

Development of Metacognitive Reflection Support System on Creative Discussion

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Abstract: Research meetings are critical forums for sharing and evolving ideas, where the depth of the discussion can significantly enhance the research content. Effective meetings require not just a recapitulation of the discussions but a thorough examination of the thoughts and decisions preceding the meeting. In this paper, we propose a support system that promotes metacognitive reflection by aligning pre-meeting preparations with post-discussion feedback, thus enhancing the overall research process and outcomes.

Keywords: Reflection support, creative discussions, metacognition, document semantics

1. Introduction

Meetings on research activities (research meeting) are creative discussions where one shares their own progress and ideas, and deepens the research content through reactions to these shared thoughts. In the reflection after the discussion, it is important not only to organize what was discussed, but also to carefully scrutinize what one was thinking and the decisions made before the meeting. If this is done with careful preparation that includes metacognitive activities before the meeting, the reflection after discussion will also be meaningful.

Metacognitive activities are actions that involve monitoring and control one's own thoughts (Nelson, 1990). For example, when a learner engaged in research on learning support systems proposes to enhance support functions using large language models (LLMs), it is important not just to list these support methods in the documents used for discussion, but also to deliberate and provide concrete examples that effectively convey the enhanced support, such as, "Let's show concrete examples that convey the enhanced support," and "Is this example appropriate for explaining the novelty of the support content?" If such preparations are carefully made by oneself before a research meeting, it can increase the likelihood of eliciting meaningful comments during the discussion. Furthermore, after the discussion, it is important to engage in *metacognitive reflection*, which not only reflect on the agreed results but also acquires and refines thought processes and metacognitive knowledge. For example, paying attention to comments from others on the proposed method, such as "Couldn't you also argue about the significance and value of the research?", can lead to the heuristic learning of metacognitive knowledge, such as "When proposing new ideas, it is important to think of specific examples, but stepping back and considering the overall value and significance of the research also increases persuasiveness." Even if one intends to understand the importance of such matters routinely, if the "conditioning"—when and under what circumstances to use this knowledge—is not established, it may not always be applied appropriately in the right situations (Bransford et al., 2000). The value of metacognitive reflection lies in acquiring such conditioned metacognitive knowledge from others' comments about one's thought processes.

In this research, we tackle the research question, "How can we realize adaptive support that encourages metacognitive reflection through the confrontation between one's own pre-discussion thoughts and the comments of others that deepen the research?" More specifically, we propose a reflection support system that captures the changes in learners' thoughts about their research through discussions, and based on this mechanism, encourages metacognitive reflection.

2. Approach

2.1 Difficulties of Metacognitive Reflection in Research Activity

In research activities, it is required to repeatedly engage in three key processes: (a) preparing documents for discussion while organizing thoughts about one's own research, (b) discussing proposed content in research meetings, and (c) reflecting on the discussions.

Learners refine their thoughts through internal self-conversations of organizing research content and preparing documents to share with others, deepening their research. Externalizing thoughts that have been considered internally can deepen understanding and lead to new insights (Chi et al., 1989). On the other hand, decision-making during the research process, and scrutinizing the logical consistency and intentions behind the content of documents, can often be tacit for novice researchers. Therefore, reflecting after research meetings is not necessarily easy, as it involves recalling the thought processes that occurred before the discussion (Difficulty 1).

In addition, reflection activities should not only focus on the results of discussions but also critically examine the research content organized so far in light of the discussion content. It is challenging to reflect on the differences in premises between one's prior thoughts and the process leading to conclusions, and so on (Difficulty 2).

Moreover, the reasons behind other participants' comments may not always be expressed during discussions, and learners must infer the others' thought processes (metacognitive activities) in light of their own metacognitive skills. However, it is difficult for learners who have not sufficiently developed metacognitive skills to pay attention to the cognitive activities of others (Difficulty 3).

2.2 Support for Thought Organization and Document Preparation Prior to Discussion

To reduce Difficulty 1, we examine a mechanism that encourages the elaboration and externalization of internal self-conversations in learner's thought organization and document preparation by extending the thought organization support system (Mori et al., 2019).

