The Model of Metacognitive Skill and How to Facilitate Development of the Skill

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Abstract. Through a survey of several computer-based learning environments and the methods under the title "metacognition", we recognize there are various concepts called "metacognition", and lack of common vocabulary and a system of concepts to represent cognitive and/or metacognitive phenomena. We propose a double-loop model of metacognitive activities as our criterion to distinguish metacognitive activities from cognitive activities. Based on the model, we consider difficulties to do metacognitive activities, especially, how to support a learner's development of self-regulation skill. So, we also propose a learning support environment to facilitate development of a learner's self-regulation skill. The environment provides learners with opportunities to develop their self-regulation skill gradually: first, they learn the skill by observational learning, and then, they learn the skill using it as a kind of the basic cognitive activity. Finally, they try to use the skill as one of the metacognitive skills with computer system's supports.

Introduction

Recently, several computer-based learning environments and the methods are described in the literatures, whose titles have the terms like ‘metacognition’, ‘self-regulation (SR) skill’, ‘executive control’ or ‘reflection’. There are several terms (e.g., self-regulation, executive control) used to describe the same phenomenon, and the same term (e.g., metacognition) is used to describe different phenomena (Brown, 1987; Kluwe, 1982; Livingston, 1997; Lories, et al., 1998). It confuses us and makes metacognition mysterious. What is metacognition? Are metacognitive activities similar to basic cognitive processes or is there something special to metacognition as opposed to cognition? How do people reflect on their cognitive processes? (Yzerbyt, 1998) Through a survey of related works, we recognize there are various concepts called by the same term “metacognition”, and lack of common vocabulary and a system of concepts to represent cognitive and/or metacognitive phenomena (Mizoguchi & Bourdeau, 2000). So, our research objectives include constructing common vocabulary to represent cognitive and/or metacognitive phenomena, and providing clear criteria to distinguish terms in the vocabulary.

There are two approaches to metacognition: the researchers who identify the metacognition as some special cognitive activity and try to clarify its mechanism (Brown, 1987; Flavell, 1976), and the researchers who suppose that the metacognitive activity is similar process with basic cognitive activity (Livingston, 1997; Lories, et al., 1998) and what difference between them is the target of monitoring and control activity, that is, the target of cognitive activity is in the outside world of a person, while the target of the metacognitive activity is in the inner world of the person who performs the activity. We have been adopting the latter approach, and proposing our model to distinguish what metacognition is and what cognition is (Kayashima & Inaba, 2003a; 2003b; 2003c). Many phenomena called metacognitive activity are interpreted as the same mechanism with basic cognitive activity (Yzerbyt, 1998), and we can design supporting methods and systems by assuming the same mechanism. In this paper, we introduce our double-loop model of metacognitive activity and consider difficulties to do metacognitive activities. Especially, we concentrate on how to support a learner’s development of SR skill. So, we also propose a learning support environment to facilitate development of a learner’s SR skill.

The SR skill is one of the metacognitive skills, and allows a learner to think about his/her own thinking process, and to control his/her own thinking process for achieving his/her goal by him/herself (Brown, 1987). It is a skill which is independent of subject-domains, that is, once a learner masters the skill, he/she can apply it across domains and even in domains where he/she has little prior background knowledge. So, the skill is important to improve a learner's competence. Some learners develop the skill by themselves; but some learners do not. The former are intelligent novices who can plan how to solve a problem, apply their knowledge to authentic tasks, and monitor and regulate their problem solving process (Bruer, 1993); the latter may have difficulty in learning, especially it is difficult for them to apply their knowledge to authentic tasks, and to monitor and regulate their

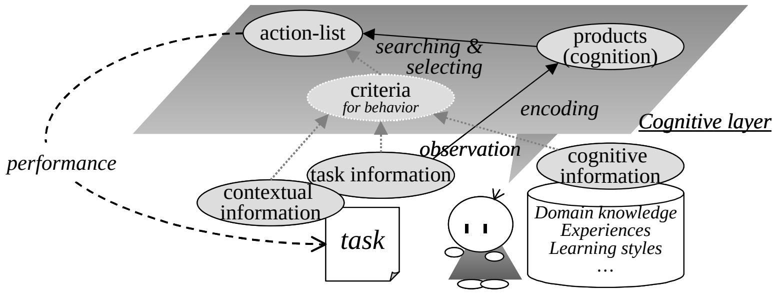

Figure 1: A Model of Problem-solving Process

thinking process. However, many researchers had paid much attention to how to support acquisition of domain knowledge, but little attention to how to improve learners' SR skills.

