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# A New Perspective for Metacognition-Driven Learning

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**Abstract.** While the importance of metacognition is widely acknowledged in education, some researchers indicate that the domain of metacognition is one that lacks coherence. In order to overcome this issue, it is necessary that each researcher explains what he addresses as metacognition by using his own or other people's framework of metacognition. We propose a new framework for metacognition which explains what types of metacognitive activity occurs and what types of metacognition-driven learning they cause. With this framework, it becomes possible not only to identify what types of metacognitive activity or what types of metacognition-driven learning a computer system supports but also to propose new functions that support the various types of metacognitive activity and metacognition-driven learning.

**Keywords:** Metacognition, framework, metacognition-driven learning, an abstraction operation, an instantiation operation, a modification operation

## Introduction

Metacognition is defined broadly as "cognition about cognition," and it consists of metacognitive knowledge, which is knowledge about human cognitive activities, and metacognitive activities that control cognitive-activity processes [4, 8].
Metacognition training is becoming an important issue in computer-based learning environments [2, 3, 5, 7, 10] so that metacognition is widely acknowledged as an important element for successful learning [10, 14].

However one issue that has been raised about the current situation is the difficulty of mutual understanding and sharing of achievements in metacognition research among researchers [17]. A conceivable solution to overcoming this current situation is that each researcher explains his own research by his or other's framework of metacognition. Explanation of research achievements based on a framework of metacognition enables sharing and mutual understanding of research achievements [1].

A number of models and conceptual frameworks for metacognition and self-regulated learning have already been proposed [12, 15]. We also constructed a framework [11]. Unfortunately, however, our previous framework was not successful in explaining how metacognition-driven learning happens and what types of metacognitive activity cause such learning. With the framework extended to cover metacognition-driven learning presented in this paper, it becomes possible to analyze existing metacognition training systems and identify which system supports which type of metacognition-driven learning; in addition, it enables us to propose new functions for facilitating metacognition-driven learning the systems do not support yet.

In this article, we first describe metacognition-driven learning and what types of metacognitive activity cause the learning. Then, we describe an extended framework for metacognition. Finally, based on the extended framework, we analyze Betty's Brain [2, 3] and Error Based Simulation (EBS) system [10], and we propose new functions to be added to respective systems in order to support a metacognitive activity to cause metacognition-driven learning.

## 1. Metacognitive Activities and Metacognition-Driven Learning

### *1.1 Metacognition-Driven Learning and three new types of Metacognitive Activities*

Collins and Brown claim that the simplified expressions of problem solving processes enable the learner to recognize features of the learner's own problem solving processes, and they enable students to characterize problem solving strategies in terms of abstractions such as backward reasoning [5, p7]. Abstractions can be constructed in a form that is critical to developing good metacognitive strategies [5, p17]. They also claim that students can reflect any differences between their problem solving results and the correct result, trying to understand what led to those differences [6, p.463]. Deriving abstractions about one's own problem solving process is a type of metacognitive activity because the operation makes one to reflect one's own problem solving process. We call such operation an *abstraction operation,* that is, one can lift a specific instance up to a class-level expression that it belongs to. We believe that a leaner can understand what causes the problem solving outcome, only by deriving abstractions. We believe such understanding is the key to *Metacognition-driven learning.*

Let us explain an abstraction operation and metacognition-driven learning by taking the EBS as an example [10]. EBS exhibits strange behavior when a learner draws erroneous force vectors on the blocks. If a learner draws force vectors of gravity and normal reaction forces on blocks without considering their lengths (quantity of the force) EBS exhibits that the block is buried in the ground or the block flies away in the sky. Most learners having used EBS say "When I drew the force of gravity and the normal reaction force on blocks at first time, the block flew away in the sky." It means that the learners recognize an association between the force vectors drawn on blocks and strange behavior of the blocks at an instance level. Only one learner says "I did not consider the lengths of the force vectors." In our interpretation, he could derive abstraction about his problem solving process. There might be a learner who can derive higher-level abstraction than the learner above such as "I carelessly solve a problem." Learners who can derive abstractions like those might be able to discover or understand their good metacognitive strategies that can derive their metacognitive activities such as "let us consider the lengths of the force vectors" or "let us carefully solve a problem." The discovery of metacognitive strategies is partly a kind of the *metacognition-driven learning*.

