Improving Students' Meta-cognitive Skills within Intelligent Educational Systems: A Review

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Abstract. Metacognition aims at monitoring and regulating one's thinking devoted to problem-solving processes and learning habits among others cognitive tasks. Hence, individuals engaged in better acquisition of domain knowledge achieve higher scores when they are bewaring of how to exploit their metacognitive faculties. Thus, we present a review of some models and methods with the purpose to understand what metacognition is and know how stimulate metacognitive skills. In addition, we propose a Metacognition-Driven Learning paradigm as a reference to guide the design of Intelligent Educational Systems oriented to improve students' metacognitive skills.

Keywords: Metacognition, metacognitive skills, metacognitive models, Metacognition-Driven Learning, Intelligent Educational Systems.

1 Introduction

John Flavell of Stanford University was a pioneer researcher of the metacognition field. He coined the metacognition term and set the earliest formal model for metacognition. Flavell's publications show the influence of the work achieved by Jean Piaget [1]. Such a work accounts the notion of *intentionality* to presuppose: "A kind of deliberative and goal-driven thinking that plans a sequence of actions". Later on, Flavell states the *metamemory* term to label: "The individual's skill to manage and monitor the input, storage, search and retrieval of mental contents of her own memory" [2]. Soon afterwards, Flavells defines the metacognition concept as: "In any kind of cognitive transaction with the human and the non-human environment, a variety of information processing activities may go on…" [3].

Flavell also claims: "Metacognition concerns to the active monitoring, regulation and orchestration of information processes in relation to cognitive objects on which

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they bear". In consequence, metacognition is intentional, foresighted, conscious, purposeful and devoted to fulfill a goal. However, other viewpoints argue that metacognition does not necessary evoke awareness [4, 5].

Metacognition is a cognitive faculty of human beings, whose activity is driven by a sort of metacognitive skills, such as: reflection [6], self-awareness [7], self-monitoring [8], self-regulation [9], self-assessment [10], self-management [11] and so on. They organize and supervise cognitive activities that an individual performs. Metacognitive skills hold knowledge, strategies, experience, goals and tasks [12]. They enable individual to set goals, make plans, initiate tasks, monitor the development of mental activities, estimate the likely achievement of goals, detect deviation on tasks, correct cognitive processes, and keeping track the effect of one's behavior on others.

Metacognition skills are independent of subject-domain. Although an individual holds little background, once she masters a skill, she is able to apply it across domain. Some people naturally develop metacognitive skills, but others need external advice [13]. Because metacognition plays a critical role in successful learning, it is necessary to stimulate students' metacognitive skills. So Intelligent Educational Systems (IES) should pursue a twofold objective: engage learners to be aware of their own metacognitive activity and demonstrate how students can be taught to better apply their cognitive resources by the use of metacognitive skills.

Therefore, in order to provide a useful reference to tailor effective ELS the remainder of the paper embraces the following subjects: A survey of formal models for metacognition and a review of approaches for stimulating metacognitive skills are depicted respectively in sections 2 and 3. Afterwards, we present our Metacognition-Driven Learning paradigm that holds a model and a method. Hence, a hierarchical-loop metacognitive model is outlined in section 4; whereas, a three-stage method is set in section 5. Conclusions section is devoted to describe some contributions of the proposal and identify the future work to be accomplished.

2 A Sample of Metacognitive Models

In this section we try to respond the question: How can we shape metacognition? Wherefore, by a profile of representative models we try to describe metacognition. We focus on the items, relationships, hierarchies and flows of cognitive information to identify involved components and understand their role as follows.

2.1 Essentials Metacognitive Phenomena

The "Formal Model for Metacognitive Monitoring" proposed by Favell in 1979 is a starting point to depict metacognition [12]. He claimed that: "Knowledge, experience, goals-tasks and strategies are four types of phenomena that hold some kind of relationship to support metacognitive activity" [14].

Metacognitive knowledge is a sort of phenomenon that contains individual's knowledge or beliefs about the factors that bias cognitive activities. It embraces three sorts of variables: person, task and strategy. The first variable concerns with the individual's knowledge and beliefs about himself as a thinker or learner, and what she believes about other people's thinking processes. It is split into three versions: intra-individual (i.e. assertions about the interests, propensities, aptitudes, abilities of oneself), inter-individual (i.e. comparisons between people in a relativistic manner), universal (i.e. generalizations an individual sets about learning and learners in general). The task variable heads the person in the management of a task, and provides expectations about the success that it is likely to meet. The strategy variable represents goals and criteria for selecting cognitive processes to apply in their fulfillment.

