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Review Article

Operations of the Cognitive-Metacognitive System in Promoting Learning: A Brief Theoretical Analysis

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Metacognition helps educators develop better teaching and learning strategies, contexts, and materials. But, the development and use of good teaching and learning strategies and materials as guided by metacognition require understanding of how it promotes the efficiency of the cognitive system in learning. This article proposes a cognitive-metacognitive system that illustrates how the metacognitive system promotes the efficiency of the cognitive system based on pioneers' research on the subject (1979 to 2009). Cognitive system performs cognitive activities of knowing, understanding, applying, analyzing, synthesizing, and evaluating of cognitive inputs to reach at cognitive goals. Metacognitive system performs metacognitive activities of assisting the cognitive system to promote its efficiency. The proposed cognitive-metacognitive system enters into a six-step sequence of mental activities to process cognitive inputs (i.e., data, information, lessons, observations, problems, tasks, and other inputs) and yield cognitive outputs (i.e., actions, artifacts, and behaviors). Metacognition promotes learning by identifying and deploying appropriate and effective cognitive strategies and tools for cognitive processing and metacognitive strategies for regulating cognitive processing. This article also proposes that the effectiveness of the cognitive-metacognitive system in promoting learning depends on its ability in helping learners' generate manageable meta-level models of cognitive inputs for cognitive processing.

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Introduction

Metacognition is regarded as one of the most important tools in learning across disciplines and educational levels. Making use of this important tool in teaching and learning, nonetheless, depends on having a very clear and detailed understanding of it – which is unfortunately not the case. Researchers in the area would not come together and produce clear taxonomies of the various components of metacognition, their descriptions, applications, etc and their relations with cognition (e.g.[1]). In its three decades of existence, it can be argued that metacognition was not yet presented in a simple way to be easily and effortlessly understood and used by teachers and planners of instruction.

The defining state of affairs among researchers working in metacognition are the high degree of complaint for the lack of unifying understanding about the construct and the absence of efforts to work towards bringing a unifying understanding. For example, the first article on the journal "Metacognition and Learning" (Volume 1, pp. 3–14) calls for unified definition of metacognition and its components. However, the authors of the same article, in an effort to establish a distinction between cognition and metacognition began with a proposition that goes "...If metacognition is conceived as (knowledge of) a set of self-instructions for regulating task performance, then cognition is the vehicle of those self-instructions"[1]. "Knowledge of a set of self-instructions for regulating task performance" is cognitive. It is, in fact, procedural cognitive knowledge[2].

What constitutes metacognition in this case, the present author contends – is one's awareness in regard to one's knowledge of any learning content or material (e.g. a set of self-instructions for regulating task performance). Another statement that compounded the lack of clarity in the construct, which appeared in the same article, is related to metacognitive skills. Veenman and co-workers contend that metacognitive skills are "person's procedural knowledge for regulating one's problem-solving and learning activities"[3]. Krathwohl[2] would attest that person's procedural knowledge is cognitive. Metacognitive skill, the present author contends, is learners' ability of deploying the metacognitive system in assisting the operations of the cognitive system. In line with proposition, Brown[4] considered metacognitive skill as people's voluntary (conscious) control over their own cognitive process.

The purpose of this article is to provide a model on how the metacognitive and cognitive systems work together to facilitate learning by analyzing the works of several pioneering researchers in metacognition. First, it is helpful to provide a brief review of the construct and taxonomy of its components as background.

Metacognition and Its Components

The most commonly held definition of metacognition is the knowledge (i.e., awareness) of one's cognitive processes and the efficient use of this self-awareness to self-regulate the cognitive processes[5][4]. According to this definition, metacognition is viewed as a way of knowing about our cognitive processes and a way of deliberate and conscious control of such processes[6]. These components are usually called knowledge of cognition and regulation of cognition, respectively[7][8]. Nonetheless, Flavell[9], a pioneering researcher on the construct, classifies metacognition into metacognitive knowledge and metacognitive experience. In his later work, he described metacognition as a construct that includes knowledge of cognition and executive skills (i.e., regulatory strategies)[10]. Hence, according to the current understanding, three components – metacognitive knowledge (i.e., knowledge of cognition), metacognitive regulation (usually called self-regulation) and metacognitive experiences – are apparent[11].

