency or logical contradictions, so as to reconstruct one's own thought.

However, in writing academic reports, it is difficult for ordinary learners to be aware of logical inconsistencies or lacks of some viewpoints even by monitoring their own documents. On the other hand, experts can do well by demonstrating their metacognitive monitoring activities in their critical reading processes according to the cognitive dissonance. Consequently, marks, comments and error-corrections attached to the documents by the experts are results of their metacognitive activities. It is essentially a good chance for learners to become aware of their immature metacognitive thinking processes by carefully reading experts' intentions from their corrections or comments. However, in most situations, learners tend to dedicate themselves to just adopting experts' corrections without any careful reading of intentions underlying such corrections; They do not tend to adopt a learning-oriented behavior but rather a problem-solving oriented one, i.e., they set their goals to finish writing, and even when they tried to infer, it is difficult since the metacognitive processes of experts are implicit and only their corrections are described in the documents in many cases (Schraw and Moshman, 1995).

On the other hand, it would be beneficial for learners to find meaningful metacognitive knowledge by themselves in their thought context rather than to be taught metacognitive knowledge as principles in a context independent situation. In our research, we define “metacognitive inference activities (MIA)” as learners’ activities of inferring experts’ metacognitive knowledge in their critical readings of learners’ documents. We aim to prompt learners’ metacognitive inference activities to find their meaningful metacognitive knowledge by developing useful learning methods whereby the learners themselves concentrate on the task with the clue of indirect information in order to train their critical reading skills, and also to cultivate their attitudes towards performing metacognitive learning. As an example of promising stimulation that affects learners’ question generation activities for promoting MIA, we focus on the ‘eye-movements’ of learners and experts during their critical reading.

In this paper, we set a research hypothesis that a part of metacognitive thinking processes appears in readers’ ‘eye-movements’ during their critical reading. According to cognitive load theory (Sweller, Van Merriënboer and Paas, 1998), appropriate instructional designs can reduce extraneous cognitive load and redirect learners' attention to cognitive processes that are directly relevant to the construction of schemas. Therefore, we carefully design learners’ learning activities and provide eye-movements information as stimuli for promoting their MIA by causing attention. Several studies have focused on utilizing eye-movements for promoting learning activities. Jarodzka, et al. (2013) investigated the effects of showing the eye-movements of experts with multimedia learning materials. The result showed that eye-movements information contributes to having a gain in guiding students’ attention and also fostered learning by improving students’ visual search and their ability to identify relevant information. While the basic idea of our study is similar to Jarodzka’s approach, we used eye-movements of experts as stimuli for promoting MIA. Merten and Conati (2006) proposed a student model designed to assess learner’s metacognitive activities based on eye-movements during interaction with an adaptive learning environment for the domain of mathematical functions. By comparison with the related works, our study focuses on indeterminate-formed academic documents as learning materials and adopts eye-movements information as stimuli to support for learners to infer experts’ metacognitive models in their minds. In the rest of the paper, in section 2, we first consider the difficulties of metacognitive knowledge acquisition, and design effective learning processes to promote learners’ metacognitive inference activities. Then, in section 3, by utilizing learners/experts eye-movements information, we propose three types of visualization methods intended to promote learners’ metacognitive inference activities without direct instructions. In section 4, we discuss the experiments to analyze the effects of the visualization methods. In the experiments, we also mention the effects of ‘think-aloud’ data during experts’ critical reading as a direct way of representing their metacognitive activities. Finally, we conclude in section 5.

2. Learning Design for Promoting Metacognitive Knowledge Acquisition

2.1. Difficulties in Constructing, Teaching, and Applying Metacognitive Knowledge

Figure 1 describes a flow of academic documents elaboration. We focus on learners’ academic reports or research papers elaboration activities which also involve cooperative discussions with experts.