The second class of phenomena, metacognitive experiences, is a cognitive awareness that is relevant to one's thinking processes. Such a class is a stream of consciousness process in which other information, memories, or earlier experiences may be recalled as resources in the process of solving a current cognitive problem.

The metacognitive goals and tasks compound the third class of phenomena to depict the desired outcomes or objectives of a cognitive activity. It cares about comprehension, committing facts to memory, producing something, improving one's knowledge about something. The emergence in the child of awareness of the flow of time, and awareness of future time could support the ability to form metacognitive goals.

The fourth class of phenomenon corresponds to metacognitive strategies. They are ordered processes used to control one's own cognitive activities and to ensure the accomplishment of a cognitive goal. They enable a person to oversee her own learning process, plan and monitor ongoing cognitive activities, and to compare cognitive outcomes with internal or external standards.

2.2 Metacognitive Model Based on Knowledge and Regulation

Essentially, Brown acknowledges two cognitive components of metacognition: knowledge and regulation [15]. He shapes a model, where knowledge of cognition depicts activities that involve conscious reflection on ones cognitive skills and activities, and regulation of cognition concerns with self-regulatory mechanisms during an ongoing attempt to learn or solve problems. Both components are closely related, each feeding on the other recursively, although they can be easily distinguishable as follows.

Knowledge of cognition represents stable and frequently fallible information that an individual holds about her own cognitive processes. It aims individual retreats and contemplates her cognitive activities as target of thought and reflection, usually referred to as “knowing that”.

Regulation of cognition is devoted to regulate and monitor cognitive performance. It embraces a sort of processes oriented to: plan activities, select strategies, predict outcomes, undertake the solution of a problem, oversee cognitive activities, test results, qualify outcomes against criteria of efficiency and effectiveness, and reconsider alternative courses of action. These activities are relatively unstable, not necessary statable and relatively age independent (i.e. task and situation dependent) [16].

2.3 Hierarchical Metacognitive Models

There are other models that organize cognitive processes into several interrelated levels with the purpose to distinguish metacognition from cognition. One of them corresponds to the “Meta-level/object-level” model outlined by Nelson and Narens [17]. At meta-level, regulation skill is carried out to modulate cognitive activity that occurs at object-level. Cognitive activity undertakes the achievement of a mental goal or takes over the individual-external world interaction. It is accomplished at object-level. In addition, meta-level holds a cognitive model of the object-level. Such a model is structured according to specific metacognitive principles. Moreover, the meta-level monitors the object-level by bottom-up information (e.g., source monitoring in memory retrieval, error detection) that comes from the object-level. In consequence, meta-level controls the object-level by top-down information flows (e.g., resource allocation, error correction, planning, inhibitory control, conflict resolution) in order to initiate, modify or terminate cognitive actions.

Another double-level model is the "Executive Function" model set by Norman and Shallice [18]. The executive function involves the ability to monitor and control the information processing necessary to produce voluntary action. The executive function model holds an executive system at top level and a set of schemas at bottom level. The executive system contains a model of the perceptual and cognitive functions existent at the bottom level. Schemas are basic units of thought and action. They can be exogenously activated by environmental cues (e.g. automatic processes) and endogenously triggered or inhibited by input from the executive system (e.g. voluntary process). Thus, schema selection depends on perceptual information (i.e. a sensorial bottom-up flow) and attentional modulation (i.e. a control top-down flow).

A four-tier model for metacognition is the one proposed by Tobias and Everson [19]. They claim that: "Metacognition is the ability to monitor, evaluate, and make plans for one's learning". Thereby, they design a hierarchical metacognitive model to take over learning. The model is organized into four ascending dependency levels. At the bottom appears the knowledge monitoring component. It is the ability of an individual for knowing what she knows and knowing what she does not know. At second layer the evaluation learning item is found. It holds criteria for determining the degree of satisfaction achieved according to former expectancies. Selection of strategies is an element stated at third level. It represents the attempt to set or adjust the course of action according to some guidelines. At the top of the hierarchy, the planning component is allocated. It defines the path of actions to be accomplished under the strategy's criteria to carry out the pending learning goals.

