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Reflection Support System in Ill-defined Problem Solving

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Abstract: In this research, we focused on research execution activities as a field of ill-defined problem solving and developed a mechanism to grasp learners' thought processes based on interpretation rules and a generic ontology of research activities. The idea behind this mechanism is to prompt learners' awareness of their own thinking processes so as to foster their metacognitive skills. In this paper, we discuss the features of a support system that we developed to achieve this goal.

Keywords: ill-defined problem, reflection support

1. Introduction

In problem-solving activities, the importance of metacognitive skills in obtaining a comprehensive view of one's thought processes (monitoring) and appropriately controlling them is widely recognized (Ge 13, Jonassen 97). Similarly, in research activities, it is important to exercise control as when changing the approach to achieving one's research objective from the viewpoint of "the objective and means seem to be inconsistent with each other" and "it's time to reexamine the experimental method." However, for a learner with undeveloped metacognitive skills, it is not easy to demonstrate or acquire such metacognitive skills. Acquiring metacognitive skills goes hand in hand with execution, but it is difficult for an unskilled learner to execute those skills (Kayashima 2005). The research introduced in this paper aims to facilitate the acquisition of skills for monitoring and appropriately controlling one's thought processes in problem-solving activities.

In problem-solving, the target may be a well-defined problem in which problem formulation and the conditions or procedure leading to a solution are clear. It may also be an ill-defined problem in which the conditions or procedure leading to a solution are unclear or nonexistent. Learning that targets a well-defined problem (e.g., solving a quadratic equation) proceeds by repeating the application of problem-solving operators until reaching a solution that satisfies certain constraints (criteria). Problem-solving operators and their application process can be acquired in this way. On the other hand, learning that targets an ill-defined problem (e.g., research activities) features unclear constraints (criteria) that the solution must satisfy in contrast to a well-defined problem, so the learner must specify the problem (Ge 2013, Jonassen 1997, Masui 1999, Namsoo 2003, Pieger 2018, Rena 2013, Veenman 2006). In addition, while problem-solving operators may be partially given as context-independent meta-knowledge, their application process is generally vague and latent, that is to say, unclear. Consequently, in learning associated with an ill-defined problem, it is considered that the learner reflects on one's own problem-solving process so that an objective that promotes the acquisition of metacognitive operators and their application process comes to be set.

However, a novice unskilled in comprehending the structure of a problem domain encounters difficulty in applying appropriate operators at the appropriate time and even has difficulty in appropriately monitoring and controlling that process (Kayashima 2005). In particular, learning through problem-solving targeting an ill-defined problem is accompanied by more metacognitive difficulties compared with well-defined problems.

In this study, we focus on research activities as ill-defined problem-solving activities. Here, to facilitate the monitoring and controlling of one's thought processes, all assumptions and hypotheses underlying decision-making must be understood before making decisions, such as "I need to examine my assertion and determine whether I am maintaining consistency from a variety of viewpoints." "Is the basis of my approach valid?" "To what extent should I review or reexamine an assertion that I want to change?" or (when a clear goal lies under unclear conditions) "What should I think about next (on expanding the search space)?" In short, importance should be attached to metacognition (application of metacognitive operators) that targets processes in long-term research activities.

Such operators on the metacognitive level acquire operators and their application process by promoting reflection of one's research process. However, thinking activities in a research process are tacit and unclear, and as a result, looking back and ascertaining all the assumptions and hypotheses or guidelines used at the time of decision-making is a difficult task.

As a form of metacognitive support in research activities within the research field of intelligent learning support systems, Mori et al. (Mori 2019) have proposed a mechanism for partially reducing the ambiguity of operators and the difficulty of their application (searching). This is accomplished by specifying "questions" that require execution of problem-solving operators and by presenting them within the context of research activities performed by novice researchers. Here, the learner can systematically organize the output of one's thinking activities by answering presented questions and forming a chain of questions and answers. The system also provides a stimulus for partial application of metacognitive thinking activities (metacognitive operators) based on part of the thinking context visualized as "questions" and "answers" (problem space searched for by the learner) and on ontology. This can be viewed as a means of support for applying context-independent meta-knowledge as metacognitive knowledge to one's thinking context.

