Towards Shared Understanding of Metacognitive Skill and Facilitating Its Development

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Abstract. Our research objective is to organize existing learning strategies and systems to support the development of learners' metacognitive skill. It is difficult to organize them because the term metacognition itself is mysterious and ambiguous. In order to achieve the objective, we first organize activities in cognitive skill and metacognitive skill. It enables us to reveal what activity existing learning strategies and systems support as metacognitive skill or what activity they do not support. Next, we simplify existing learning strategies and systems by ontology. It helps us to understand what of learning strategies and support systems is respectively different, and what of them is respectively similar. It will contribute to a part of an instructional design process.

1 Introduction

Recently many researchers who are convinced that metacognition has relevance to intelligence [1,26], are shifting their attention from the theoretical to practical educational issues. As a result of this shift, researchers are designing a number of effective learning strategies [15,16,23,24,25] and computer based learning systems [5,6,8,20] to facilitate the development of learners' metacognition.

However, there is one critical problem encountered in these strategies and systems: the concept of metacognition is ambiguous and mysterious [2,4,18]. There are several terms currently used to describe the same basic phenomenon (e.g., self-regulation, executive control). The varied phenomena that have been subsumed under the term, metacognition, are described. Also cognitive and metacognitive functions are often used interchangeably in the literature [2,4,7,15,16,17,18,19,22,27]. The ambiguity mainly comes from the following three reasons: (1)it is difficult to distinguish metacognition from cognition; (2)metacognition has been used to refer to two distinct area of research: knowledge about cognition and regulation of cognition; and (3)there are four historical roots to the inquiry of metacognition [2].

With this ambiguous definition of "metacognition", we cannot answer the crucial questions concerning existing learning strategies or systems: what they have supported, or not; what is difficult for them to support; why it is difficult; and

essentially what is the distinction between cognition and metacognition. In order to answer these questions, we first should clarify how many concepts are subsumed under the term metacognition and how each of these concepts depend upon each other. This clarification enable us to consider the goals for learning strategies, and systems to support the development of learners' metacognition; what and why it is difficult to achieve each of these goals; and how we eliminate difficulties in achieving each of the goals using strategies and support systems.

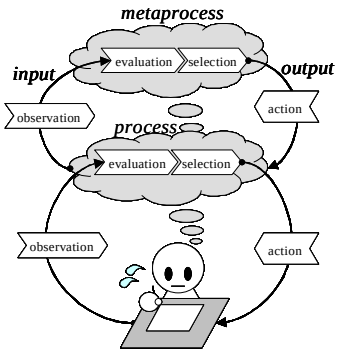

Fig. 1. Double Loop Model

Our research objective is to organize existing learning strategies and systems to facilitate the development of learners' metacognition which is not knowledge about cognition, but regulation of cognition that we call metacognitive skill. In this paper, we organize activities in cognitive skill and metacognitive skill for the understanding of metacognitive skill, with correspondence to all of the varied and diverse activities that have been subsumed under the heading of metacognition. By giving target activities of each existing learing strategies and systems a label corresponding to the organized activities, we can share the understanding of them each other. Existing strategies and systems adopt mainly collaborative learning or interaction with computer systems as a learning style. Moreover, we simplify existing learning strategies and systems by using the frame of Inaba's "Learning Goal Ontology" [9,10]. It helps us to understand what of learning strategies and support systems is respectively different, and what of them is respectively similar. For example, one strategy may have the same goal as another strategy but supporting methods may differ.

2 Activities in Cognitive Skill and Metacognitive Skill

We organize activities in cognitive skill and metacognitive skill based on a *double loop model* which we propose to define activities of metacognitive skill and cognitive skill in a similar manner using two layers of mind: the cognitive and metacognitive layers as seen in Fig. 1[11,12,13,14]. Within these two layers of mind and the outside world, we integrate activities of the layers into two kinds of activities: input of information from the external layer and output of it to the internal layer; and the processing of information at the internal layer.

In terms of the two kinds of activities and the target of the activity, we categorize activities of cognitive skill and metacognitive skill as seen in Table 1. Each of the skills is subdivided into two activities: we regard the cognitive skill as Basic Cognition and Cognitive Activity; the metacognitive skill as Basic Metacognition and Metacognitive Activity. Basic cognition and basic metacognition respectively include "Observation", basic cognition and basic metacognition respectively encompass "Evaluation", "Selection", and "Action/Output" as an activity.