Looking into the lines of research in metacognition reveals these components more clearly. There are three fairly distinct lines of inquiry related to the construct. Developmental, educational, and cognitive psychology researchers study different aspects of metacognition. They base their inquiry on distinct premises. Developmental psychology researchers study the development of metacognition in relation to various persons' variables such as age[9], novice versus expert[12], gifted versus non-gifted[13], intelligence[14], and high academic achievers versus low academic achievers[15][16]. These imply that metacognition is treated as an object of study.

Educational psychology researchers, on the other hand, explore into the roles of metacognition as a means or tool of [self-regulated] learning. Studies in this area look into the relationship between metacognition and academic achievement/performance[17], transfer of learned contents[18][19], retention of learned material[18][19], problem solving[20], and independent, self-regulated, or autonomous learning[21]. They also study how metacognition is enhanced through instruction[22]. Finally, cognitive psychology researchers examine the bases and accuracy of metacognition in memory. The studies explore into the roles of metacognitive experiences (as judgments and feelings) in monitoring cognitive states and subsequent control of cognitive processes[23][24][12]. They are narrowly confined to examining how memory processes are monitored and controlled.

Good use of metacognition as an effective tool in teaching and learning, i.e., as a tool in augmenting the cognitive system and/or complementing its limitations, depends on understanding the operation of the cognitive-metacognitive system and the role of each component of metacognition in the operation. Hence, clarifying the roles of the three components of metacognition in the operation of the cognitive-metacognitive system would help teachers and designers of instruction to choose the right learning context that would encourage learners employ appropriate metacognitive knowledge and strategies in

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learning. Consulting of the works Flavell[25][9][10] and many others after him[23][26][2][12][27][22][28][29][30][31][7][8][4][32] would help us provide the most complete description of the components of metacognition as follows.

> Metacognitive knowledge refers to individuals' knowledge (awareness) of what they know about: themselves and others as cognitive processors (i.e., knowledge of person variables), nature of tasks and ways of processing them (i.e., knowledge of task variables), and cognitive strategies (i.e., knowledge of strategy variables). Metacognitive regulation, on the other hand, refers to regulation of cognitive processes and learning experiences by assisting cognitive system in selecting and deploying a set of regulatory strategies and/or initiating regulatory activities in planning, execution, and evaluation steps of learning processes. Finally, metacognitive experiences refer to experiences that have something to do with the current, ongoing cognitive endeavor, expressed as feelings, (e.g., feeling of familiarity, difficulty, confidence, and satisfaction) and judgments (e.g., judgments of learning, solution correctness, and two tasks' similarity). Metacognitive experiences could be information-based and experience-based.

The three components and subcomponents as well as their corresponding descriptions are given in **Table** 1. The descriptions are made by assuming a task called "Understanding the Rotations of the Earth and the Sun" is at hand.