Thus, given a research process expressed by the above thought organization support system, this study considers that promoting reflection of metacognitive thinking applied by the learner might raise awareness about the acquisition of operators on a metacognitive level in the context of one's thinking. To investigate this possibility, we previously proposed a mechanism for manifesting and visualizing metacognitive activities that might be conducted tacitly by the learner and the thought processes (metacognitive activities) that should be followed as determined by the system so as to promote reflection that is conscious of metacognition.

In this paper, we discuss a reflection support system developed on the basis of this idea and its practical implementation.

2. Approach

Given that the research process tends to be tacit in nature and generally based on trial and error, it is not uncommon to fall into a situation echoed by such comments as "Why was I thinking like this? I've lost track of my assumptions and hypotheses." "I've gone off on other thinking activities without noticing that I've deviated from my original objective and assumptions." or "At that time, I thought it was unnecessary to think about that, but I later realized that it was necessary." In this study, we consider it important to prompt an awareness of acquiring operators on the metacognitive level by reflecting on one's way of thinking in the research process in a chain-like, concatenated manner. With this in mind, we set as our objective the development of a reflection support system.

To manifest the thought processes that should be reflected on to provide such support, a mechanism is needed to capture thinking activities in the learner's research execution activities on the meta-level and base level. In this section, we discuss thinking targeted for reflection and describe the mechanism proposed in this study to capture thinking activities.

2.1 Thought processes targeted for reflection

No clear procedure exists in ill-defined problem-solving. As a result, it is not unusual for problem-solving activities to be performed on a day-to-day, impromptu manner with no application of metacognitive-level operators to regulate one's thinking. This state of affairs may lead to reworking or inconsistencies.

In this study, we consider that thought processes that reflect on the way that one thinks and that adjusts activities accordingly can contribute to the acquisition of operators on the metacognitive level. In the following, we focus on three types of thought processes that should be the target of reflection.

(1) Thought process that considers thinking result and validity of reasoning

In research execution activities, reflecting on one's thought processes and on whether a thinking result and the reasoning leading up to that result are valid can help make searching of the problem space more effective. An example of such reflective thinking is as follows: "Reconsidering the learning support method involves a change in the learning goal. Reviewing this change in the learning goal, the basis of a support method, is appropriate, and what's more, the reasoning behind such reconstruction through this review is valid."

(2) Thought process that's conscious of the validity of metacognitive thinking in the problem-space search process

In research execution activities, it is important to reflect on one's thought processes and to attach conditions to metacognitive thinking. An example of such thinking is as follows: "At first, I could not sufficiently examine my research objective and evaluation method, but since then, I've noticed inconsistencies between them. Thinking about the rationality of the research objective and evaluation method should be a precondition to moving forward with research."

(3) Thought process that attaches conditions to metacognitive thinking

In research execution activities, it is important to be aware of the validity of metacognitive thinking in the problem-space search process. An example of this type of thinking is as follows: "The research objective and evaluation method should be consistent with each other in the task structure of research execution. When the time comes to think about the evaluation method, thinking about it while being aware of the need for consistency with the research objective is meaningful from the viewpoint of ensuring consistency."

These thought processes focus on the assumptions and hypotheses associated with decision-making. They should be reflected on given their importance in acquiring and refining metacognitive knowledge based on personal experience. On the other hand, they tend to be unconscious in nature and difficult to verbalize even in retrospective reports.

In this study, we take up these thought processes as targets of reflection to raise awareness about the acquisition of operators on the metacognitive level in the context of one's own thinking and to promote their verbalization.

2.2 Mechanism for capturing thinking activities

To raise learner's awareness about the acquisition of operators on the metacognitive level, it is important to focus on thinking activities that should be reflected on in the context of the learner's own thinking and to reflect on thinking results and reasoning, the validity of metacognitive thinking, and the attaching of conditions to metacognitive knowledge as described in section 2.1.