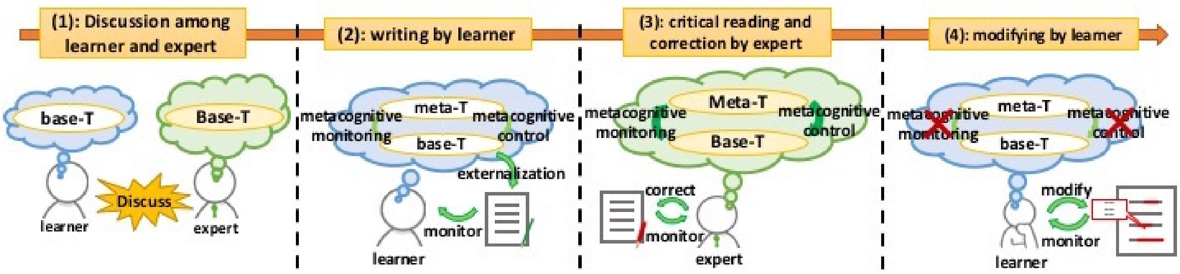

Figure 1: Flow of Elaborating Documents with Experts.

Table 1: Factors of Difficulties in Constructing, Teaching, and Applying Metacognitive Knowledge.

Viewpoints	Factors of difficulty
Constructing metacognitive knowledge	D1: Difficulty of being motivated to attempt to construct the metacognitive knowledge
	D2: Difficulty of inferring experts' metacognitive activities based on their correction results
Teaching metacognitive knowledge	D3: Difficulty of verbalizing implicit metacognitive knowledge
Applying metacognitive knowledge	D4: Difficulty of applying general metacognitive knowledge in own specific thought contexts

In the process of discussion among learners and experts (Fig. 1(1)), they consider which contents/topics should be included and explicitly share their ideas with each other. Learners then try to externalize their base-T, and check logical consistencies via critical reading. In this process, learners read their own externalized documents and conduct metacognitive monitoring and control in their thought (Fig. 1(2)). It is difficult for ordinary learners to detect and correct logical inconsistencies thoroughly because of their immature metacognitive thinking skills, whereas experts can do so via critical reading (Fig. 1(3)). In the process, experts attach marks, comments and error-corrections on the documents as results of their metacognitive activities. While these correction results could be used as clue to find metacognitive knowledge for monitoring and control (correct) their own thought, learners rather dedicate themselves to just modifying the documents based on correction results without deep consideration of the reasons why such corrections were performed (Fig. 1(4)). Thus, they tend to lose precious opportunities to construct their metacognitive knowledge by inferring the experts' metacognitive processes of how they critically read the documents.

The necessity of constructing metacognitive knowledge as well as when and how they should be applied by learners themselves was reported (Schraw, 1998). In many situations however, learners often lack of consciousness about constructing metacognitive knowledge, so that they just tend to focus on modifying superficial error-corrections (*difficulty 1*). In addition, even if learners try to infer experts' correction processes/intentions, it is no less difficult to do so, since the correction processes of how experts find logical inconsistencies and contradiction do not remain in the results (*difficulty 2*). On the other hand, the importance of teaching to learners the metacognitive knowledge by experts was also pointed out (Wilson and Bai, 2010). However, it is difficult for experts to directly verbalize metacognitive knowledge because of its essentially implicit nature (Veenman, Van Hout-Wolters and Afflerbach, 2006) (*difficulty 3*). Furthermore, even if experts teach learners about certain metacognitive knowledge as general principle, to simply know is one thing, and to apply them in one's own thought context is quite another story (*difficulty 4*).

Table 1 summarizes the difficulties mentioned above and their implications in constructing, teaching, and applying metacognitive knowledge. We tackle these problems by designing learning processes so as to reduce these difficulties and prompt learners' metacognitive activities in order to help them find fruitful metacognitive knowledge in their thought contexts.

2.2. Learning Design to Promote Metacognitive Inference Activities

In this study, as discussed in the previous section, we focus on leaners' documents production activities with experts and consider them as great opportunities to foster learners' context-aware metacognitive knowledge construction. We set a research hypothesis that eye-movements during