In the system, learners can visually organize their thoughts in a chain of inquiries and their answers to articulate their ideas and the intentions behind them. The system includes a "research activity ontology," defined using ontological engineering methods (Mizoguchi & Bourdeau, 2016), which captures the semantic structure of inquiries to be considered in research activities. This ontology allows the system to identify potential inquiries that learners should consider but might not have considered, thus potentially uncovering overlooked inquiries. For example, when a learner considering inquiry: '*What are the learning support methods?*' selected from the inquiries list displayed on the interface, the system has the function to present as candidates the predefined necessary premises such as '*What are the difficulties in learning?*' and '*What are the learning materials?*'.

This study aims to enhance learners' readiness for research meetings by considering mechanisms for mapping semantic information related to research activities (concepts from the research activity ontology) and information indicating logical roles in discussions, such as 'evidence' and 'claims' (concepts from the "logical structure intention ontology").

2.3 Measuring Multimodal Interactions in Discussion

With the aim of providing clues for inferring others' cognitive activities (reducing Difficulty 3), we utilize CSCL system development platform developed by Sugimoto et al. (2020).

This platform is designed for real-time multiparty interactions in distributed environments, and can develop and operate CSCL systems that measure both verbal and non-verbal information. The developed systems can measure and store multimodal interaction information such as the timing of participants' utterances and the gaze target information on the participants' video and documents (when and which participant/document section was being looked at), using external measuring devices like eye trackers and headset microphones.

The documents created based on the document preparation support function (Section 3.1) are semantically linked to the (i) research activity ontology and the (ii) logical structure intention ontology, allowing the participants' gaze coordinates during the discussion to be associated with the corresponding semantic information (e.g., (i): 'difficulties in learning', (ii): 'evidence') applied to the area, thereby capturing situations such as "*participants X is gazing at the contents of 'difficulties in learning' explained as an 'evidence' in the discussion.*"

In this study, the measured discussion interaction information is used as a resource for the metacognitive reflection activities.

2.4 Support for Promoting Metacognitive Reflection

To encourage reflection on changes in thinking and the decision-making process and to provide clues for inferring the thoughts of others, we consider the implementation of a function to provide advice the need for reevaluating the reflection content, and the function to visualize the gaze information of discussion participants, using it as a resource to infer their intentions. These functions are intended to reduce Difficulties 2 and 3.

Ogino et al. (2019) defined activities for inferring other's metacognitive activities as metacognitive inference activities and measured the gaze information during critical reading activities of learners and their supervisors on research reports written as reflections after research meeting. It is suggested that by presenting to learners the gaze information on where and how supervisors are focusing on the research report, learners are able to discover metacognitive knowledge by their selves. In this study, we leverage these findings to support activities that infer the thought processes of participants who made comments deepening the research during discussions. Specifically, it involves providing learners with gaze information of the participants—what and how much they focused on during the discussion—to support the activity of inferring the participants' thoughts.

In addition, we utilize a reflection support environment proposed by Shono et al. (2021). The environment includes a rule-creation support system that detects reflection intervals to promote learners' reflection using document semantics and multimodal information attached to the documents, and a reflection support system that applies these rules to encourage introspection during discussions. In this study, we expand the system to embed functions that encourage reconsideration based on gaze information, the discussion document, and the content of reflections, thereby supporting metacognitive reflection.

3. Proposed Systems

3.1 Internal Self-conversation Support System

Figure 2 shows the internal self-conversation support system that promotes interaction between thought organization and document preparation by expanding the thought organization support system (Mori et al., 2019). This system has the following main functions. Thought Organization Support Function: In their daily research activities, learners engage in organizing their research content in the thought organization area (Figure 1, left) using a chain structure of 'questions' and 'answers.' This system equips a support function that externalizes deepened thoughts and decisions that tend to remain implicit, by progressing the organization of their own research into thought nodes. For example, when considering '*What are the learning support methods?*' the system presents related inquiries predefined in the research activity ontology, such as '*What are the difficulties in learning?*' and '*What are the learning materials?*' as explained in Section 2.2.