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1. Metacognitive Knowledge It refers to one's knowledge (awareness) of what s/he knows about cognitive beings, cognitive tasks, and cognitive strategies. **1.1 Knowledge of Cognitive Beings**: Refers to one's knowledge (awareness) of what s/he knows and believes of human beings as cognitive organisms. (a) *Knowledge of Self as Cognitive Being*: Knowledge of what one does and doesn't know and believe about "Rotations of the Earth and the Sun"? Knowledge of what one knows in regard to one's cognitive capacity and limitations in "Understanding the Rotations of the Earth and the Sun"? (b) *Knowledge of Others as Cognitive Beings*: Knowledge of what one does and doesn't know and believe in regard to someone's knowledge and belief or lack thereof about "Rotations of the Earth and the Sun"? Knowledge of what one knows about someone else's cognitive capacity and limits in "Understanding the Rotations of the Earth and the Sun" compared to her/him? (c) *Knowledge of* Homo sapiens *as Cognitive Beings*: Knowledge of what one does and doesn't know and believe in regard to humans' knowledge and belief or lack thereof about "Rotations of the Earth and the Sun"? **1.2 Knowledge of Cognitive Tasks**: Refers to one's knowledge (awareness) of what s/he knows about the nature of tasks, ways of dealing with the tasks, and conditions for processing them. (a) *Declarative Knowledge of Tasks*: Knowledge of what one does and doesn't know about the nature of the task "Understanding Rotations of the Earth and the Sun"? (b) *Procedural Knowledge of Tasks*: Knowledge of what one does and doesn't know about the procedures and tools needed/not needed to carry out the above task"? (c) *Conditional Knowledge of Tasks*: Knowledge of what one does and doesn't know about the conditions for using the procedures and tools in carrying out the above task"? **1.3 Knowledge of Cognitive Strategies**: Refers to one's knowledge (awareness) of what s/he knows about learning, thinking, and problem solving strategies. (a) *Knowledge of General Strategies*: Knowledge of what general cognitive strategies one does and doesn't know/master in carrying out tasks similar to "Understanding Rotations of the Earth and the Sun"? (b) *Knowledge of Specific Strategies*: Knowledge of what specific cognitive strategies one does and doesn't know/master in carrying out the above task? (c) *Knowledge of Effectiveness of Strategies*: Knowledge of what one does and doesn't know in regard to effectiveness, usefulness and limitations of the cognitive strategies s/he considers to carrying out the above task?
2. Metacognitive Regulation It refers to regulation of cognitive processes and learning experiences by assisting the cognitive system to select and deploy a set of regulatory strategies and/or initiate regulatory activities. **2.1 Regulation in Planning Cognitive Activities:** Refers to regulation of the planning of cognitive activities by selecting and deploying appropriate strategies and/or initiating regulatory activities. (a) *General Knowledge and Skills of Regulation*: Knowledge and skills of what general regulatory strategies one does and doesn't know/master in planning the execution of tasks similar to "Understanding Rotations of the Earth and the Sun"? (b) *Specific Knowledge and Skills of Regulation*: Knowledge and skills of what specific regulatory strategies one does and doesn't know/master in planning the execution of the above task? **2.2 Regulation in Executing Cognitive Activities**: Refers to regulation of the execution of cognitive activities by selecting and deploying appropriate strategies and/or regulatory activities. (a) *General Knowledge and Skills of Regulation*: Knowledge and skills of what general regulatory strategies one does and doesn't know/master in executing tasks similar to "Understanding Rotations of the Earth and the Sun"? (b) *Specific Knowledge and Skills of Regulation*: Knowledge and skills of what specific regulatory strategies one does and doesn't know/master in executing the above task? **2.3 Regulation in Evaluating Cognitive Activities**: Refers to regulation of the evaluation of cognitive activities by selecting and deploying appropriate strategies and/or initiating activities. (a) *General Knowledge and Skills of Regulation*: Knowledge and skills of what general regulatory strategies one does and doesn't know/master in evaluating cognitive tasks similar to "Understanding Rotations of the Earth and the Sun"?

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(b) *Specific Knowledge and Skills of Regulation*: Knowledge and skills of what specific regulatory strategies one does and doesn't know/master in evaluating the above task?
3. Metacognitive Experience It refers to one's feelings and judgments in regard to current, ongoing (online) cognitive endeavors. **3.1 Metacognitive Feelings**: Refers to one's reflections or inferences in regard to one's own fluency or interruptions of cognitive activities. (a) *Feelings of Familiarity*: One's feeling of familiarity or lack thereof of the topic "Rotations of the Earth and the Sun"? (b) *Feelings of Difficulty*: One's feeling of difficulty or lack thereof of understanding the topic "Rotations of the Earth and the Sun"? (c) *Feelings of Confidence*: One's feeling of confidence or lack thereof to/in mastering the learning topic "Rotations of the Earth and the Sun"? (d) *Feelings of Satisfaction*: Feeling of satisfaction or lack thereof with one's efforts and cognitive activities in learning "Rotations of the Earth and the Sun?" **3.2 Metacognitive Judgments**: Refers to one's judgments in regard to one's own cognitive endeavors based on some information and/or experiences. (a) *Judgments of Learning*: One's judgment of learning or lack thereof of the topic "Rotations of the Earth and the Sun". (b) *Judgments of Solution Correctness*: One's judgment of solution correctness or lack thereof of end-of-topic test on "Rotations of the Earth and the Sun". (c) *Judgments of Task Familiarity*: One's judgment of task familiarity or lack thereof of end-of-topic transfer test on "Rotations of the Earth and the Sun"? (d) *Judgments of Knowing*: One's judgment of knowing or lack thereof of the learning topic called "Rotations of the Earth and the Sun"? (e) *Judgments of Performance*: One's judgment of performance or lack thereof of end-of-topic test prepared to assess higher order thinking skills related to the topic "Rotations of the Earth and the Sun"?