This paper is organized as follows; first, we describe our model to distinguish metacognitive activity from cognitive activity and why it is difficult to master the metacognitive skill. Then we survey existing learning support systems and methods of helping a learner develop his/her metacognitive skill, and describe which difficulties the systems and methods reduce. Finally, we describe what difficulties still remain and then propose a learning environment to help a learner master the skill with computers.

Metacognitive skill and its Difficulties

In this section, we describe our notion what basic problem-solving process is and what metacognitive skill is. And then, we consider why it is difficult to master and to execute the skill.

What is the metacognitive skill?

We suppose a model of problem-solving process as [Figure 1]. When a learner solves a problem or accomplishes a task, first, he/she observes the task condition and his/her own cognitive information about the task domain. Next, the learner creates *products* in his/her working memory, and the *products* represent what the task is. If the learner has some knowledge on the domain and some of them can be used to accomplish the task, he/she searches his/her knowledge base and makes an *action-list*. Then, the learner applies actions in the *action-list* to the task, and the action can be observed as the learner's behavior. Some actions update the state of *products* in the working memory. In this case, we cannot observe the action, but the *action-list* will be changed based on the updated *products*. The process is repeated until achieving a goal. The learner may also create *criteria* about the task in his/her working memory. The *criteria* include goals of the task and constraints to do the task; and they may influence making the *action-list* (Carver & Scheier, 1998; Winne & Hadwin, 1998). In this cognitive activity, it is important how to create the *products*, that is, how the learner cognizes the outside world and encodes it. The *products* should be abstracted at an appropriate level in order to make his/her prior knowledge applicable to the current task, and the prior knowledge and experiences should be activated for searching similar task or applicable solutions (Davidson, et al., 1994; Gama, 2001).

When we consider metacognitive skill, we suppose two layers in a learner's working memory: cognitive layer and metacognitive layer. The metacognitive problem-solving process uses two layers shown in [Figure 2], while the problem-solving process shown in [Figure 1] uses only the cognitive layer. We have been proposing this "double-loop model" of metacognitive skill (Kayashima & Inaba, 2003a; 2003b; 2003c) to distinguish the skill from other skills. We mean the term "metacognitive skill" as skillful activity at the metacognitive layer; for example, self-monitoring skill, self-assessment skill, and self-regulation skill. We can say that the metacognitive activity is a cognitive activity (at the metacognitive layer) for a cognitive activity (at the cognitive layer), that is, the metacognitive activity includes observing, evaluating, and regulating the cognitive activity. To perform the metacognitive activity, it is necessary for a learner to recognize the goals of the cognitive activity, the constraints of it, and the process of the learner's cognitive activity at the cognitive layer, and to encode them to the metacognitive layer. During problem-solving process, the learner observes his/her own working memory at the cognitive layer to evaluate the process and to regulate his/her cognitive activity. The learner evaluates whether the problem-solving process is going well or not. If the process is decided as "not good", the learner may trace his/her cognitive activity to verify it carefully, and search his/her long-term-memories to get some knowledge that can be used to make the