Table 1. Activities in Cognitive Skill and Metacognitive Skill

Activity	Definition of activity	Target of activity	Denomination	Skill
Observa-tion	To input information from the external layer and output it to the internal layer.	Information at the external layer	Basic cognition	Cognitive skill
			Basic Metacog-nition	Metacognitive skill
Evaluation	To process information at the internal layer.	Information at the internal layer	Cognitive activity	Cognitive skill
Selection			Metacognitive activity	Metacognitive skill
Output				

Observation as basic cognition is to take information from the outside world into working memory (WM) at the cognitive layer. As a result, a state or a sequence of states is generated in WM at the cognitive layer. Evaluation and Selection as cognitive activity is to evaluate the sequence of states in WM, select actions from a knowledge base, and create an action-list. Consequently, a state or a sequence of states in WM at the cognitive layer is transformed. Output as cognitive activity is to output actions in an action-list as behavior. Observation as basic metacognition is to take information of cognitive activities and information in WM at the cognitive layer into WM at the metacognitive layer. As a result, a state or a sequence of states in WM at the metacognitive layer is transformed. Evaluation and Selection are to evaluate states in WM at the metacognitive layer, select actions from a knowledge base, and form actions to regulate cognitive activities at the cognitive layer as an action-list. In this way, a state or a sequence of states in WM at the metacognitive layer is transformed. Output as metacognitive activity is to perform actions in an action-list to regulate cognitive activities at the cognitive layer. As a result, cognitive activities at the cognitive layer are changed.

We clarify the target activities of learning strategies and systems by consideration of the correspondence of organized activities in Table 1 to target activities. Consider a learner's activity with Error-Based Simulation (we abbreviate it as EBS) [8] and the Reflection Assistant (we abbreviate it as RA) [5, 6]. EBS is a behavior simulation generated from an erroneous equation for mechanics problems. The strange behavior in an EBS makes the error in the equation clear and gives the learner a motivation to reflect, and provides opportunities that a learner monitors his/her previous cognitive activity objectively. RA consists of three phases to help learners do three reflective activities; understanding of goals and given facts of the problem; recalling previous knowledge; organizing the problem, and thinking about strategies to solve the problem. These reflective activities allow learners to identify knowledge about problem solving; strategically encode the nature of the problem and form a mental representation of its elements; select appropriate strategies depending on the mental representation. Based on the organized activities in cognitive skill and metacognitive skill, RA facilitates learners' basic cognition and cognitive activities while EBS facilitates metacognitive activities.

We should consider support systems and methods to facilitate learners' mastering activities of metacognitive skills in light of the target of the activity and how the

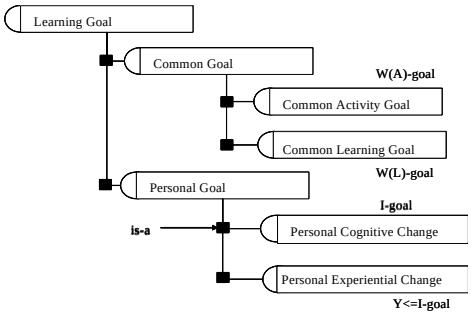

Fig. 2. Learning Goal Ontology

activity is performed, because these would influence the weight of the cognitive load of the activity, and the difficulty to master the activity [12,13,14]. Concerning cognitive load, it would increase in the following order: basic cognition, cognitive activity, basic metacognition, and metacognitive activity. The cognitive load of basic cognition would read (Observation) only, while cognitive activity would read, operate, and write. The cognitive load of basic metacognition and metacognitive activity would be higher, because the activities are involved in complicated activities: allocating one's mental resources for the activities of basic cognition, cognitive activity, basic metacognition, or metacognitive activity while engaging basic cognition or cognitive activity. Clarifying target activities within organized activities in Table 1 is important in understanding the difficulty in mastering skills, and to select appropriate learning strategies.

3. Learning Goal Ontology for Metacognitive Skill

In this section, we represent concepts of learning strategies and support systems which support the development of metacognitive skills. The concepts are described using the frame of Inaba's "Learning Goal Ontology." Utilizing the ontology and approximate models for representing the learning theories, we can simplify learning strategies and support systems, helping in their understanding. Of course, this understanding is partial and rough in comparison with the knowledge base of learning strategies and systems. However, it would be useful for understanding difference between strategies, which strategies are effective for development of a learner's metacognitive skill, etc.