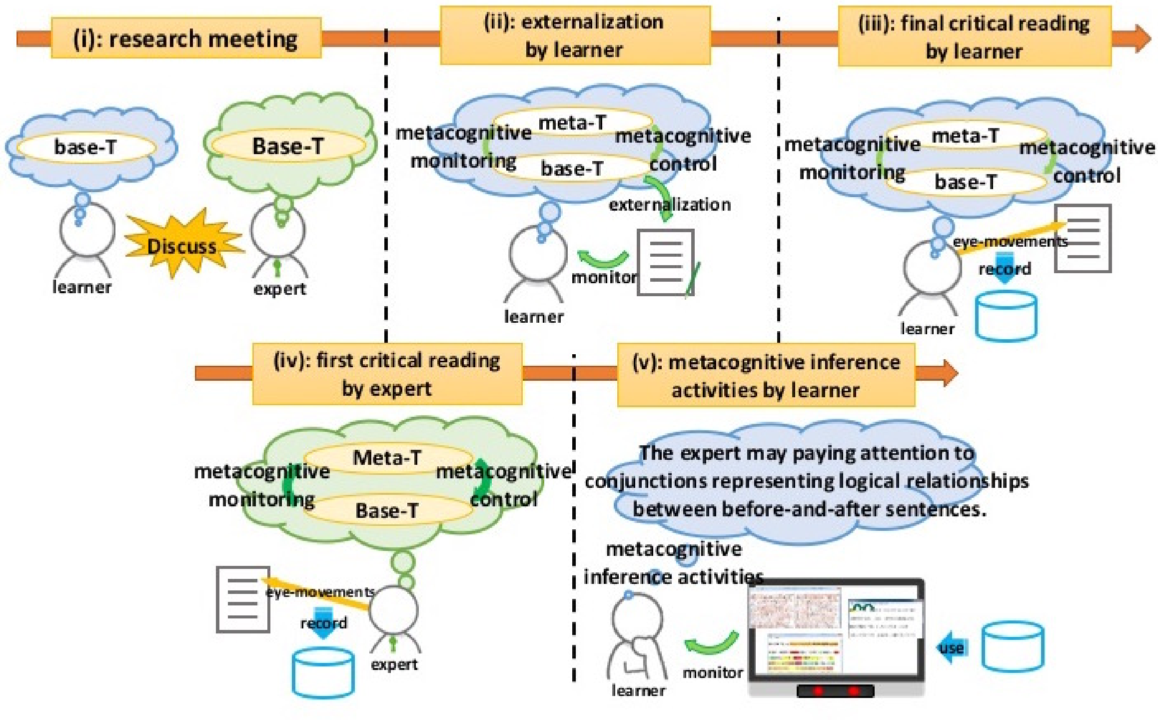

Figure 2: Learning Design for Promoting Learners' Metacognitive Inference Activities.

one's critical readings reflect a part of the one's metacognitive activities. Then, we employ the learners' eye-movements during their critical readings to their own documents and experts' ones as learning materials. Based on the eye-movements data, we design promising visualization methods for promoting learners' MIA to construct their metacognitive knowledge (see section 3). In the rest of this section, we discuss the appropriateness of our learning materials settings and learning activities (Fig. 2) to reduce the difficulties described in Table 1.

Learning materials: 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. To solve the difficulty of D4, we do not employ pre-arranged learning materials but rather employ learners' documents 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 essentially requires their critical readings.

In general, in order to create academic papers, learners and experts first share contents that should be written in documents through discussion (Fig. 2(i)). Then, learners try to organize the contents as documents in a logical manner (Fig. 2(ii)). Since the documents reflect their thought contexts of research activities, they should write the contents with deep understanding of their own research. However, in most cases, it is difficult for ordinary learners (novice writers) to critically check their own written contents because of lacking of metacognitive skills, whereas experts can read and correct them critically from the standpoint of research collaborators.

A simple but promising idea here is to focus on the differences in critical reading activities of learners and experts, which reflect the differences of their metacognitive activities. In the flow of creating the paper by learners, we focus on eye-movement processes captured just before their submissions to experts (Fig. 2(iii)). These activities can be regarded as learners' final critical reading processes to check whether there exists logical inconsistencies and gaps between what they wrote and what they intended to write. In addition, we utilize experts' eye-movements during their critical reading of submitted documents by learners (Fig. 2(iv)). Of course, the experts' eye-movement processes differ from learners' ones. It is expected that these differences could be utilized as stimulation for activating learners' MIA. In this way, we tackle the difficulty of D3 by not teaching