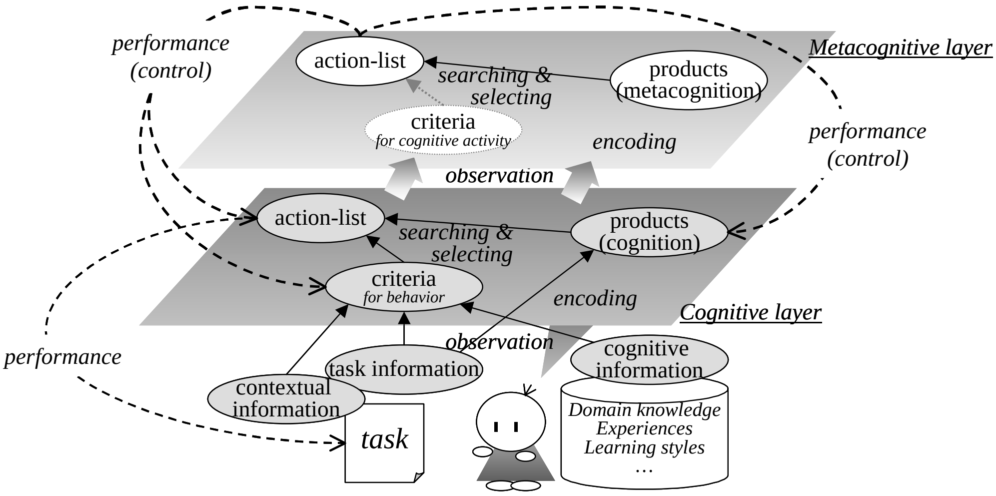

Figure 2: A Model of Metacognitive Activity during Problem-solving Process

situation better, and then applicable actions are stored in the *action-list* at the metacognitive layer. The actions in the list are applied to change not the states of the task, but the states at the cognitive layer.

Why is mastering the metacognitive skill difficult?

So far, it has been pointed out that the metacognitive skill is difficult to learn and also execute. Of course, the difficulties include common difficulties for skill learning, and idiosyncratic difficulties for metacognitive skill. However, there are little researches to clarify and list the difficulties, consider their causes, and propose methods clarifying which difficulties the methods reduce. We have been clarifying the difficulties based on our hierarchical model of skills (Kayashima & Inaba, 2003a, 2003c). Here, we consider the difficulties by dividing them into two categories: difficulties in learning the skill and difficulties in executing the skill.

The difficulties in learning the skill include common problems to all skills, like motor skill, cognitive skill, and so on. As you know, mastering a skill is difficult as compared with acquisition of specific (declarative) knowledge. It is difficult to explain how to use a skill explicitly even for a person who has already mastered the skill. So, a learner who wants to master the skill has to use, adjust, and coordinate each action which composes the skill after he/she gets outline knowledge about how to use the skill. Moreover, there are some idiosyncratic problems for learning the metacognitive skill: If the skill that a learner wants to master is one of motor skills, the learner can observe the process that another person uses the skill. For the metacognitive skill, however, its monitoring and controlling target is in the person's mind, and the process to use the skill is also performed in his/her mind. So, the learner cannot observe the process to use the skill and what changes occurred as a result of using the skill. Due to the invisibility, it becomes more difficult for the learner to imitate the skill.

On the other hand, there are difficulties in executing the metacognitive skill. As shown in [Figure 2], the metacognitive skill uses many resources compared with basic cognitive skill. The person who does not use the skill encodes task information and cognitive information about task-domain as a result of cognition (*products*), and creates *criteria* referred to these information and contextual information. Then, he/she searches his/her knowledge base and assembles applicable knowledge into *action-list* in order to change states of the task. In addition to the resource consuming, the person who uses the metacognitive skill encodes his/her cognitive activity as result of metacognition (*products* at the metacognitive layer), and creates *criteria* for the cognitive activity. Then, he/she searches again his/her knowledge base and assembles applicable knowledge into *action-list* at metacognitive layer in order to control the objects in the cognitive layer. Therefore, there are two additional problems: capacity of working memory (Winne & Hadwin, 1998) and multi processing in mind. Moreover, it is difficult for learners to be aware when they should use the metacognitive skill, because the learners can sometimes solve problems even if they do not use the metacognitive skill.

A Method of Supporting a Learner's Development of Self-regulation Skill

We summarize the difficulties described in the previous section in [Table 1]. We have surveyed related works to find supporting methods to master the skill and clarified the relation between existing methods and the difficulties

Table 1: Difficulties in Learning and Executing Skills

	Difficulties in learning the skill	Difficulties in executing the skill
Skill	*L-a*: No one can convey how to use the skill explicitly in words or writings. *L-b*: Need to adjust and coordinate each action which composes the skill.	
Cognitive skill	*L-c*: The process using the skill is invisible.	
Metacognitive skill	*L-d*, *L-e*: The input and output for the skill are invisible. It is unclear when a person uses the skill, what its trigger is, and what its result is.	*E-a*: Capacity of working memory *E-b*: Multi processing in mind *E-c*: To be aware when they should use it
Self-regulation skill	*L-f*: It is rare to have an experience to monitor and regulate someone in regular schooling.	*E-d*: Objective monitoring and evaluating to their own cognitive activity

which are intended to reduce in the methods. Then, we propose a method to facilitate a learner's development of SR skill.