Table 1. Components of Metacognition and Exemplified Descriptions

Control and Monitoring in Metacognition

Examination of the operations of the cognitive-metacognitive system to be presented in this article shall, therefore, be based on the understanding of metacognition and its components as presented above. Having these descriptions as a background, it is helpful to show how the operation of the cognitive-metacognitive system works. Nelson and Narens[33] suggested that the metacognitive system has two facets – the knowledge objects and operations. In the knowledge facet, metacognitive system specifies that people represent information, i.e., produce mental models at two levels – the 'object-level' and 'meta-level'. It is helpful to note that the information from which mental models are generated refers to activities, lessons, observations, problems, tasks, and other cognitive inputs. Here, there is one important question worth posing. Does the above proposition signify that people represent cognitive input at two levels simultaneously?

Regardless of the answer to this question, however, the 'object-level' representations need to be understood as mental models generated by the cognitive system alone and the 'meta-level' representations need to be understood as mental models generated the cognitive system supported by the metacognitive system. Since the term 'object-level' can be replaced by 'cognitive-level', the mental representations of information generated by the cognitive system alone can be called 'cognitive-level model' and the mental model generated with support of the metacognitive system as 'meta-level model'. The cognitive-level and the meta-level models being mental representations of the same cognitive input, their differences, the present author contends, lie on their *quality*. Whereas cognitive-level models are, relatively speaking, *crude*, the meta-level models are *refined*. Also, while cognitive-level models

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are mental representations of cognitive inputs, meta-level models are mental representations of cognitive-level models. These imply that the cognitive- and metal- level models of a given cognitive input develop subsequently.

The operations facet, likewise, is represented by two levels of dominance relations – 'monitoring' and 'control'[34][33]. According to Nelson and Narens[33], control is interpreted when the meta-level model *modifies* the cognitive-level model but not vice versa (emphasis original). The meta-level model could: change the state of processes of the cognitive system, or change the processes of the cognitive system. These produce some kind of action in the cognitive system, which could be initiation, continuation or termination of a task. Monitoring, on the other hand, is interpreted when the meta-level model *is informed* by the cognitive-level model (emphasis original), which leads to changes in the state of the meta-level model of the learning material.

Several works have been published based on these postulates until the 2000s. But many of the works have exacerbated the lack of understanding of the construct and its components to the extent that they become extraordinarily hazy for teachers and practitioners (e.g., Efklides et al.[35]; Nietfeld et al.[36]; Schraw[37]). In this case too, it is helpful to provide distinctions between cognitive-level and meta-level models on the one hand, and cognitive and metacognitive systems on the other. These distinctions help clarify how the control and monitoring systems of metacognition work – involving the systems and the models. Logically speaking, an entity or a system with monitoring role should have the ways and means of accessing all or part of the information regarding the entities or systems it monitors. Hence, monitoring role of metacognition should not be interpreted as the meta-level model being informed by the cognitive-level model as Nelson and Narens[33] postulated. It has to be rather interpreted as the cognitive-level model of a cognitive input *being accessed by* the metacognitive system from which meta-level model is generated. Similarly, controlling role of metacognition should not be interpreted as the meta-level model modifying the cognitive-level model as Nelson and Narens[33] postulated, but as the metacognitive system modifying the cognitive system.

The existence of two distinct biological systems is not implied. It is rather being claimed that there are two systems with fairly distinct inputs, processing, and outputs, i.e. cognitive and metacognitive systems running within the same biological system. The systems constitute the cognitive-metacognitive system. Learners with well-developed metacognitive capacities would have concurrently running cognitive and metacognitive systems. Therefore, as the cognitive system undertakes its activities, the metacognitive system is right there providing immediate assistance. The following paragraphs explain how.

If we begin with a given cognitive input, the following six mental processes would occur, in sequence, in the cognitive-metacognitive system. (a) The cognitive system creates a cognitive-level model of the input. (b) The cognitive-level model of the input is accessed by the metacognitive system. (c) The metacognitive system creates meta-level model of the input. (d) The metacognitive system becomes aware of the input, one's cognitive faculties, and the state of the cognitive processing of the input (i.e., monitoring). (e) The metacognitive system modifies the cognitive system (i.e., control). (f) The cognitive system processes the cognitive input to reach at cognitive goal. Whereas the output of the monitoring process is a manageable or handy meta-level model of a cognitive input and its processing, the outputs of the controlling process are cognitive strategies and tools that process the cognitive input and metacognitive strategies and tools that regulate the cognitive process.

