Building a Framework to Design and Evaluate Meta-learning Support Systems

Kazuhisa Seta, Minoru Fujiwara, Daijiro Noguchi, Hiroshi Maeno, and Mitsuru Ikeda

[1] Osaka Prefecture University, Department of Mathematics and Information Sciences, 1-1, Gakuen-cho, Naka-ku, Skai, Osaka, 599-8531, Japan
[2] JAIST, 1-1, Asahi-dai, Nomi, Ishikawa, 923-1292, Japan
seta@mi.s.osakafu-u.ac.jp,
{fujiwara,noguchi}@kbs.cias.osakafu-u.ac.jp, ikeda@jaist.ac.jp

Abstract. It is difficult to generalize and accumulate experiences of system development as methodologies for building meta-learning support systems. Therefore, we need to build a framework that is useful to design and evaluate meta-learning support systems. Thus we propose a framework as a basis to design and evaluate meta-learning support systems. In this paper, we firstly describe our philosophy to solve the problem. Secondly, we propose a meta-learning process model as a basis to understand meta-learning task and what kinds of factors of difficulty exist in performing meta-learning activities. Thirdly, we explain our conceptualization as a basis to design support functions for prompting meta-learning processes. Then, we integrate a meta-learning process model and the conceptualizations, so that we can design and evaluate meta-learning systems. Finally, we illustrate the usefulness of the framework by taking our presentation based meta-learning system as an example.

Keywords: meta-learning, model-directed approach, meta-learning model.

1 Introduction

The meaning of the concept "meta-cognition" [1, 2] is quite vague, so that the contents of meta-cognitive activities cannot be identified clearly. Therefore, the contents of "meta-cognition support" implemented in learning systems indicate different kinds of supports without explicit analysis/ descriptions [3]. This problem also causes the effects for the evaluation of meta-cognition support systems: it is difficult to evaluate each function embedded into the system eliminates/ removes which factors of difficulties in performing meta-cognitive activities. Therefore, we cannot evaluate the usefulness of each function in detail, although we can show the effectiveness of the system by performing transfer exam. This also means that it is difficult to generalize experiences of system development as methodologies for building meta-learning support systems [4, 5, 6, 7]. Therefore, we need to build a framework that is useful to design and evaluate meta-learning support systems.

In this paper, we firstly describe philosophy of our research to understand our model-directed approach. Secondly, we propose a meta-learning process model as a

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basis to understand meta-learning task and what kinds of factors of difficulty exist in performing meta-learning activities. Thirdly, we explain our conceptualizations as a basis to design support functions for prompting meta-learning processes. Furthermore, we integrate a meta-learning process model and the conceptualizations, so that we can design and evaluate meta-learning systems based on the deep understanding of meta-leaning processes. Finally, we illustrate the usefulness of the framework by taking our presentation based meta-learning system as an example.

2 Underlying Philosophy of Our Research

Our research aims to build a meta-learning support system that facilitates learner's learning skill development through reflecting his/ her own learning processes. We call “learning of learning activities” (learning of learning methods) as meta-learning. It is well-known that providing meta-cognitively aware instruction is significant to facilitate meta-learning processes [8]. In learning history, for instance, the student might be asking himself as internal self-conversation, “who wrote this document, and how does that affect the interpretation of events,” whereas in physics the student might be monitoring her understanding of the underlying physical principle at work.

In learning software development method, not only to memorize how to depict each diagram in UML but also to prompt internal self-conversation processes, e.g., inquire his /herself to answer the reusability and functional extendibility of a designed class structure, is quite important to deepen the learner's own understanding. Meta-cognitively aware instruction is to give learners domain-specific adequate inquiries from the teacher to deepen their understanding. It also facilitates their acquisition of these kinds of domain-specific learning strategy. In our system, we had realized a guidance function that provides meta-cognitively aware instruction based on learning skill ontologies [6].