What Difficulties the Existing Methods Reduce and What Difficulties Still Remain

Several methods have been proposed to facilitate development of the metacognitive skill: for example, Error-Based Simulation (EBS: Hirashima & Horiguchi, 2001), Intelligent Novice Tutor (Mathan & Koedinger, 2003), reciprocal teaching (Palincsar & Brown, 1984), ASK to THINK - TEL WHY (King, 1999), a KITCHEN SINK approach (Schoenfeld, 1987) and so on.

Visualization of an erroneous equation for mechanical problems is the target of EBS. EBS is a behavior simulation generated from an erroneous equation. The strange behavior in an EBS makes the error in the equation clear, and provides opportunities that a learner monitors his/her cognitive activity objectively. The Intelligent Novice Tutor teaches cell reference skills of a spreadsheet. The tutor notifies a learner about his/her errors, and provides alternatives to correct them. The learner chooses one from the alternatives with the tutor's help. In this sense, both EBS and Intelligent Novice Tutor reduce the difficulty *E-d*, however, the systems do not provide any viewpoints for the learner to be aware of errors. So, unfortunately, the learner cannot become a learner who can use the SR skill without the systems' helps.

In the KITCHEN SINK approach, four methods are proposed and each of them is independent (Schoenfeld, 1987). Three methods of them provide learners opportunities to learn the metacognitive skill by observational learning (Bandura, 1971). In the learning environments, some stimuli are used to evoke learners' SR skills: (1) a videotape recording another learner's problem-solving process, (2) a teacher who solves a problem with think-aloud, and (3) a teacher who regulates discussion process among learners. Remaining method (4) is that a teacher asks learners the following three questions at any time: (i) What (exactly) are you doing?, (ii) Why are you doing it?, and (iii) How does it help you? Although learners answer nothing at first, they are getting to prepare answers to the questions even if the teacher does not ask them. Considering these questions induce learners to keep track of what they are doing is reasonable or not, and where they are in their plans. The methods (1) and (2) just provide learners opportunities to be aware of using metacognitive skill, (3) shows learners the process a teacher regulates other persons' discussion process with input information (discussion process) and output (the teacher's advice), and (4) exactly evokes monitoring and evaluating functions. So, we can say the KITCHEN SINK approach reduces the difficulties *L-a*, *L-c*, *L-d*, *L-e*, *L-f*, and *E-c*.

The reciprocal teaching provides guided practice in the use of four strategies designed to promote understanding text. The learner who is a discussion-leader and a teacher lead discussion in small group on shared text. The teacher plays an important role to support the discussion-leader as scaffolding. In this learning environment, the method induces learners to use the others-regulation skill by playing the role of discussion- leader. The method is like Cognitive Apprenticeship (Collins, 1991), and reduces some difficulties: *L-a*, *L-b*, *L-d*, *L-e*, *L-f*, and *E-c*.

The ASK to THINK controls peer tutoring in the small group with a template for questions, such as review question, thinking question, and monitoring question. The learner, who plays as a peer tutor, teaches other learners about comprehending text. In this method, a tutor asks only five types of questions, and tutees only answer and they do not ask questions to the tutor. Here, the tutor tries to practice the other-regulation skill, and the input of the skill is