The "Hierarchy Model of Skills" tailored by Kayshima and Inaba highlights a semantic net of skills to define common and particular attributes [20]. They set at the top the skill class to associate a sort of attributes to generalize the properties of any skill. At second level, two kinds of skills are found; one corresponds to motor skills (i.e. perceptual-motor skill such as type a keyboard) and the other represents cognitive skills (i.e. a skill achieved in the mind). This is split into basic cognitive skills (i.e. they fulfill cognitive activities to meet a goal. Their target is found at the outside-world of the individual) and metacognitive skills (i.e. they take over the performance of basic cognitive skills. The inner-world of the person is their target).

3 Two Sorts of Metacognitive Approaches

Once metacognition has been characterized by the collection of models earlier stated, we wonder: How can we stimulate metacognition? The answer to such a question is given by the exposition of two kinds of metacognitive approaches. One is devoted to depict metacognitive methods oriented to develop individuals' metacognitive skills. Another introduces some IES applications that stimulate metacognitive skills.

3.1 Metacognitive Methods

"ASK to THINK – TEL WHY" is a method to stimulate self-regulation skill [21]. It is a peer tutoring method that structures interaction between tutor-tutee roles, where peers exchange roles. The interaction follows a question-asking process. When an individual plays the tutor role, she only asks five types of questions to acquire and organize domain knowledge. Individuals who perform the learner role only provide answers. Thus, tutor gradually acquires the ability to make suitable questions to learners. These experiences are cognized by tutor to improve her self-regulation skill.

The "Whole-Class Discussions" is a method oriented to promote reflection skill [22]. The method encourages the discussion of a given problem between learners by the moderation of the tutor. Tutor does not show the solution to learners neither leads them to find it. She monitors the learners' discussion as input to regulate and provides suggestions to learners to regulate their own thinking. Thus, learners act to reflect their intention to communicate about their reasoning.

Other metacognitive methods are: "Kitchen Sink" set by Schonfeld [23], "Supporting Learners to Develop their Self-regulation Skill" designed by Kayashima and Inaba [24], and "Reciprocal Teaching" proposed by Palinscar and Brown [25].

3.2 Intelligent Educational Systems Oriented to Metacognition

In the IES arena there is tendency to build applications devoted to exercise students' metacognitive skills, such as scaffolding, tools to recreate learning environments and functionalities in intelligent tutoring systems (ITS). A sample of them is given next.

Ecolab is software scaffolding that aims students to improve their seeking and task selection skills [26]. Story-station is an agent-based scaffolding tool to stimulate metacognitive skills involved at writing. It uses animated agents to advice student about issues of writing [27]. Se-Coach is a ITS that provides several levels of prompting and scaffolding to progressively improve students' self-explanation skill [28].

Betty's Brain is a multi-agent environment that heads student to learn by teaching. It aims student to reflect about the domain knowledge provided to a learner agent, Betty, by evaluating its responses and explanations to quizzes and queries [29]. Collect-UML is a ITS that stimulates students to acquire collaborative skills. It accounts a collaboration model represented as a set of meta-constraints [30]. Plan Externalization is a workgroup tool that facilities the design of a problem-solving process. Where a solver sketches her plan and others monitor and question the solution [24].

4 The Model of the Metacognition-Driven Learning

We propose a Metacognition-Driven Learning paradigm to guide the design of IES. It embraces a model and a method. The former is a "hierarchical-loop metacognitive" model; whereas the later is a workflow composed by three stages. In this section, we describe the three levels of the model and a sequence of class activities.

4.1 A Hierarchical-Loop Metacognitive Model

Based on the formal metacognitive models prior introduced, we tailor a hierarchical-loop metacognitive model to identify three levels of activity, as it is sketched in

Figure 1. At the bottom of the hierarchy, the external level is allocated and the cognitive level is found in the middle tier. At the top, the metacognitive level is stated. Moreover, a loop of activities is achieved at each level and a cognitive information flow goes bottom-up and backs top-down between couples of levels [31].