First, we describe briefly Inaba's "Learning Goal Ontology" [9, 10]. As Fig.2 shows, "Learning Goal" is divided into two kinds of goals: "common goal" relates to the group as a whole, and "personal goal" refers to the individual learner's goal. The "personal goal" is also subdivided into two types of goals: the goal represented as a change of learner's knowledge/cognitive states (I-goal), and the goal attained by interaction with others (Y<=I-goal). Similarly, the "common goal" is subdivided into two kinds of goals: activity goal for the whole group (W(A)-goal), and learning development goal for the whole group (W(L)-goal).

We pick up four learning strategies; two from the strategies and two from learning support systems which help the development of learners' metacognitive skills: ASK to THINK–TEL WHY (we abbreviate as AT) [15,16], reciprocal teaching (we abbreviate as RT)[23], RA [5,6] and EBS [8].

Table 2. I-goals

I-goal		Definition	Source
Development of Cognitive Skill	Other regulation	To infer others' cognitive activities from their behaviors, evaluate them, and ask a question or advise others on how to regulate their cognitive activities.	[15,16,23, 24]
	Reference	To refer to similar problems and strategies, solve, and verify the solution.	[5, 6]
Development of Metacognitive Skill	Awareness	To be aware of one's own mistakes.	[8]

Table 3. Y<=I-goals

Y<=I goal	Definition	Source
Learning by Trial and Error	Learning by applying various knowledge or skill to other learners and guiding the learners.	[15, 16]
Learning. by Self-expression	Learning by externalizing self-thinking process, such as self-explanation and presentation.	[15, 16]
Learning by Awareness	Learn by being aware of one's own mistakes.	[8]
Learning by Practice	Learn by demonstrating knowledge or skill to other learners and guiding the learner.	[23, 24]
Learning by Discussion	Learn by demonstrating knowledge or skill to other learners.	[23, 24]
Learning by Referring	Learn by referring to similar problems	[5, 6]

Table 4. W(L)-goals

W(L)-goal	Definition	Source
Comprehension	Setting up the situation for comprehending expository text.	[15,16,23,24]
Problem-Solving	Setting up the situation for solving some problem.	[5, 6, 8]

Table 5. W(A)-goals

W(Activity)-goal	Definition	Source
Setting up the situation for ASK to THINK–TEL WHY	Setting up the situation where a learner is assigned a "Questioner" role and the other learner is assigned a "Teller" role.	[15, 16]
Setting up the situation for reciprocal teaching	Setting up the situation where a learner is assigned a "Dialogue Leader" role and a teacher is assigned a "Facilitator" role.	[23, 24]
Setting up the situation for using Reflection Assistant	Setting up the situation where learners interact with the Reflection Assistant.	[5, 6]
Setting up the situation for using EBS	Setting up the situation where learners can interact with the EBS.	[8]

We identify goals for these learning strategies and systems for each of the four categories: I-goal, Y<=I-goal, W(A)-goal, and W(L)-goal. For I-goal, we adopt Inaba's classification of I-goals for collaborative learning: acquisition of content specific knowledge, development of cognitive skills, development of metacognitive skills, and development of skill for self-expression. Each I-goal has a developmental stage. The I-goal "acquisition of content specific knowledge" has three phases of learning: accretion, tuning, and restructuring. Each I-goal of skill learning has three stages: cognitive stage, associative stage, and an autonomous stage.

We identify the concept of development of cognitive skill and metacognitive skill in detail based on our organized activities in Table 1. As Table 2 shows, in the two learning theories and two support systems for development of metacognitive skills, there are three I-goals: "Other regulation", "Reference" and "Awareness". Our organized activities reveal that "Other regulation" and "Reference" are cognitive skills while "Awareness" is a metacognitive skill, which is explained below.

"Other regulation" infers others' cognitive activities from their behaviors, evaluates them, and asks a question or advises others on how to regulate their cognitive activities. The target of the activity is other learners' cognitive activities, that is, it is the world outside of the person. The activity is to observe the outside world, encode its result into the WM at the cognitive layer, evaluate the state, select what to do next, and perform it. "Other regulation" is thus classified as basic cognition and cognitive activity.