To support such reflection activities, we investigate a method in which the system infers the thinking activities that should be reflected on from the learner's research activities (research execution activities, reflection activities) and presents those thinking activities as stimuli to the learner. To this end, we previously proposed a mechanism for capturing a learner's thought processes using (1) a research activity log, (2) interpretation rules, and (3) ontology of research activities (Mori 2018). The framework for inferring thinking activities in this way is shown in Fig. 1. Here, the system records research execution activities as well as reflection activities in a research activity log and infers the thought processes that the learner should reflect on using interpretation rules and research activity ontology. The following describes each of these system components.

(1) Research activity log

The interface to the thought organization support system (Mori 2019) developed by Mori et al. is shown in Fig. 2. In the figure, blue and orange nodes denote "questions" and "answers," respectively. This system displays instances of the "question" concept in the ontology of research activities as questions (Fig. 2 (1)). The learner selects such a question or inserts a self-created question thereby expressing the thinking context (problem solution space) of one's research activities.

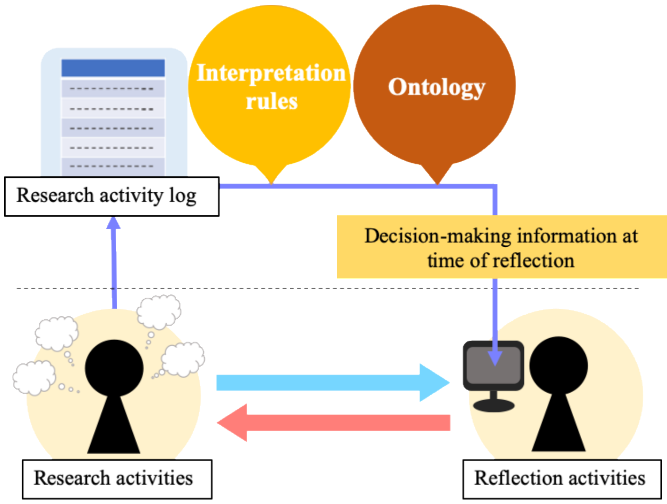

Figure 1 *Framework for inferring research activities*

In this study, we consider that operations performed on this system (node creation, revision, deletion, etc.) correspond to the learner's thought processes and that recording the history of these operations can capture those thought processes at the activity level. The research activity log in the example of Fig. 2 created the question node "What kind of problem did you discover?" and the answer node "Reflection time is short." This answer node was later edited to "There are few opportunities for reflection." The system records operation history in this way.

In addition to operation history, the system in this study also records learner decision-making information that comes into play when interacting with reflection support as a log and records these two types of information as a research activity log.

(2) Interpretation rules

The semantic interpretation of research activity logs on the whole is not necessarily unique. Nevertheless, while keeping this in mind, we specified interpretation rules for interpreting the research activity log and proposed a mechanism for inferring the thought processes for reflection by performing a matching process with the research activity log.

(3) Ontology of research execution activities

We use the ontology of research activities created by Mori et al. to capture task structure in research execution activities. This ontology is specified in a state that enables the concepts required by research execution activities to be computer-readable. It systematizes mainly "metacognitive activities," "cognitive activities," and "actions" organizing them in a form corresponding to "questions." It also specifies sub-activities, input, and output as partial concepts making up each concept. For example, in defining "thinking of an implementation hypothesis (cognitive activity), input can be set as "implementation objective," which is itself the output of the thinking action "thinking of the implementation objective (cognitive activity)," while output can be set to "implementation hypothesis."

At the present stage, it could not be said that the ontology of research activities constructed here is complete in terms of specified concepts. Rather, it is assumed that it will be refined over time through practical use.

3. Reflection Support System

We developed a reflection support system to support learner reflection of thought processes in research execution activities. We implemented this system in a form that links to the thought organization support system of Mori et al. as a precondition. Envisioning that this system would be used in conjunction with daily reflection activities that accompany research activities, we implemented it as a web application accessible via a browser.