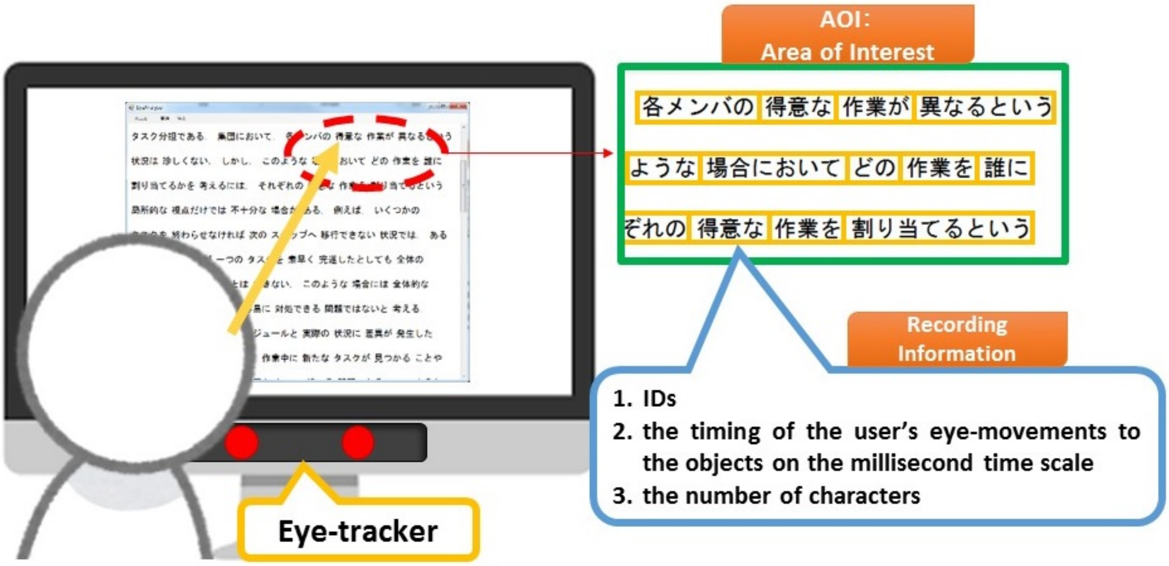

Figure 3: Interface of the System

Figure 4: Three Types of Visualization.

the metacognitive knowledge explicitly but utilizing the eye-movement processes during critical readings as learning materials in an indirect fashion.

Learning activities: In order to reduce the difficulty of D1, we develop a visualization system of captured eye-movement information that allows leaners to concentrate on MIA to construct their metacognitive knowledge in their thought context (Fig. 2(v)), e.g., "*the expert might be paying attention to conjunctions representing logical relationships between previous-and-next sentences*." To not provide correction results (answers) but rather the processes of eye-movement information contributes to eliminate the difficulty of D2. By devising visualization methods as promising stimuli, we expect that learners can be aware of their immature metacognitive activities, so that they try to construct their new metacognitive knowledge by themselves without instructions.

3. Developing System

The methodology of using the eye-movement information as stimuli to promote a learner's metacognition have not yet been proposed. We propose a promising idea that promotes learners' metacognitive activities to find metacognitive knowledge by themselves without instructions. More concretely, we proposed three types of visualization methods, i.e., *comparative heat map, overlaid degree heat map, and eye-movements visualization*, each of which is designed to trigger learners' awareness based on the differences between the learner's own eye-movements and those of an expert during check/correction of the learner's document.

In order to utilize a learner's and an expert's eye-movements, we developed a system that captures and records their gaze data when reading a document. Figure 3 shows the interface of the system that embeds a screen-based eye-tracking device (Tobii Technology). The system starts when a learner inputs a target document as text format in Japanese, then it divides the texts into a set of minimal word units each of which has a syntactic function using a Japanese dependency parser (Kudo and Matsumoto, 2002). After processing, the system automatically sets area-of-interest (AOI) regions to respective word units and displays them. Based on the AOI regions, the system detects if the eye-movements fall within such an AOI at each frame; it records the timing of the user's eye-movements on the objects on a millisecond time scale and their respective IDs, whereas AOIs are transparent so as to be invisible for learners.

Based on the recorded information, the system can provide the following three types of visualization:

Comparative heat map (C-view): This visualization method is designed to make the learner be aware of the differences between gazing-time of respective sentence-objects of him/her and those of the expert so that he/she can find metacognitive knowledge. The interface includes two heat maps each of which statically represents the aggregations of gazing times of the learner (left side) and expert (right side) at each sentence-object (Fig. 4). In the heat maps, the background color of each sentence-object becomes darker red proportionally to their gazing time at the object. The proportional density of each sentence-object is set up by two steps: First, we calculate the total gazing times at the object. Then, we calculate the normalized total time of each object by dividing the total gazing time by the number of characters that compose the object.