This function is our original based on the valid knowledge in educational psychology field, however, we don’t think it is not enough to accumulate sharable knowledge to develop meta-learning support systems. Thereby, we adopt model-directed approach to clarify the intention of the function, i.e., which factors of difficulties in performing meta-cognitive activities we intend to remove/ eliminate according to a model. This approach is meaningful for the development of human-centric systems in general.

Our meta-learning support system and a learner compose an interaction loop: the system gives stimulations according to the learner’s behaviors and they encourage their own intellectual activities prompted by them.

Therefore, we must recognize the learner as a part of the system to achieve our goal of meta-.learning support.

On the other hand, we could not take it into account systematically since cognitive activities of human beings are quite various, latent and context dependent, so that a system developer of a human-centric system can design a sophisticated interaction loop between the system and the learner. Therefore, they tend to design support functions that seems to be subjectively valid based on their experiences without clarifying design intentions. Then, they investigate the validity by performing exams. It means relations among theories clarifying characteristics of cognitive activities in human

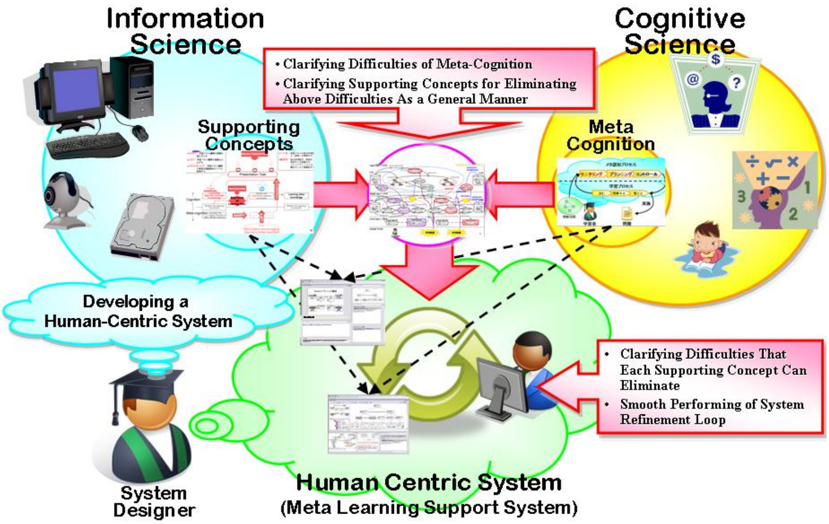

Fig. 1. Model Directed Approach for Building Human Centric Systems

mind and support functions tend to be weak, thereby experiences in developing a system cannot be used/ shared well.

Figure 1 outlines our model directed approach. A system developer, who intends to develop a human-centric system has to design adequate interaction loop to encourage learners' meta-learning activities.

In our framework, we clarify meta-learning model as a reference model to understand which difficulties developers intend to eliminate by extending Kayashima's computational model that is specified based on knowledge in cognitive psychology field (upper right circle). Furthermore, we specify information system support concept at the specific system independent level (upper left circle). Then, we integrate them as a foundation to design and evaluate support functions that eliminates the difficulties. Therefore, they can design support functions based on the understanding of what kinds of difficulties they have to eliminate for the learner and what kinds of support functions they have to realize.

One of the significant differences between ordinary and our approach is that we can clarify design rationales of each support function implemented into the system.

3 Foundation to Build the Framework

In this section, we overview the structure of meta-learning processes to understand the meta-learning task. Then, we build meta-learning process model corresponding to upper right circle in fig. 1, and explain our conceptualizations corresponding upper left circle in fig. 1.

3.1 Structure of the Meta-learning Task

Figure 2 represents cognitive activities in performing problem-solving processes (left side) and the ones in performing learning processes (right side), respectively. A problem-solver performs cognitive activities, e.g., reads, understands a given problem and solves it. At this time, he/ she also performs cognitive activities that monitor, re-plan and control them. These are called meta-cognitive activities in the sense of cognitive activities that handle cognitive activities.