At external level, the individual interacts with her outside-world, sets goals to achieve and deals with problems to be solved. She uses her motor skills to behave and socialize with others every day. The surrounding objects and the performance of her physical actions are perceived by her senses. The cognized information is an input to her basic cognitive skills. In consequence, they trigger physical actions as output.

At cognitive level, the individual uses her basic cognitive skills to achieve mental or physical goals. They are activated as loops of cognitive activities, such as: *observation* of sensory and perceptive stimuli from the outside-world, *rehearsal* to hold information needed by other cognitive activities on short-term cognitive memory, *evaluation* of external conditions, *virtual execution* of candidate cognitive activities, *selection* of the cognitive activity to be achieved through physical activities. The execution and results of cognitive activities is an input to the metacognitive skills. As a result, they control the behavior of cognitive activities as output [32].

At metacognitive level, the individual uses her metacognitive skills to assess and regulate the performance of cognitive skills and assure the accomplishment of goals. They essentially apply similar cognitive activities, as the basic cognitive skills do, but the difference is the concerned source and target. Hence, *observation* monitors the course of the activity and the results achieved at cognitive level, *rehearsal* maintains information requested by other metacognitive activities on short-term metacognitive memory, *evaluation* qualifies the activity and outcomes fulfilled at cognitive level, *virtual execution* simulates the activation of metacognitive activities, *selection* chooses the metacognitive activity to be carried out for controlling cognitive skills.

4.2 Class Cognitive Activities

Metacognition is a matter of generalization of knowledge, strategies, experiences, tasks and goals that is applied to a wide sort of purposes and issues. The acquisition, tuning and application of such metacognitive resources are fulfilled by abstraction, modification and instantiation metacognitive activities.

The abstraction focuses on key attributes of a given object or activity to shape a class of metacognitive resources. Such a class embraces conceptual items that depict pieces of knowledge, main guides of strategies, key issues gained from experiences and procedural descriptions of how to carry out a task and meet a goal.

The modification refines conceptual items of the class in order to improve its generality and usefulness. It applies three tasks to manipulate classes, such as: *addition* devoted to create a new class, *modification* oriented to update conceptual items of a given class, *deletion* aimed to unlearn conceptual items and eliminate the whole class.

The instantiation applies a given class to a current matter. So it provides specific values to the conceptual items of a class for tailoring an instance. The instance reveals the way to deal with a present object or activity based on metacognitive resources.