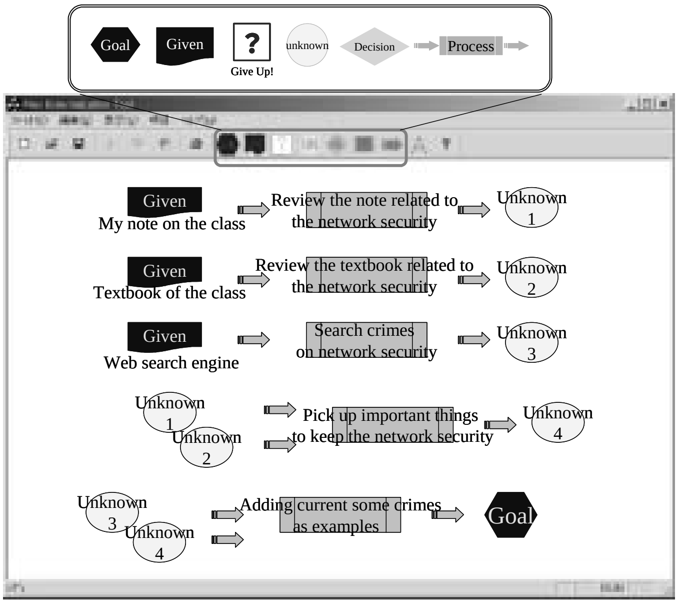

Figure 3: The Plan Externalization Tool

visible to a certain extent by externalizing tutees' thinking process and cognitive activities through their answers. The output becomes to be visible by the tutor's regulation through asking questions. This method reduces the difficulties *L-a*, *L-b*, *L-d*, *L-e*, *L-f*, and *E-c*.

As we described above, reducing the difficulties at learning phase are relatively considered well, and no method is designed to reduce the difficulties *E-a*, *E-b*, and *E-d*. So, adopting the existing methods, we propose our supporting method to facilitate learners with development of their SR skill gradually to help learners overcome all those difficulties. What we emphasize on the method is that it gradually increases cognitive (or metacognitive) loads for learners. For the difficulty *L-c*, we design some learners use other-regulation skill through discussion. It makes the process how, when and why the learners regulate other learner's activity visible. For the difficulties *E-a*, *E-b*, and *E-d*, we design a plan externalization tool that allows a problem-solver to use a computer as an extended working memory and allows other learners to observe the problem-solver's cognitive activity.

Plan Externalization Tool to Reduce the Difficulty with Resource Allocation

Resource allocation is an important issue in supporting development of the SR. Analyzing human planning process, Hayes-Roth & Hayes-Roth assume that the planning process consists of the independent activities of five distinct cognitive demons (Hayes-Roth & Hayes-Roth, 1979). The control-target of the SR is the activities of five distinct cognitive demons, resource allocation for them is difficult for human. Supporting learners to allocate their resource to the independent activities of five cognitive demons, we design and construct the prototype of a plan externalization tool. In other words, the learner can use the tool as an extended working memory for recording the cognitive products and the criteria in [Figure 2]. Since the tool shows the criteria to the learner, it may trigger to compare his/her cognitive activity with the criteria, that is, the learner will evaluate his/her cognitive activity. So, we expect to reduce the difficulties *E-a* and *E-c* by the tool. By requesting the learner to point out where he/she is, the tool also helps the learner confirm his/her execution process of the plan. It also makes the plan and the learner's recognition visible for other learners.

The plan externalization tool allows a learner to externalize his/her plan for problem solving rather than to assist appropriate planning. While there are several tools to facilitate development of metacognitive skill, the most of them are designed to represent the results of a learner's cognitive activities, that is, *products*. We design the plan externalization tool to represent the plan, especially, to plan a learner's cognitive activities in the tool. Of course, many outcomes of cognitive activities are unknown in the planning phase, and these will be overwritten by concrete values in the executing phase. The tool permits hierarchical planning, that is, it allows several tentative, incomplete plans to coexist. Thus the plan externalization tool itself is a simple one. [Figure 3] shows the main window of the externalization tool and the example shows a plan for an assignment "do a paper on the problem of network security".

Its toolbar has six elements for externalizing the plan. The element “Goal” is put on the goal of the desired solution. The element “Given” is put on the starting point of the plan: given data of the problem. The “Process” has input and output. It represents the process to transform the given input into a desired output, and is written by a simple sentence. If the output of “Process-A”, which is unknown, becomes the input of “Process-B”, a learner can connect both “Process-A” and “Process-B” by putting the element “Unknown” between them. When a learner has alternative plans, the learner can leave both plans as they are and put the element “Decision” on it. It means if one of the plans is successful, another plan can be ignored. The element “Give Up!” can be put if it is impossible for the learner to make any progress from there on. The learner can put “Unknown” on unknown input or unknown output. Usually, input and output of the element “Process” is “Unknown” at planning, and the element “Unknown” may be replaced by certain value during the on-going attempt to solve the problem.