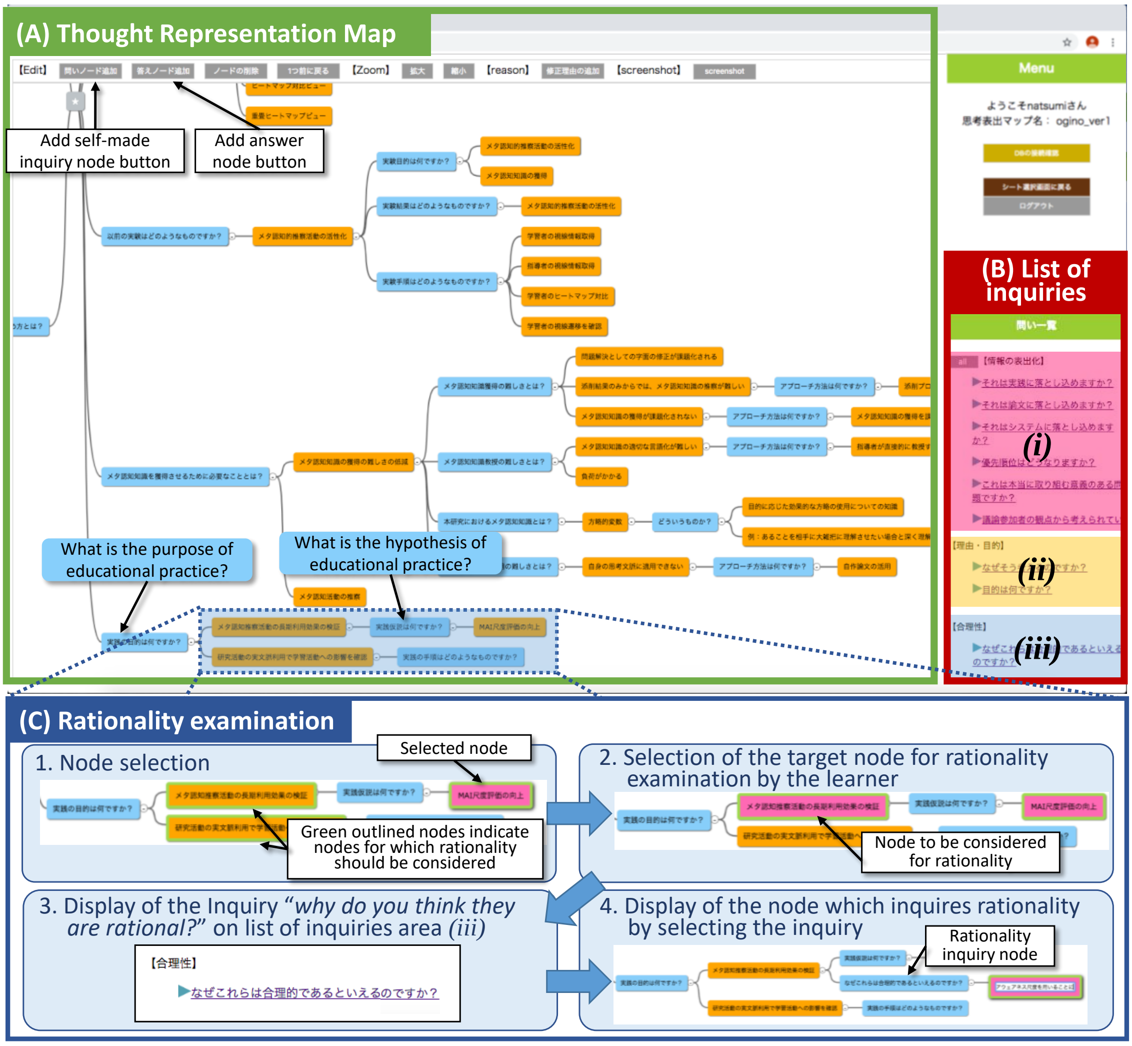

Figure 2 Thought Organization Support System (Mori 2019)

3.1 System configuration

The configuration of the reflection support system proposed in this study is shown in Fig. 3. The system adopts a server/client configuration with the server side using Macintosh, Apache, MySQL, and PHP (MAMP) and Prolog and the client side using HTML and JavaScript. This system consists of a database storing the learner's research execution activities and reflection activities in the form of an operation history (reflection support database built with MySQL), a database connection module for connecting to that database, and the three modules summarized below.