Kayashima et. al. constructs a framework by which we can understand factors of difficulties in performing meta-cognitive activities in problem-solving. It clarifies factors of difficulties based on cognitive psychology knowledge, e.g., segmentation of process, invisibility, simultaneous processing with other activities, simultaneous processing with rehearsal, a two-layer working memory, acquisition of criteria for cognitive activity and so on.

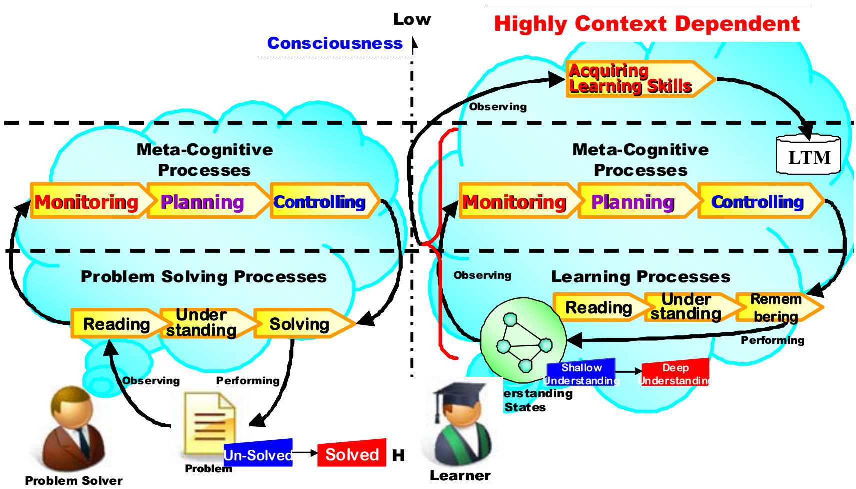

Fig. 2. Structure of Meta-Cognitive Task in Performing Problem-solving Processes (left side) and Learning Processes (right side)

On the other hand, performing meta-cognitive activities in learning (planning of learning processes) is more difficult than the one in problem-solving (planning of problem-solving processes), since problem-solving activities and their results are visible whereas those of learning activities and their results (learner's understanding states) are in-visible. Thus, the learners do not tend to be aware of necessity of monitoring and controlling their learning processes. Thereby, they do not tend to perform meta-cognitive activities spontaneously.

Furthermore, planning learning activities compels heavier cognitive loads to the learner since they require monitoring activities of one's own invisible understanding states, It is difficult for ordinary learners to perform even though they intend to do.

Furthermore, learning know-how for learning process planning (top layer in fig. 2(right)) by reflecting learning activities performed at the second layer is more latent and higher level activities than meta-cognitive ones performed at the second level in problem-solving processes.

3.2 Meta-learning Process Model

Here, we give more detailed model of meta-learning activities. Figure 3 shows a meta-learning process model by extending Kayashima's computational model capturing meta-cognitive activities in problem-solving processes (see [3] in detail). It captures meta-learning processes in a learner's head (working memory). It is separated by three layers. It represents changing processes of the learner's understanding states by performing learning activities at the lowest layer, ones of planning learning processes at the middle layer, and ones of reflecting activities for acquiring learning skills at the top layer, respectively. Each ellipse represents a product produced at each layer and "t*" represents the time. Therefore, the order of "t*" represents changes of a product.

The model represents that the learner had intended to make himself/ herself understand the feature of functional extendibility of the Iterator Pattern in software design pattern (at the middle layer). But he/ she could not understand well by itemizing these features (at the lowest layer). Then she got be aware of the lack of her understanding by monitoring own understanding states and re-plans her learning processes (at the middle layer).

If this meta-cognitive activities (learning process planning) adequately performed, e.g., make the learning plan to understand functional extendibility of the iterator patterns by considering a correspondence between functional extendibility and class structures, she can understand the topic deeply.

Learning-skill acquisition processes at the top layer require following cognitive activities: (i) reflecting and observing the learning processes (reflecting cognitive activities performed at the lowest), (ii) detecting meaningful domain-dependent learning operators that had deepened his/ her understanding states, and (iii) re-evaluate, generalize and store them into the long term memory.