The method of supporting a learner’s development of the self-regulation skill

The method of supporting a learner’s development of the SR skill is composed of three phases: first phase, a learner observes the process that other learners use the other-regulation skill which is a basic cognitive skill and requires the learners of similar knowledge and rules with the SR skill; second phase, the learner tries to use the other-regulation skill through discussion and there is a template of question as a support for regulating the other; finally, the learner tries to use the SR skill as a metacognitive skill supported by the externalization tool.

[Figure 4][1] shows the learning environment we propose here. First, a learner plays the role of observer (learner-C in the figure) and learns the SR skill as the other-regulation skill by observational learning. Here, the other-regulation skill is a regulation skill in cognitive level. Next the learner plays the role of monitor (learner-B). The learner monitors the problem-solver’s behavior and tries to regulate his/her cognitive activities. Finally the learner plays the role of problem-solver (learner-A) and tries to monitor his/her cognitive activities and to regulate them by him/herself. The questions for learner-A as triggers of SR are the same with the questions for learner-B as other-regulation. We assume the cognitive activity and the metacognitive activity are the same mechanism to different targets; it is useful to master the activity to relatively easy target before practicing it to main target. So, first, the learner tries to master the other-regulation skill which is regulation activity at the cognitive level, and then the learner practices the SR skill which is regulation activity at the metacognitive level.

Learning the self-regulation skill by observational learning

In order to learn the SR skill by observational learning, it is ideal that input to the skill, process using the skill, and output of the skill are visible for the observer. In this learning environment, the observer (learner-C) learns it by observing the process in which the monitor (learner-B) uses the other-regulation skill. Its input information is the problem-solver (learner-A)’s cognitive activity, and its outputs are questions that the monitor asks the problem-solver. The process using the skill is observed as discussion among the monitors. It reduces the difficulty *L-a* and *L-c* in [Table 1] like Shoenfeld’s KITCHEN SINK approach. Both of the process and output are visible for the observer. Thanks to our externalization tool for the problem-solver, the input information is also visible, and it reduces the difficulties *L-d*, and *L-e*. Therefore, the observer can observe all elements: input, process, and output: observational learning is realized.

Learning the self-regulation skill as other-regulation skill

The monitors observe, evaluate, and try to regulate the cognitive activities of the problem-solver through discussion among the monitors. The monitors have a checklist which has a template of some questions. We adopt the questions that Schoenfeld proposed, and proposed in the ASK to THINK – TEL WHY (King, 1999). These questions are intended to trigger off both the SR skill of the problem-solver and the other-regulation skill of the monitors. They also give the monitors the viewpoint of monitoring: what and how they should observe the problem-solver’s cognitive activities. But these questions do not indicate how to regulate. The monitors need to talk about which question should be selected in the checklist. This discussion leads monitors to monitor the problem-solver’s behavior and to decide how to regulate it. As the result of this discussion, they attempt to regulate the cognitive activities of the problem-solver. Through the discussion and attempt at regulation, the monitors are expected to master their other-regulation skill (King, 1999). For example, the problem-solver designs a problem-solving plan and then executes the plan while he/she points where he/she is in his/her plan using our externalization tool. The monitors can

[1] In this figure, computers for each learner and network among them are not drawn to avoid complicating the figure. Actually, each learner uses a computer and all computers are connected to network. Every learner can share the same screen information and use communication channel like a chat system.