- Thought organization support system module: This module manages the operations of the thought organization support system. It supports organization of the leaner's thought processes by creating question nodes and corresponding answer nodes in a tree format. It also gathers information on the learner's behavior on the system such as the addition, deletion, and editing of nodes and stores that information in the database via the database connection module.
- Matching module: This module gets the research execution activities log (behavior information) stored in the reflection support database and uses it to infer thinking that the learner may have performed but that is not clearly visible in that log. The matching model is described in Prolog format together with ontology of research activities created with the Hozo ontology editor and interpretation rules. Matching this ontology and interpretation rules with the research execution activities log confers interpretations to learner thought processes. The detected activity interval is a natural language sentence to which a template has been applied. The result is used as learner reflection information.

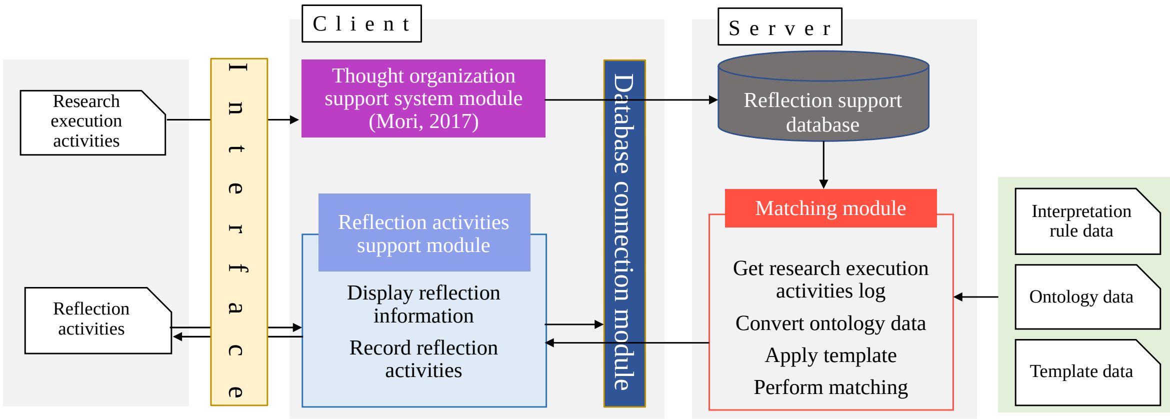

Figure 3 Configuration of reflection support system

- Reflection activities support module: This module supports reflection activities. It gets reflection information and displays that information on the learner's interface. The reflection activities carried out by the learner are recorded as a research execution activities log in the database.

3.2 General

The screen of the reflection support system that we developed is shown in Fig. 4. The learner first performs research activities using the thought organization support system. Then, on selecting a period for reflection, the reflection support system presents the learner with the information shown in Fig. 4. This "reflection information" consists of information promoting awareness of thinking activities as taken up in section 2.1 (Fig. 4 (1)), information promoting the conscious execution of activities (Fig. 4 (2)), and information promoting the attachment of metacognitive conditions (Fig. 4 (3)). The following explains each of these three types of reflection information.

- Reflection information promoting awareness of thinking activities (Fig. 4 (1)): This information suggests thinking activities that the learner is considered to have executed. It is presented with the aim of raising learner consciousness about one's own thinking activities and promoting self-awareness. If the learner acknowledges those thinking activities, they are recorded and made available for later review (section 3.3).
- Reflection information promoting the conscious execution of activities (Fig. 4 (2)): This information suggests thinking activities that should be executed with the aim of raising learner consciousness about thinking activities that should be executed. If the learner acknowledges those thinking activities, they will be recorded. If not, the system will then require an explicit decision in the form of "Will consider later" or "Will not consider later" as a future activity. This decision-making promotes the conscious execution of thinking activities while also promoting the conscious execution of activities judged to be necessary (metacognitive control).
- Reflection information promoting the attachment of metacognitive conditions (Fig. 4 (3)): This information suggests executed activities even though the learner judged them to be unnecessary in the past and asks for the reason why this change in judgment was made. This raises learner's awareness of changes in judgments associated with the execution of thinking activities and promotes the attachment of conditions to metacognitive knowledge as that reason. Here, an example of such reflection activity is "Research objective and evolution method must be rational, but on revising my research objective, I was not able to realize how that change would affect the evaluation method that I had been thinking about." Such reflection is expected to promote the attaching of conditions to metacognitive knowledge within the learner's range of experience and thinking context. This attachment of conditions can be recorded and made available for later review.