This model plays a role of clarifying factors of difficulty in performing meta-learning process. It will be described in section 4.

3.3 Conceptualization to Design Support Functions for Meta-learning

By building the detail meta-learning process model, we can conceptualize general support concept in-dependent of concrete support functions.

Table 1 shows five concepts for supporting meta-learning that we specified from the viewpoint of information system development: SHIFT, LIFT, REIFICATION, OBJECTIVIZATION, TRANSLATE. This conceptualization corresponds to the upper left circle in fig. 1.

SHIFT means that stagger the time of developing learning skills after performing learning processes.

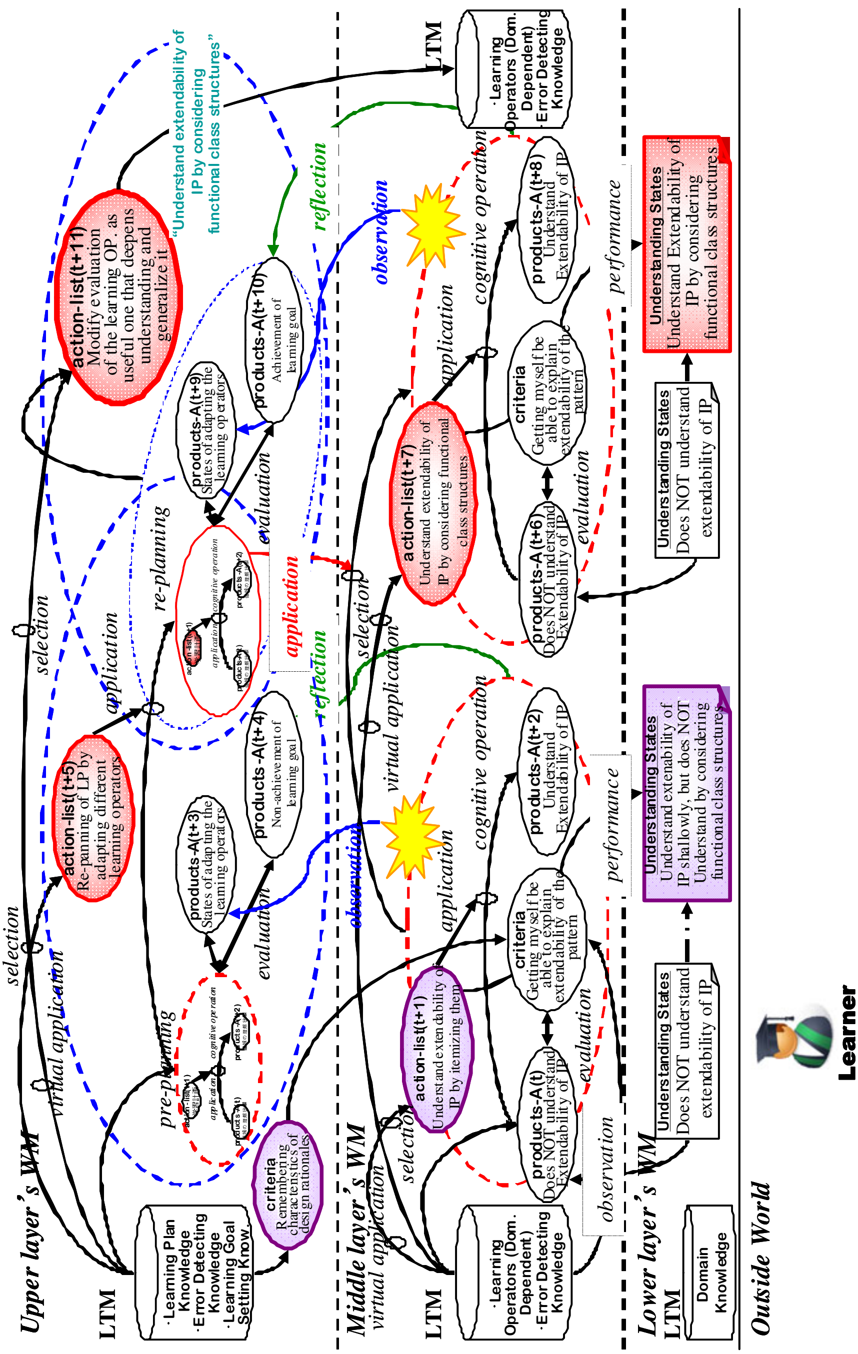

Fig. 3. Meta Learning Process Model

Table 1. Correspondence Among Supporting Concepts and Their Targets

Conceptualization	**Meaning**	**Target to eliminate factors of difficulties**	**Learning Scheme Design**
SHIFT	Stagger the time of developing learning skills after performing problem-solving processes	• Simultaneous processing with other activities • Planning • Influence on virtual application at a lower layer	Task Design (giving a presentation topic the learner had already learned)
LIFT	Make the learner be aware of learning skill acquisition	• Invisibility • Influence on virtual application at a lower layer (learning process • Planning	Visualization Environment
		• Reduce a three-layer WM to a two-layer WM • Evaluation of influence on virtual application at a lower layer (problem-solving)	Guidance Function
		• Acquisition of learning operators	Guidance Function
REIFICATION	Give appropriate language for his/her self-conversation to acquire learning skills	• Segmentation of process	Providing Domain Specific Terms of Learning Activities
TRANSLATE	Transfer the learning skill acquisition task (LSAT) to a problem-solving task that includes same task structure of LSAT.	• Reduce a three-layer WM to a two-layer WM • Influence on virtual application at a lower layer	Task Design (giving a presentation task to explain to other learners)
OBJECTIVIZATION	Objectify her/his self-conversation processes by externalizing them for learning communications with other learners	(Context Dependent)	CSCL Environment

Furthermore, it is needed to give appropriate stimulation to encourage their meta-cognition. This stimulation can be interpreted that it gets the meta-cognitive task as easy as cognitive task by changing internal self-conversation task to usual conversation task. Thus, we conceptualize LIFT as making the learner be aware of learning skill acquisition as a principle for the system development in this research.