Document Preparation Support Function: This function supports the preparation of documents for use in discussions, based on the thought nodes presented in the thought organization area. Learners create documents in the document preparation area (Figure 1, right), reflecting the ideas they want to explain during the discussion. The thought contents (nodes) reflected in the document preparation area retain their semantic information (concepts defined in the ontology) while allowing for flexible rewriting of content to suit the discussion. The created

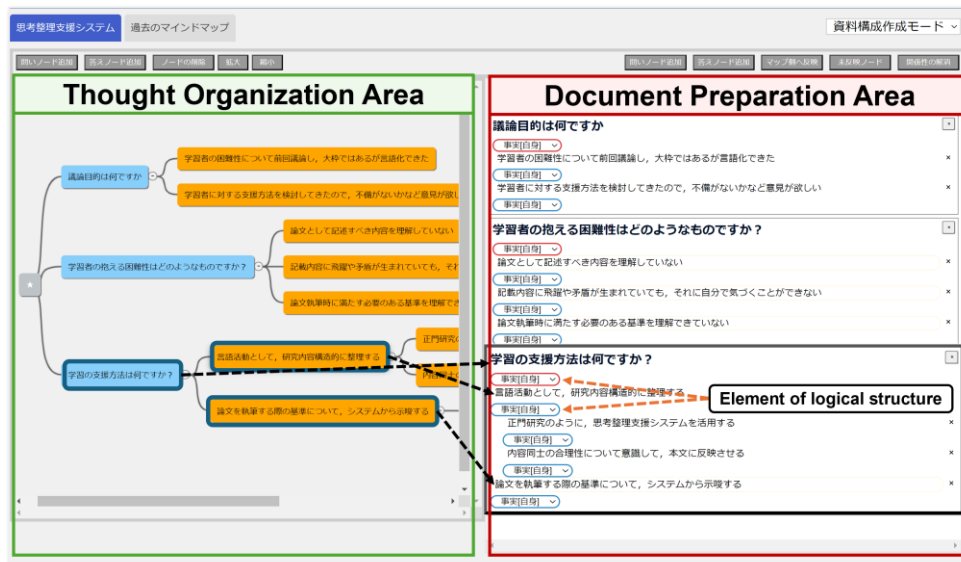


Figure 1. Internal Self-conversation Support System.

documents can be output in a format that can be read by the system used during discussions (Section 3.2).

Logical Structure Intention Setting Function: This function allows learners to map their intended elements of logical structure (e.g., ‘*propose*,’ ‘*question*,’ ‘*claim*,’ ‘*judgement*,’ ‘*assumption*’) to each content written in the document creation area (Figure 1, right). By enabling learners to carefully examine how their thoughts fit within the logical structure and what ideas they supplement during the setting of logical structure elements, we aim to enhance readiness for discussion and promote the reconstruction of their internal self-conversation. More specifically, learners can explicitly establish logical relationships in the content (sentences or items) reflected in the document preparation area, such as tagging with ‘*difficulties in learning*’ as ‘*grounds*’ for ‘*proposing*’ ‘*learning support methods*.’ This process enables them to reassess the coherence of these contents.

3.2 Discussion Support System

The system uses the document information output from the internal self-conversation support system as input, and is designed to facilitate discussions by utilizing video chat and document sharing functions. This system can be executed on the CSCL platform (Sugimoto et al., 2020).

Areas of interest for detecting gaze are set up in each area of the participants’ videos and document content, allowing for automatic measurement of what and when the participants were looking at during the discussion. Additionally, information about when participants start and stop speaking is also automatically recorded. By utilizing such information, the activities of discussion participants (e.g., *Participant X is commenting while focusing on the ‘learning support methods’ as ‘propose’*) can be interpreted in connection with the semantic information of the shared documents. This information is used in the following reflection activities.

3.3 Metacognitive Reflection Support System

In this system, learners first reflect on discussions while reviewing ideas expressed in the internal dialogue system, examine how their thoughts have changed, and work on activities to add or modify the content of their thoughts in the thought organization and document preparation areas. After learners decide that they have sufficiently reflected on the discussion, they engage in activities within the metacognitive reflection support system (Figure 2) that encourages them to reconsider if the reflection content is sufficient, and to infer the thoughts of other participants who have made comments that deepen the research.

3.3.1 Advice Presentation Function to Promote Reconsideration of Reflections



Figure 2. Metacognitive Reflection Support System.