Overlaid degree heat map (OD-view): This visualization method is designed to emphasize the difference between total gazing time of a learner and an expert on each sentence-object by overlaid degree information based on the above C-view. Figure 4 shows the interface of OD-view. Here, we use four types of combinations of learner and expert's gazing degrees (*'frequently'* / *'scarcely'*) to each sentence-object as shown in Table 2. We heuristically define the combinations that could contribute to making the learner be aware of metacognitive knowledge based on the information such as only the expert focused on certain sentence-object (i.e., learner = *'scarcely'* and expert = *'frequently'*) and both of them focused on (i.e., learner = *'frequently'* and expert = *'frequently'*).

Respective degrees for each object are calculated by following three steps: First, we calculate normalized density of each statement-object by the same way of C-view. Then, we calculate both the μ (mean) and σ (standard deviation) of the normalized densities of all the statement-objects for the learner and the expert, respectively. Finally, we judge whether 'frequently' or 'scarcely' by calculating if the normalized density of certain statement-object is greater than $\mu+\sigma$ *('frequently')* or smaller than $\mu-\sigma$ *('scarcely').*

Eye-movements visualization (EM-view): This represents the untouched 'processes' of eye-movement of reading/correction activity according to the timing data of the expert's eye-movements to statement-objects. Through the EM- view, the learner can follow the expert's reading processes which reflects his/her metacognitive knowledge activities. In the interface, the gazed statement-object at the time is highlighted in turn. While this visualization method might be quite straightforward, we expect that it could help the learner touch the expert's metacognitive monitoring processes, i.e., how the expert reads the document by monitoring his/her gazing processes, e.g., he/she is repetitively gazing at the same part.

4. Experimental study

Table 2: Combinations of Gazing Degrees of Learner and Expert and the Highlight Color.

Learner	Expert	Highlight color
'frequently'	*'frequently'*	Red
'scarcely'	*'frequently'*	Orange

In the previous section, we introduced three types of visualization methods (C-view, OD-view and EM-view). In our previous work, we have already conducted initial experiments to confirm whether the displayed information in the C-view and OD-view promotes the learner's MIA (Ogino et al., 2016). Through observing gaze information in respective views, we asked learners to attempt to infer the expert's metacognitive monitoring activities. The results showed that some of the learners become aware of intentions underlying expert's corrections, even though we do not expect their inference results to exactly match the expert's ones; we rather aim to get them be aware of the usefulness of inferring metacognitive knowledge.

The previous experiments focused on clarifying the usefulness of gaze information appearing in respective views for prompting their metacognitive activities, especially from the viewpoint of differences between the amounts of gazing targets (statement-objects) of the learner and expert (i.e., C-view and OD-view). On the other hand, since eye-movement involves the motion in the first place, it is worthwhile to check whether the information of eye-movement processes (i.e., EM-view) could also contribute to promoting the learner's metacognitive monitoring activity. Let's note that a lot of naked eye-movement information may impose cognitive load on the learner, which might result in disturbing their MIA.

Therefore, the objective of this experiment is to analyze the effects of the displayed information of the active eye-movement (EM-view) in addition to the static one (C-view) in terms of promoting the learner's MIA.

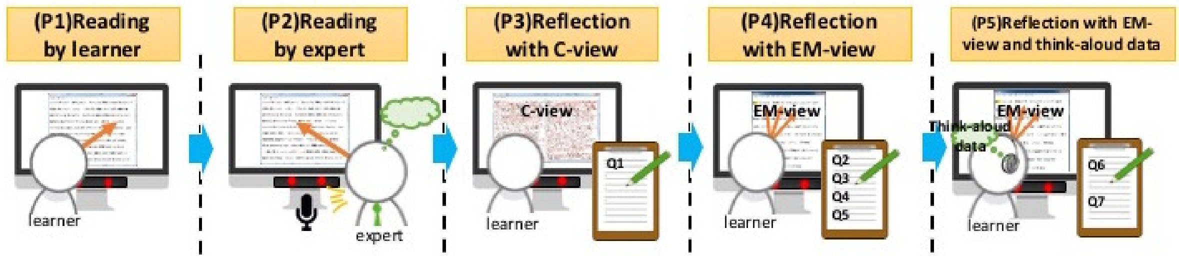

Figure 5: Experimental Procedures.