The learners who did metacognition-driven learning may use their metacognitive strategies to achieve their goals. To use them, they bring the class-level constraints down to the instance level to regulate actual cognitive activities. We call the operation an *instantiation operation*. In addition, modification of metacognitive strategies such as making a combination of metacognitive strategies is called a *modification operation*. In summary, the metacognitive activities for metacognition-driven learning that we suppose include an abstraction operation, an instantiation operation, and a modification operation in addition to observation, evaluation, selection, and execution of one's own cognitive activities.

### *1.2 Extended Metacognitive-Activity Framework*

Our previous metacognitive-activity framework is constructed based on the presumption that cognitive activities and metacognitive activities are the same but involve different target objects. We assume five basic types of cognitive activity for problem solving, i.e., observation, evaluation, selection, virtual application, and rehearsal, and considered that the environment, such as a given problem, cognitive activities of others, and products of one's own working memory (WM) serve as objects. However, only observation, evaluation, selection and performance are shown in Figure 1(a). As virtual application is included in selection, and rehearsal is concurrent execution with all cognitive activities, the two are omitted in Figure 1(a). We extended this previous framework as shown in Figure 1(b). First, we added an abstraction operation, a modification operation, and an instantiation operation to the previous metacognitive activities (arrows in Figure 1). Then, we added metacognition-driven learning driven by the added metacognitive activities. Metacognition-driven learning achieves either of class addition, class deletion (unlearning), and class modification (rectangles in Figure 1).

## 2. Analysis of Training Systems Based on the Extended Framework

We analyzed Betty's Brain system [2, 3] and EBS[10].

### *2.1 The Self-Regulated Learning: Betty's Brain*

Betty's Brain aims at acquisition of complex scientific knowledge and learning self-regulation skills by teaching a computer agent named Betty. The trigger for observing use of self-regulated learning strategies is Betty's response or Davis's advice. With Betty's