We think that how we can realize the SHIFT and LIFT is the key issue for developing meta-cognitive skills.

REIFICATION means that giving appropriate language for the subject of meta-cognition. Of course, since we can not realize the LIFT if we do not give appropriate reification. Thus the concept of REIFICATION is included in the concept of LIFT. But we can not always realize appropriate LIFT even if we realize REIFICATION; we need to give suitable REIFICATION to prompt learners' meta-cognition. Thus, we separate the REIFICATION from LIFT concept since it is easy to discuss from the technical aspects.

By OBJECTIVIZATION, we intend making the internal self-conversation processes objective by discussing with others.

TRANSLATE means changing the learning skill acquisition task to a problem-solving task that includes same task structure of learning skill acquisition task.

The conceptualizations play a role of principle for our learning scheme design.

4 Integrating Meta-learning Process Model and Conceptualizations

In this section, we integrate the meta-learning process model and conceptualizations to build a framework to design and evaluate meta-learning support systems.

Meta-Learning process model clarifies the factors of difficulties in performing meta-learning processes. Third row in Table 1 shows them: simultaneous processing with other activities, planning, invisibility, three-layer WM, acquisition of learning operators and so on.

Table 1 represents correspondence among conceptualizations and their targets to eliminate/ remove factors of difficulties in performing meta-learning processes. For example, SHIFT removes factors of simultaneous processing with other activities and eliminates those of planning and influence on virtual application at a lower layer, while REIFICATION does factors of segmentation of process. Furthermore, TRANSLATE reduce a three-layer WM to a two-layer WM and removes difficulty of influence on virtual application at a lower layer by translating learning skill acquisition task to the problem-solving task.

Consequently, we can understand which factors of difficulties we should eliminate and how we should realize.

The right row in the table illustrates concrete supports implemented in our presentation based meta-learning scheme. For example, based on SHIFT principle, we set presentation task whereby the learner makes a presentation material about already learned topic. Therefore, developers can refer/ compare what kinds of support functions are implemented to realize each conceptualization in designing support functions for their systems.