3.3 Function for reviewing reflection activities

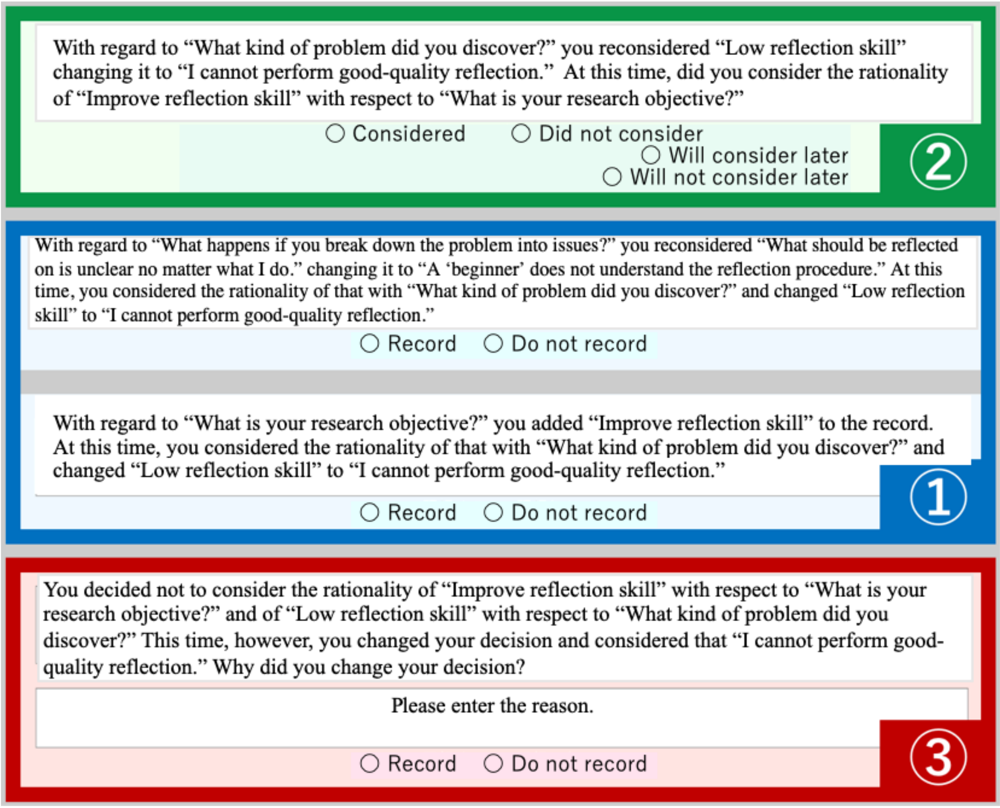

Figure 4 Reflection Support System Screen

The reflection support system includes a function for reviewing the learner's history of reflection activities (Fig. 5). This function makes it possible to clearly capture thinking activities such as the assumptions and hypotheses made in decision-making and the acquisition of metacognitive knowledge based on one's experience. We can expect the reviewing of such thinking activities to enable the creation of a personal research diary that delves into thinking activities that while important are difficult to express.

4. Evaluation Experiment

We are currently conducting an evaluation experiment to assess the effectiveness of the reflection support system described in section 3. In this experiment, 12 members of our research laboratory (10 undergraduate students, and two master's student) were asked to use the system in their daily research activities continuously for about 2 weeks. The following summarizes this evaluation experiment.

In the experiment, we are conducting a questionnaire-based survey in which subjects are asked whether the system helps to contribute to reflection activities, raise awareness of own cognitive activities. In the following, we pick up some comments got in our questionnaire surveys.

Regarding changes of their consciousness of reflective activities, a master student answered after using the system that he got consciousness intending to clarify his own thought in his reflective activities, whereas he answered before using the system that he just wrote a memo of summarization of his daily activities to remind himself of his own activities performed. In addition, he also answered the system makes it easier for him to be aware of implicit and tacit changes of his own consciousness with useful information from the system.