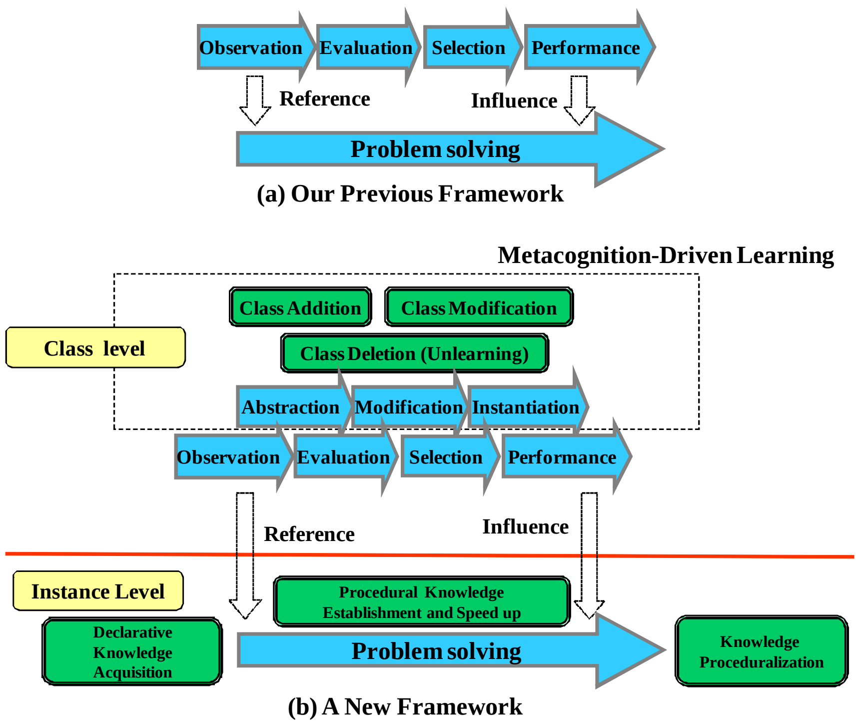


**Figure 1. An Extended Framework for Metacognition**

response, the learner reflects whether the learner has been effectively using the strategies on Betty. This reflection is an observation on the result of strategy application at the instance level and corresponds to the observation in Figure 1. Davis's advice is an explanation of how, when, and why to use each learning strategy. Davis's advice promotes to drive an instantiation operation of the strategies, but does not lead to an abstraction operation of strategy application or metacognition-driven learning.

The extended framework allows us to notice how a new function promotes an abstraction operation: a new function initially helps a leaner reflect his learning. Next, it helps him derive abstractions about his learning process. For example, suppose that, with Betty's explanation, the learner noticed an error in the cause–effect relationship in the concept map. We propose that, at that time, the learner be asked "Explain the reason why Betty misunderstood the cause–effect relationship," so that the learner is prompted to reflect on the process of Betty’s incorrect learning of the cause–effect relationship (the process of the learner's own learning process). If the learner can successfully derive abstractions about the learner's learning process as "Multiple concepts were acquired but the relationship among the concepts was not considered," metacognition-driven learning such as "when multiple concepts are acquired, consider the relationship among the concepts" can be expected so that an abstraction operation, which has not yet been supported in the Betty’s Brain, can be implemented.

### *2.2 EBS*

Our second system is the above mentioned EBS. Upon seeing an unusual behavior of blocks that EBS exhibits, a learner realizes that he has made a serious error and carefully observes the situation presented to him. By observation, a learner strongly associates the force vector drawn (forces exerted) at the block with strange behavior of the block. The interview with students after learning with EBS demonstrated this point [10]. Although EBS does not directly support an abstraction operation, we believe that the association between the forces exerted at the block and strange behavior of the block unlearns learner’s erroneous knowledge at the class level (class deletion (unlearning) in Figure 1). Evaluation experiments of EBS successfully proved this point: compared with the ordinary class, students in the EBS class were more successful in unlearning erroneous knowledge [10].

EBS does not directly support an abstraction operation, an instantiation operation, or a modification operation except unlearning. We can propose a function to be added for EBS to directly support an abstraction operation. When a learner corrects his drawn forces on the block by trial and error, the EBS system would demonstrate two kinds of his drawn forces on the screen: one does not comply with Newton theory and the other complies with it, and asks him the different forces between the two. This new function allows the learner to recognize the difference of his erroneous drawn forces and correct them. After that, the new function asks the learner “Please explain what let you draw your erroneous forces.” If the prompt allows the learner to successfully abstract his cognitive activities such as “although there are forces that act on an block, I did not consider the resultant force,” there is a possibility that the learner would be able to discover a strategy such as “if there are forces that act on an block, I have to consider the resultant force” and understand it as metacognitive strategy. If the learner was able to discover a strategy and understand it as a metacognitive strategy, he would be able to regulate his cognitive activities using the strategy.

As described above, the analysis of EBS based on the extended framework clarifies the types of unsupported metacognitive activities and serves to create new functions for supporting the types of metacognitive activity.

## 3. Conclusion

We proposed the metacognition-driven learning and the three new types of metacognitive activities. With these, we extended the previous metacognitive activity framework to a new framework. Finally, we demonstrated by examples that, based on the proposed extended metacognitive activity framework, it is possible to analyze existing metacognition training systems and explain the features and limits of the individual methods and systems using the same vocabulary, and also to add new functions and propose improvements to the systems.

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