Furthermore, we conducted the experiment using expert's verbalized thought information during the correction processes by think-aloud method (Jaspers et al., 2004) in addition to the eye-movement information. Then, we analyzed the effects of the metacognitive knowledge acquisition as the final goal of our research by increasing the information gradually.

4.1. Experimental Setting

In the experiments, we had seven participants as *learners*, who are laboratory members (undergraduate and graduate students), two of their supervisors from the same laboratory as *experts*. As learning materials, we used a summary document of each learner's own research. The research summary should include research backgrounds, objectives, approaches, and so on in a logical and coherent manner. Each document included about 2,000 characters in Japanese. In order to record the participants' gaze data, we asked the participants to check their documents using the eye-movements capturing system shown in Fig. 3 just before submission to their supervisors. Also, we asked the two experts to perform reading/correction activities of the submitted documents on the system.

4.2. Experimental Procedure

Figure 5 represents the experimental procedures and Table 3 shows questionnaires used in the experiments. The experimental procedure is composed of two phases: *data collection phase* (P1 and P2) and *learning phase* (P3, P4 and P5). The learners undertake the task of P1, P3, P4 and P5 and the experts only do P2.

Data collection phase:

P1. *Critical reading by learners*: After learners proofread their documents, they calibrate the eye-tracking devices and critically read their respective documents using our eye-movements capturing system.

P2. *Critical reading by experts*: After experts calibrate the eye-tracking devices, they read each learner's document using the eye-movements capturing system as well as conducting think-aloud, i.e., say whatever comes into their mind until they finished reading.

Learning phase:

P3. *Reviewing with C-view*: The learners were asked to review their documents using C-view, and answer Q1 to confirm if the visualized information in C-view promotes their metacognitive activities.

P4. *Reviewing with EM-view*: The learners were asked to review their documents using EM-view in which an expert's eye-movement is displayed. Then, they were asked to answer Q2 to Q5: Q2 is set to confirm if inferring an experts' thought processes with visualized eye-movement promotes learners' metacognitive monitoring. Q3 is to clarify whether the EM-view further activates their metacognitive activities in comparison with the results of Q1. Q4 and Q5 are to clarify the possibilities that the learners themselves could find their metacognitive knowledge.

P5. *Reviewing with EM-view and think-aloud data*: The learners are asked to review their documents using EM-view with synchronized think-aloud data of an expert. Then, they are asked to answer Q6 and Q7 that are set to clarify the possibilities if the learners can acquire metacognitive knowledge from the thought information. This was conducted by four learners out of the initial seven.

Table 3: Questionnaire Items.

Q1	List up the points that should be modified in your document by referring to the expert's gaze behavior.
Q2	Think-aloud what the expert was thinking about during his reading your document by referring to his gaze behavior.
Q3	List up the points that should be modified in your document.
Q4	Do you think you thought about what you answered in Q2 during your writing/reviewing? (*yes* or *no*)
Q5	Do you think you thought about what you answered in Q2 when you wrote other documents? (*yes* or *no*)
Q6	List up what the instructor was thinking about during his reading by listening to his think-aloud.
Q7	List up what you didn't conduct in reviewing your own paper but noticed by listening to experts' think-aloud.

Experimental Result and Discussion

Table 4 represents the number of each learner's comments on Q1, Q3, Q6 and Q7. The numbers in parentheses of Q6 and Q7 indicate the number of comments which does not correspond to the expert's think-aloud contents. Table 5 shows the examples of think-aloud contents in Q2 by learners during their learning phase P4, whereas Table 6 summarizes the total number of learners' *yes-no* answers in Q4 and Q5.

Effectiveness of Comparative heat map (C-view): 35 comments are totally given by learners in Q1. This suggests that adding the visualized information onto their documents, which they judged adequate through their critical reading, in each learner's and expert's heat maps contributes to prompting their MIA to some extent.

Table 4: The Number of Comments by Each Learner on Q1, Q3, Q6 and Q7.