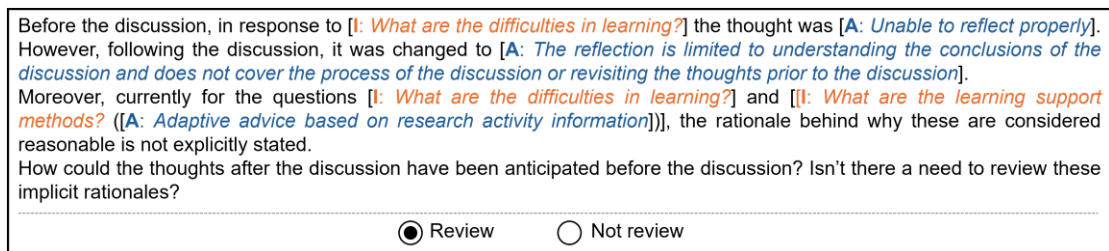


Figure 3. Advice for Reconsideration of Reflection.

By inputting results of the learner's organized and reorganized thought before/after discussion, the system can detect changes (differences) in the learner's thoughts. Based on this, the system generates and displays advice to the learners to reconsider the content they have reflected on. For instance, consider a scenario where a learner, who had not concretely scrutinized 'difficulties in learning' before the discussion, did consider it (by editing nodes on the thought organization area) after the discussion, but did not examine the 'rationality' in relation to 'learning support methods.' Since the connections between research activities are defined in the research activity ontology, the advice (e.g., Figure 3) can be presented to the learner in the advice presentation area (Figure 2(d)).

This advice is automatically generated based on the predefined advice template. The contents under [I] and [A] represent the *inquiries* and *answers* from the thought organization maps expressed by learners before and after discussions, respectively. These aim to capture and make explicit the potential connections specific to the research field, deeply rooted in the learners' research content, and provide advice that prompts reconsideration.

In response to such advice, learners explicitly record their decision to review or not review, along with the rationale (free description format). The goal is to encourage verbalization and reconsideration not only of the results of the discussions but also of the process leading to those results and the changes in prior thought contents.

3.3.2 Function to Encourage Inference of Others' Thought Processes

The system includes functions that visualize the amount of attention and gaze transitions based on the discussion period focused on to infer the intentions of a participant who made comments that deepen the research.

For example, to infer the intentions of a participant who asked "Is the learning difficulty specific?" during the discussion, learners can select the time period of interest in the discussion by dragging in the discussion situation confirmation area (Figure 2(a)). The system uses gaze information stored in the database to visualize the amount of attention in the

During this time period [from 40 to 300 seconds after the discussion started], the participant seems to have focused on [C: **methods of learning support** (*Providing the function to visualize eye movement information during discussions*)] and [C: **difficulties in learning** (*Inability to reflect appropriately*)]. Related to the [C: **methods of learning support**], the participant may have considered questions like [I: *What kind of learning materials are there?*], [I: *What kind of learning model is used?*] and, related to the [C: **difficulties in learning**], questions like [I: *What kind of person do you imagine as the learner?*]. Based on this information, let's try to infer the thoughts of the participant.

Figure 4. Advice for Inference of Others' Thought Processes

relevant section as heat-map fashion (Figure 2(b)). Additionally, by using the information from areas responsive to the measured gaze of participants, it can highlight the corresponding areas according to the playback time of the discussion video to check the order in which the participants were looking at the document content and other participants (Figure 2(c)).

Furthermore, based on the time period of interest in the discussion selected by the learner, the system provides advice (e.g., Figure 4) in the advice presentation area (Figure 2(d)), using the connection between the participant's points of focus and the semantic information of the research activities, as clues to examine the participant's thought process.

In Figure 4, [C] represents the concepts from the research activity ontology that correspond to the content described in the documents created by the learners (the underlined part indicates this concrete content). Clues aimed at inferring the thought processes leading to the participants' comments are provided to the learners based on the focus areas of the participants.

Based on such advice and the visualized gaze information, it is expected to use clues to infer the thought processes of the participant, such as, *"Even while explaining 'learning support methods,' many participants are focused on the 'difficulties in learning,'" and "The participants might have been aware during the explanation of 'learning support methods' that the 'difficulties in learning' were ambiguous."*

4. Conclusion

In this study, we proposed a metacognitive reflection support system which encourages the refinement and expression of thoughts and focuses attention on learner's own decision-making and the thought processes of others.

As future tasks, we plan to continue the practical use of the system in authentic research activities, verify the long-term effectiveness of the system that promotes metacognitive reflection, and refine and improve the advice and the system's support functions.

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