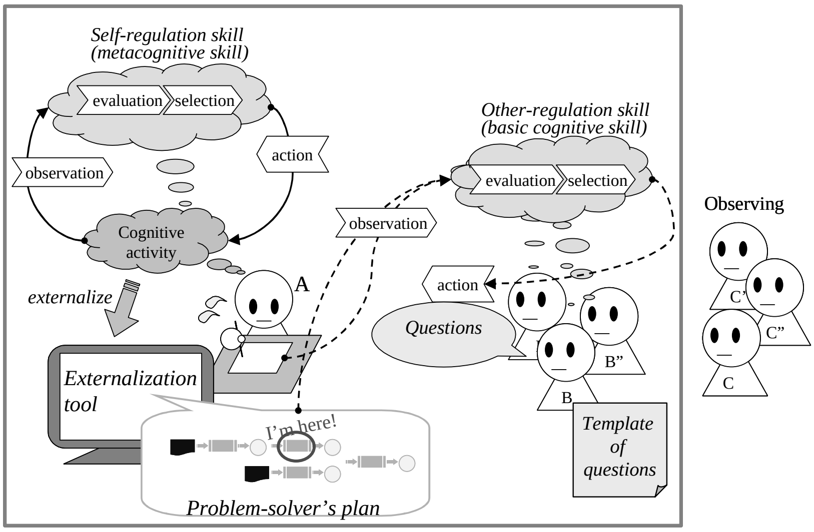

Figure 4: The Learning Environment Gradually Supports Learners' Development of Self-regulation Skill

observe the plan, where the problem-solver points in the plan, and what he/she actually does, because the screen is shared among the problem-solver, the monitors, and the observers via network. This means that the monitors can observe the problem-solver's cognitive activity to a certain extent. If the monitors evaluate the problem-solver's behavior as wrong, for example, the behavior is not suitable for the plan, or he/she does not point correctly where he/she is in the plan, the monitors select one of questions in the checklist and ask it to the problem-solver. If this question would trigger the SR of the problem-solver, the problem-solver's plan or/and behavior would be changed. In this phase, the checklist works as a trigger for the monitors to monitor other learner (learner-A)'s cognitive activity and to control it. Repeating this allows the monitors to internalize the questions which provide some viewpoints how a learner checks and regulates his/her cognitive activity. The monitors learn how to use the other-regulation skill using the checklist. So this phase reduces the difficulties *L-b* and *L-f*.

Learning the self-regulation skill as a metacognitive skill

To reduce one of the difficulties, resource allocation, we propose to use a computer as a part of a learner's working memory. The externalization tool also allows him/her to concentrate on observing his/her own thinking process objectively. Because it makes his/her thinking process and criteria visible, and it also reduces his/her cognitive load. So, in this phase, we aim to reduce the difficulties *E-a*, *E-c*, and *E-d* in [Table 1]. In this learning environment, the problem-solver draws up his/her problem-solving plan using the plan externalization tool. After planning, the problem-solver executes his/her plan while he/she points where he/she is in the plan. This behavior allows the problem-solver to be conscious of his/her cognitive activities: what (exactly) am I doing? Also, the monitor's questions cause the problem-solver to recognize consciously his/her cognitive activities. If the problem-solver becomes unable to point where he/she is in the plan, he/she may need to re-plan and execute the new plan.

This method is based on the socio-cultural theory which comes from Vygotsky (1930). He argued that the development appears on two planes: first on the inter-psychological, then on the intra-psychological. This theory means inter-psychological processes are themselves internalized by the individuals. At first, the monitor's questions act as triggers for the problem-solver's SR skill. Then the problem-solver would internalize the monitor's questions that are based on the checklist. The monitor's questions are internalized by the problem-solver, and could act as a trigger to cause his/her own SR skill.

Conclusion

We proposed the learning support environment to facilitate a learner's development of the SR skill. In the environment, we were aiming to provide learners with opportunities to develop their SR skill gradually: first, they learn the skill by observational learning, and then, by using it as a kind of the basic cognitive activities. Finally, they try to use the skill as one of the metacognitive skills with a computer system's support. Through a survey of related works, we realized there were various concepts and terms to represent metacognitive and cognitive phenomena. Especially, concerning the metacognitive skill, there were little researches to describe why mastering the skill was difficult, how to reduce each difficulty, and what difficulties still remained. Then, we considered what difficulties existing supporting methods could reduce, and proposed our method to reduce the remaining difficulties. To do metacognitive activity, there are four main difficulties: capacity of working memory, multi processing in mind, awareness when a person should use the skill, and objective monitoring to the person's own cognitive activity. The computer may support the problems of awareness and capacity. Our future work includes designing how to support learners' objective monitoring and improving the plan externalization tool by referring to the works on the effects of representational notations (*e.g.*, Suthers, 2003)

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