	A	B	C	D	E	F	G
Q1	4	4	4	16	0	5	2
Q3	3	4	4	3	0	1	0
Q6	6 (0)	8 (0)	19 (0)	18 (1)	-	-	-
Q7	2 (0)	2 (0)	5 (0)	4 (1)	-	-	-

Effectiveness of Eye-movements visualization (EM-view): The results of Q2 (Table 5) suggest that learners are prompted to guess what the expert was thinking about by referring to expert's eye-movements as clues, so that they were aware of insufficient contents of their documents such as description of a technical term not clearly defined. In addition to the results in Q1, 15 comments were provided in Q3, which suggests that learners become more aware of the expert's intentions when using EM-view in comparison to C-view. These results suggest that the expert's visualized eye-movement processes on EM-view increasingly promote learners' MIA.

Table 5: Examples of the Think-aloud Contents in Q2.

The expert might be checking if the appropriate subject is unified, and if the description is just my opinion or a fact that is theoretically backed up.
The expert might be thinking about the meaning of the term "typical learning" that I used in my document.
The expert might be thinking about a concrete example of "a convinced discussion (which is described in his document)".

Table 6: The Total Number of Answers in Q4 and Q5.

		Q4	
		Yes	*No*
Q5	*Yes*	4	0
	No	0	3

From the results of Q4 and Q5 (in Table 6), the learners are divided into two groups: one is composed of learners who could be aware of metacognitive knowledge they already have during their own critical reading processes (Q4: *'yes'* and Q5: *'yes'*); the other is composed of learners who could be aware of new metacognitive knowledge they did not have (Q4: *'no'* and Q5: *'no'*). Consequently, it suggests that the eye-movements of expert's critical reading processes contribute to learners' MIA and their awareness of new metacognitive knowledge in their thought contexts.

Effectiveness of expert's think-aloud information with EM-view: 51 and 13 comments were totally provided in Q6 and Q7, respectively. Since the number of comments for all participants was superior than in Q1 or Q3, it seems that the stimulation of the think-aloud data prompts the learner's MIA by comparison to the case where only EM-view is provided. However, as shown in the results of the numbers in parentheses (Q6 and Q7 in Table 4), almost all learners just provided some comments which directly correspond to the expert's think-aloud contents at face value except the learner D's one. This result indicates that providing the expert's think-aloud data constrains the scope of learners' MIA, so that they engaged in just commenting the untouched expert's think-aloud contents. As a corroborative evidence, some of the learners commented after the experiments that they mainly focused on listening to the expert's think-aloud information in the phase of P5, thus they had no room to read between the lines of the documents. Therefore, providing the think-aloud data might not only narrow the learners' metacognitive inference activities in a discovery way but also increasing their cognitive loads.

Based on these experimental results, we confirmed that the visualized information of expert's eye-movements prompts learners' MIA. Especially, providing the expert's eye-movement 'processes' in EM-view turned to be a great opportunity for promoting learners' inference activities. On the other hand, we also confirmed that providing the think-aloud data of expert's critical reading processes has negative aspects of their heuristic MIA. Accordingly, in order for learners to fruitfully promote their MIA, it is necessary to pay attention to utilizing carefully the think-aloud data with eye-movements information.

5. Conclusion

In this paper, we proposed a learning method of prompting learners' MIA. In order to support learners' MIA, we adopt eye-movements information during critical readings that reflects readers' metacognitive activities in an indirect way. In the context of writing academic papers by learners, we utilize the eye-movement information of learners' critical reading processes just before submitting them to the supervisors (experts), and that of experts' ones just after the submission. Based on learners' and experts' eye-movement information, the system provides three types of visualization each of which intends to promote learners' metacognitive activities to find metacognitive knowledge in their thought contexts without instructions.

Experimental results showed that the visualized information of the comparative heat map (C-view) and the experts' eye-movement processes (EM-view) promote learners' MIA. For instance, EM-view increasingly promotes their reflections toward finding out their metacognitive knowledge without instructions. In addition, we confirmed the effects of 'think-aloud' data during experts' critical readings which directly reflect the thinkers' metacognitive processes. The result indicated that think-aloud information constrains learners' own MIA, so that almost all learners did not focus on reading between the lines but rather on listening to the surface of the expert's think-aloud contents.

For future works, we plan to conduct further evaluations to establish the validity of our proposed visualization methods. In addition, we need to refine the learning design in order to promote learners' MIA under the learners' self-motivation by eliminating their cognitive loads.

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