Furthermore, another master student answered after using the system that he also got consciousness intending to trace propagations according to changes of some parts of research contents and check if the consistency of whole research contents is still maintained, as well as he answered before using the system that he especially intended to record changes of some definitions or interpretations in his own research contents. He also answered that the system gives useful information

Please set the reflection history period that you would like to review.

● Today's reflection

○ Set reflection period

From 2019/01/01 To 2019/02/21

Display reflection history

Reflection Day/Time	Reflection Statement	Operation	Future Activity	Re
2019/01/25 08:17:51	With regard to "What kind of problem did you discover?" you reconsidered "Acquisition of metacognitive-level operators is difficult for beginners" changing it to "Being aware of acquiring metacognitive-level operators is difficult for beginners." At this time, with regard to "What is your research objective?" you also reconsidered "Raising consciousness of acquiring metacognitive-level operators" changing it "Raising consciousness of acquiring metacognitive-level operators through reflection support."	Record		
2019/01/25 08:17:51	With regard to "What kind of problem did you discover?" you added "Acquisition of metacognitive-level operators is difficult." At this time, did you reconsider "Raising consciousness of acquiring metacognitive-level operators" with respect to "What is your research objective?"	Considered		
2019/01/25 08:17:51	With regard to "What is your research objective?" you reconsidered "Raising consciousness of acquiring metacognitive-level operators" changing it to "Raising consciousness of acquiring metacognitive-level operators through reflection support." At this time, did you also reconsider "Being aware of acquiring metacognitive-level operators is difficult for beginners." with respect to "What kind of problem did you discover?"	Considered		
2019/01/25 08:17:51	With regard to "What kind of problem did you discover?" you reconsidered "Acquisition of metacognitive-level operators is difficult." changing it to "Acquisition of metacognitive-level operators is difficult for beginners. At this time, did you also reconsider "Raising consciousness of acquiring metacognitive-level operators" with respect to "What is your research objective?"	Considered		
2019/01/25 08:17:51	With regard to "What exactly is this practical procedure?" you added "A 1-week test." At this time, with regard to "What is your practical objective?" you reconsidered "Checking system effectiveness" changing it to "Checking effectiveness of feedback."	Record		
2019/01/25 08:17:51	With regard to "What is your practical objective?" you reconsidered "Checking system effectiveness" changing it to "Checking effectiveness of feedback." At this time, did you also reconsider "A 1-week test" with respect to "What exactly is this practical procedure?	Didn't consider	Will not consider later	
2019/01/25 08:33:07	With regard to "What is your practical objective?" you reconsidered "Checking system effectiveness" changing it to "Checking effectiveness of feedback." You considered the rationality of this with "What exactly is this practical procedure? changing "A 1-week test" to "Perform a prior evaluation after 10 days of operation."	Record		
2019/01/25 08:33:07	With regard to "What exactly is this practical procedure?" you reconsidered "A 1-week test" changing it to "Perform a prior evaluation after 10 days of operation." At this time, did you consider the rationality of that with "Checking effectiveness of feedback" with respect to "What is your practical objective?"	Didn't consider	Will not consider later	
2019/01/25 08:33:07	With regard to "What exactly is this practical procedure?" you added "A 1-week test." At this time, you considered the rationality of that with "What is your practical objective?" thereby changing "Checking system effectiveness" "Checking effectiveness of feedback."	Record		

Figure 5 Review (history) screen of reflection activities

to be aware of own decision-making processes that is difficult to record even in a situation of using thought organization support system.

Therefore, it suggests that learners in reflective activities on their research activities tend to be conscious of their own thought activities using the system rather than behavioral activities without the system.

5. Conclusion

Taking into account the difficulty of reflecting on one's thought processes in the field of ill-defined problem-solving, we proposed a reflection support system for promoting the acquisition of operators on the metacognitive level based on a technique for capturing thought using ontology and interpretation rules.

Going forward, we plan to expand our study by analyzing the results of evaluation experiments more detail with the aim of enhancing the usefulness of the developed system.

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