"Reference" refers to problems in which a given problem is similar, solved with referring to similar problems and verifying the solution by a learner him/herself. For "Reference", the target of the activity is the outside world. The activity is to observe a given problem, encode its result into the WM at the cognitive layer, refer to similar problems and their answer which are presented by a support system, apply them, and check the answer by a learner him/herself. For "Reference", the activities are to form knowledge like a schema, that is, to acquire meta-knowledge. These are classified as basic cognition and cognitive activities.

The difference between "Other regulation" and "Reference" can be explained by our organized activities. There are four activities: observation, evaluation, selection and output as parts of cognitive skill. Although the observation and evaluation of "Other regulation" and "Reference" are almost alike, the selection of "Other regulation" is different from the selection of "Reference." The former is to select activities to regulate other's cognitive activities; while the latter is to select activities to reform a learner's own knowledge.

"Awareness" is to be aware of one's own mistakes, and hopefully to trace one's own cognitive activities back to their causes. According to our organized activities, "Awareness" is a trigger to provoke the observation state in WM and cognitive activities at the cognitive layer. So, we categorize "Awareness" as a metacognitive skill.

To achieve I-goals, a learner is expected to achieve at least one of Y<=I-goals. Y<=I-goals are achieved through interaction with other learners, a teacher or computer systems based on learning strategies and learning systems. Table 3 shows Y<=I-goals. For example, to achieve the I-goal "Other regulation (Associative stage)", some learners could follow the Y<=I-goal "Learning by Practice", while some learners could take Y<=I-goals "Learning by Trial and Error" to achieve the I-goal "Other

regulation (Cognitive stage).” Table 4 shows the W(L)-goals, and Table 5 shows W(A)-goals. To achieve Y<=I-goals, a learner is expected to achieve W(A)-goals with W(L)-goals. AT and RT have text comprehension as W(L)-goal, while RA and EBS have problem-solving as W(L)-goal.

4. Conceptual Structure of W(A)-goal

Two learning strategies: both AT and RT provide learners with support not only to comprehend a text but also to develop their metacognitive skills. Using the structure shown in Fig. 2, we show what these strategies support; the difference between the strategies; and the commonalities of the strategies.

Fig. 3 represents the W(A)-goal “Setting up the situation for AT” using the structure shown in Fig. 2. W(A)-goal basically consists of a common goal, a Primary focus, and a Secondary focus, S<=P-goal and P<=S-goal. The conceptual structure of W(A)-goal does not contain all elements representing learning strategies and systems, but rather essential elements to make the learning session effective. W(A)-goal represents an activity within the whole group: i.e. what activity the group performs. The common goal is a W(L)-goal which is the common learning goal every member shares. The Primary focus and Secondary focus are specific to role-players in the group. The P<=S-goal and S<=P-goal are interaction goals among group members, that is, a type of Y<=I-goal. The S<=P-goal is the goal of the person who participates in the learning session as the Primary focus to interact with the learners who play a role as Secondary focus, while P<=S-goal is the goal of the person who plays a Secondary focus role to interact with the learners who play a Primary focus role. Y<=I–goal consists of three parts: “I-role”, “You-role” and “I-goal”. I-role is a role to attain the Y<=I-goal. A member who plays I-role (I-member) is expected to attain his/her I-goal by attaining the Y<=I-goal. You-role means a role as a partner for the I-member. I-goal (I) is an I-goal which defines what the I-member attains. (For more details, please see [9,10])

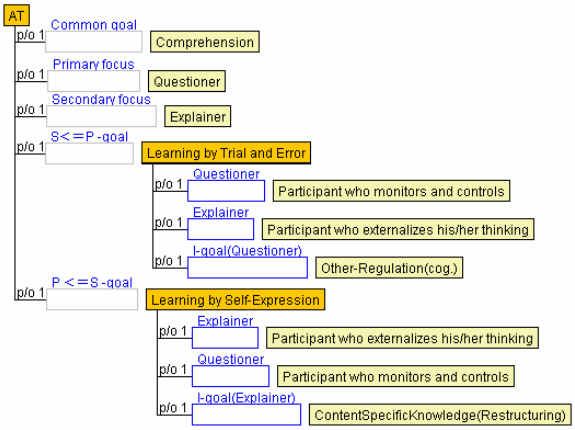

Fig. 3. ASK to THINK–TEL WHY (AT)