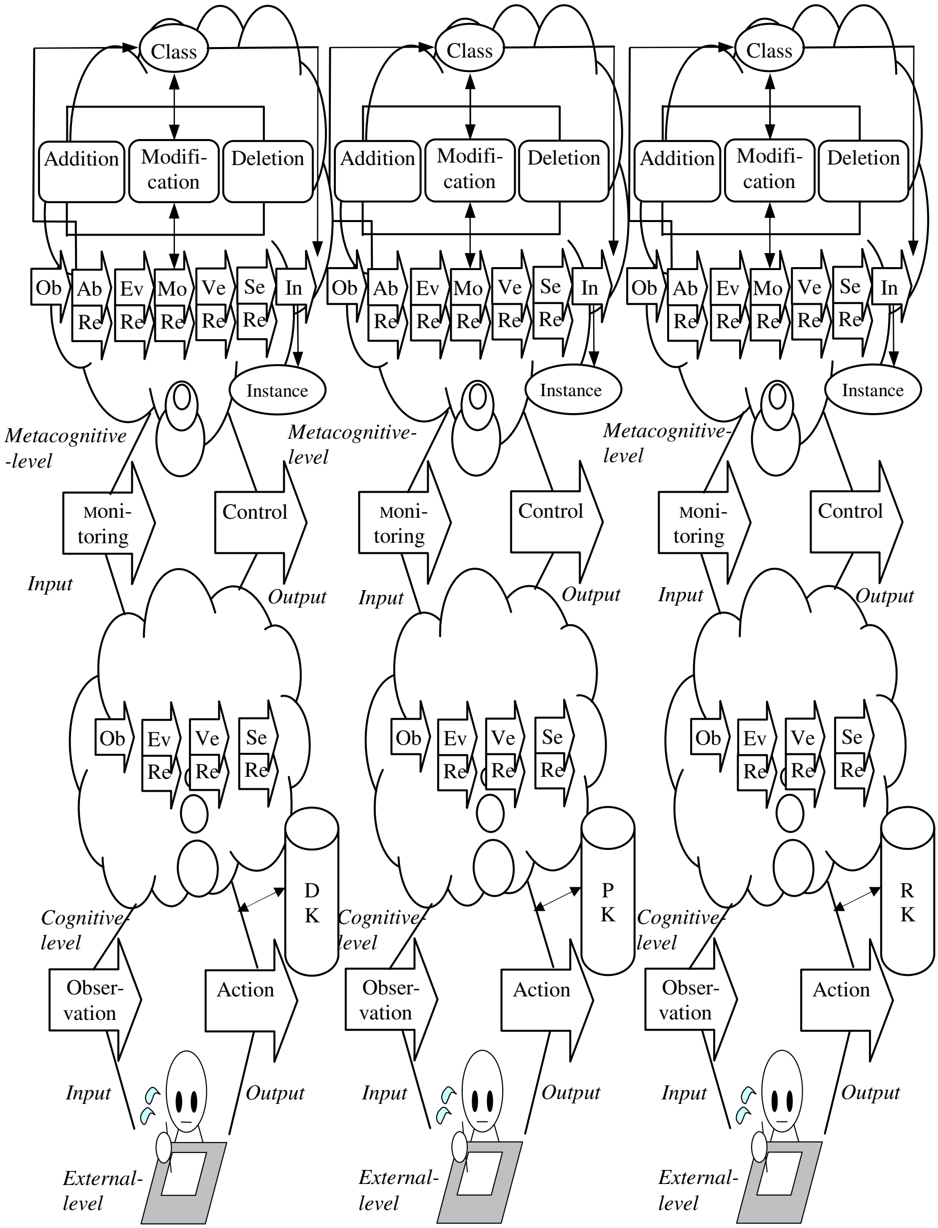

Fig. 1. Metacognitive-Driven Learning paradigm. It holds a model and a method. The model contains three levels: metacognitive, cognitive and external. The method have three stages: cognitive, associative and autonomous, Activities' id at metacognitive and cognitive levels means: *Ob*: observation; *Ab*: abstraction; *Re*: rehearsal; *Ev*: evaluation; *Mo*: modification; *Ve*: virtual execution; *In*: instantiation; *DK*: declarative knowledge; *PK*: procedural knowledge; *RK*: refined knowledge.

5 The Method of the Metacognition-Driven Learning

The Metacognition-Driven Learning paradigm also embraces a method for stimulating metacognitive skills. It follows the workflow set by Anderson [33]. As it is shown in Figure 1, the sequence begins with the cognitive stage, continues with the associative stage and ends with the autonomous stage. As soon as the individual develops the stages, she progressively acquires, evolves and extends her skills´ knowledge.

The cognitive stage enables individual to acquire knowledge by objectivism practice. The outcome is a kind of *declarative knowledge* of the skill. As a result, the individual had stated concepts that depict the nature, purpose and process of the skill.

The associative stage applies constructivism practice by problem-solving exercises. During the stage, the individual faces a diversity of problems and seeks a solution. As consequence, she gains *procedural knowledge* from the experiences.

The autonomous stage encourages the individual to deal with more domain problems of increasing complexity. Little by little, the individual is challenged to evaluate, contrast and pursue optimization of problem-solving process. During the stage, the individual's *knowledge* of the skill is gradually refined.

The Metacognitive-Driven Learning makes up a model and method into just one paradigm. Its sequence of three stages is pictured in Figure 1 from left to right. At each stage, the individual takes the corresponding lectures to produce a version of skill's knowledge. Three types of activities are concurrently performed in their corresponding level. The ascending information flow represents an input between a pair of levels; whereas, a descending one corresponds to an output [34].

6 Conclusions

In this paper we have reviewed a set of representative works to understand what metacognition is and how it can be stimulated. In addition, we have outlined a Metacognition-Driven Learning paradigm with the aim to inspire the design of IES. Our model offers a holist viewpoint to structure levels of activities and flows of information to monitor and control activities.

We acknowledge the importance of enhancing students´ learning faculties. So we assert: Individuals who are able to use their metacognitive skills increase their opportunities to accomplish educational and personal goals. As a future work, we plan to develop a computer-based prototype to implement our paradigm and develop a trial to collect empirical evidence. According to the results a new version will be outcome.

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