5 Using Framework to Design and Evaluate Our System

By building the framework, we can build a presentation based meta-learning support system with explicit clarification of design rationale of it. In this section, we illustrate the usefulness of our framework by taking our system as an example. Thereby, we describe our system briefly. See detail explanation in [6]: it is out of the subject in this paper.

5.1 Building Presentation Based Meta-learning Support System

Design principle of each support can be clarified based on the table, e.g., providing domain specific terms of learning activities intends to eliminate the difficulty of segmentation of process.

SHIFT and TRANSLATE are realized as our task design, that is, providing the task where the learner has to explain pre-learned knowledge. LIFT is realized as a function that provides the learner with guidance information for checking the validity of designed learning processes. We had embedded two kinds of guidance function: the one realizes meta-cognitively aware instruction and the other does navigation function to support meta-learning communication among learners. REIFICATION is realized as providing terms for representing learning processes and visualization environment. OBJECTIVIZATION is realized as embedding CSCL environment in the system.

In our system, more concretely, we presuppose a learner who has already learned a specific topic, UML and software design patterns [9] We give the learner the task of producing readily comprehensible presentation material for other learners whose academic ability is similar to that of the presenter. This task setting is important for the learner to focus on meta-cognitive learning: if the learner must perform both learning and making presentations, the learner cannot allocate sufficient cognitive capacity to perform the meta-cognitive activities. This task setting corresponds to the SHIFT. It staggers the time of performing monitoring and generalizing processes after performing learning. In preparing presentation materials, the learner monitors the previous own learning processes and gives queries to herself for validating them. This stimulation corresponds to the LIFT It lifts monitoring and generalizing processes to the cognitive level. Then, she discusses with others whether the presentation material is easy to understand or not. This corresponds to OBJECTIVIZATION. REIFICATION provides terms for representing learning processes, for instance, providing terms of "make the learner understand the functional extendibility of the DP by analyzing the class structure," and plays an important role to realize appropriate LIFT and OBJECTIVIZATION.

5.2 Specifying Items for Evaluating Meta-learning Support Systems

Making questionnaire items for evaluating the usefulness of individual support functions is quite hard, since it is difficult to clarify design principle of them. By clarifying the correspondence among support concepts, factors of difficulty that each support concept removes/ eliminates and concrete supports embedded into each learning scheme, we can make questionnaire items based on it.

Actually, we specified and used 31 evaluation items for constructing a questionnaire for a pilot evaluation of our system. We list some of them as follows:

- Did you feel insufficiency of your understanding in making a presentation material even you thought you had already understood the topic? [Regarding SHIFT and TRANSLATE]
- Do you think making a presentation material makes it easier to reflect your own learning methods? [Regarding SHFT]
- Do you think reading vocabulary prompts your reflection on your own learning processes? [Regarding REIFICATION an LIFT]
- Do you think your presentation structure reflects your learning processes? [Regarding LIFT]

We can compare evaluation results of learning systems even though evaluation items are different, since they are specified based on general-level support concepts.

Because of the small pilot evaluation, we could not conclude the usefulness of each questionnaire items, however, we verify that all 7 learners can understand and answer each questionnaire item even though they are not familiar with cognitive science; most items ask about their cognitive activities that require them to be aware of their cognitive activities.

6 Concluding Remarks

In this paper, we described philosophy of our research to understand our model-directed approach. Then, we proposed a meta-learning process model and our conceptualization. Furthermore, we integrate a meta-learning process model and the conceptualizations, so that we can design and evaluate meta-learning systems based on the deep understanding of meta-leaning processes. It plays an important role to accumulate and share experiences of individual learning system development. Finally, we illustrate the usefulness of the framework by taking our presentation based meta-learning system as an example.

According to the framework we could evaluate usefulness of each function more detail and some questionnaire results suggested they worked well due to our design rationales. We will carefully address this matter in another paper because it is out of the scope of this paper.

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