The AT has been used to comprehend science and social studies material. Its W(L)-goal is "Comprehension." At the AT, learners who participate in the learning session take turns playing the roles of tutor and tutee, and they are trained in question-asking skills in the tutor role and explanation skills in the tutee role. Learners in the tutor role should not teach anything, but select an appropriate question from a template of questions and ask the other learners, while the learners playing the tutee role respond to the questions by explaining and elaborating their answers. So, the learner playing the tutor role is called the "Questioner" and the tutee is the "Explainer". The questioner regulates other learners to explain what they think and elaborate upon it. The questioner acquires knowledge about what question they should ask other learners to explain and elaborate what they think using a template of questions. The "Primary focus" in this learning strategy is "Questioner", and the "Secondary Role" is "Explainer". The S<=P-goal is "Learning by Trial and Error", the P<=S-goal is "Learning by Self-Expression." I-goal (Questioner) is "Other-regulation (Cognitive stage)", I-goal (Explainer) is "Acquisition of Content Specific Knowledge (Restructuring)."

Fig. 4 represents the W(A)-goal "Setting up the situation for RT" using the structure shown in Fig. 2. The RT has been used to understand an expository text. Its W(L)-goal is also "Comprehension." At the RT, members in a group take turns in leading a dialogue concerning sections of a text, and generate summaries and predictions and in clarifying misleading or complex sections of the text. Initially, the teacher demonstrates activities as a dialogue leader, and then provides each learner who plays a role of a dialogue leader with guidance and feedback at the appropriate level. The learner who plays the role mimics teacher's activities, that is, a leader practices what he learned through observing the teacher's demonstration. Other members in the group discuss about questions of a dialogue leader and the gist of what has been read. In the form of discussion, members' thinking is externalized. So, the form of discussion helps a dialogue leader to monitor other members' comprehension, and also promotes other members to elaborate their comprehension each other. Thus, a

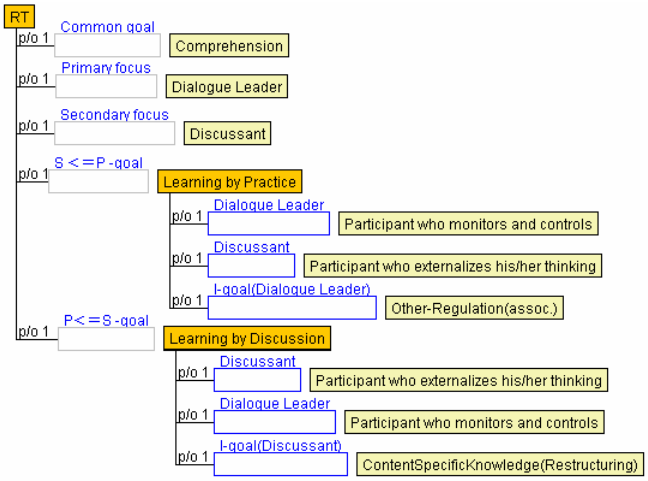

Fig. 3. Reciprocal Teaching (RT)

member who leads a dialogue is called the “Dialogue Leader” and other members in a group are the “Discussant.” A dialogue leader promotes others’ comprehensive monitoring and regulation. The discussants promote their comprehension. The “Primary focus” in this learning strategy is “Dialogue Leader”, and the “Secondary Role” is “Discussant”. The S<=P-goal is “Learning by Practice”, the P<=S-goal is “Learning by Discussion”. I-goal (Dialogue Leader) is “Other-Regulation (associative stage)” and I-goal (Discussant) is “Acquisition of Content Specific Knowledge (Restructuring).” Based on the conceptual structure of a W(A)-goal, the distinction between AT and RT is made clear. Also it is clear that what activity both AT and RT support is not learners’ metacognitive skill but cognitive skill.

5. Conclusion

The ambiguity of the term metacognition raises issues in support of the development of a learners’ metacognitive skill. To clarify this ambiguity, we have organized activities that cover a variety of activities pertaining to metacognitive skill. Based on the organized activities, we can clarify what activity learners master by using learning strategies and support systems. In this paper, we show that the activity which some computer-based systems support, which has been subsumed under the heading metacognition, is actually cognitive activity. Also, we explained existing learning strategies and support systems which support the development of learners’ metacognitive skill in relationship to Learning Goal Ontology.

In the future, we would like to identify learning goals that are proposed in other existing learning strategies and learning support systems using the organized activities in cognitive skill and metacognitive skill, and represent them with the Learning Goal Ontology.

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