As claimed by Schwartz and Perfect[38], control processes are, thus, decisions made by learners based on the output of the monitoring processes. Monitoring allows learners or thinkers to observe and reflect on the nature of the cognitive activity and their own cognitive processes, and informs them about the state of their cognition relative to their current goal. The control system increases the efficiency of the cognitive system by selecting and deploying cognitive strategies accompanied by metacognitive regulatory strategies.

The idea that mental models are vehicles of presenting learning materials in handy or manageable ways for cognitive processing has been entertained by proponents of the theory of situated cognition. According to the theory, cognition is considered as the processes and outcomes of interactions between learners and situations – where learners construct mental models of physical and social environments to simulate relevant aspects of the situations to be learned[39]. Attesting that mental models are not new, Seel further stated "... in cognitive psychology and similarly in educational psychology, mental models are considered qualitative mental representations which are developed by subjects on the basis of their available

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world knowledge aiming at solving problems or acquiring competence in a specific domain"[39].

The assertion that the metacognitive system has to access the cognitive-level model of an input to monitor the cognitive system implies that the metacognitive system acts consciously. But, whereas some authors claimed that control processes could be conscious or unconscious (e.g., Schwartz & Perfect[38]; Veenman et al.[14]), others present justifications that both monitoring and control are conscious processes (e.g., Koriat & Shitzer-Reichert[24]; Koriat[28]). The present author suggests that whether or not the cognitive system generates cognitive-level model consciously or unconsciously, the metacognitive system has to act consciously to access and make use of the cognitive-level model. The suggestion that the metacognitive system controls the cognitive-metacognitive operations by acting on the cognitive system – which involves the selection and deployment of cognitive strategies to affect the processes or the state of the process of one's cognitive system – would oblige one to further suggest that control is a conscious process or a subconscious one developed by past conscious processes.

Operations of the Cognitive-Metacognitive System

It is the interest of educators to establish a clear interplay of the cognitive and metacognitive systems to develop learning contexts that promote learning and instruction. Thus, it is helpful to begin with providing brief and clear descriptions of the systems. Cognitive system is a system that – through cognitive processes and actions – performs cognitive activities such as knowing, understanding, applying, analyzing, synthesizing, and evaluating[40]. Whereas inputs of the cognitive system can be data, information, lessons, observations, problems, tasks, and other cognitive inputs, its outputs are actions, artifacts, and behaviors (i.e., cognitive goal). Affective factors affect the efficiency of the works of the cognitive system through affecting its processes and actions. Likewise, the metacognitive system is a system that – through metacognitive knowledge, strategies, and experiences – performs metacognitive activities of assisting the cognitive system to promote its efficiency. Cognitive-level models of the inputs of the cognitive system represent the inputs of the metacognitive system, and meta-level models of the cognitive input, cognitive strategies identified and deployed to carry out cognitive processes, and the accompanying metacognitive regulatory strategies represent the outputs of the metacognitive system.

Cognitive-level models of the inputs of the cognitive system (e.g., data, information, lessons, observations, problems, and tasks) are mental representations, created by mental processes; namely, memorizing, thinking, learning and reasoning, using prior knowledge, problem solving, and information processing. Meta-level models of the inputs of the cognitive system, on the other hand, are representations of the cognitive-level models of those inputs. They are created by considering variables of the inputs, the cognitive strategies needed to process the inputs, one's faculties to process the inputs, and one's feelings and judgments in relation to the nature and pursuance of processing the inputs and their outcomes.

Now, let us consider an example – sorting plants of a given school compound into groups – to look into the operations of the cognitive-metacognitive system and roles of the three components of metacognition in assisting the cognitive system. 'Sorting plants of given school compound into groups' represents a cognitive input (i.e. a task, a lesson, or a problem). Whether the task is given to a primary school child or a seasoned plant taxonomist, the learning process has to pass through six steps to reach at cognitive output or cognitive goal if the metacognitive system is in play. In other words, the cognitive-metacognitive operating system needs to pass through six steps to help one reach at cognitive goal *effectively*. The steps are:

- Step 1: *Cognitive-Level Model of the Task*: Learners (thinkers) generate a model of the task at hand at the cognitive-level.
- Step 2: *Metacognitive Awareness of the Cognitive-Level Model of the Task*: The metacognitive system accesses the cognitive-level model of the task.
- Step 3: *Meta-Level Model of the Task:* Learners' metacognitive knowledge, feelings, and judgments are applied to generate meta-level model of the [accessed] cognitive-level model of the task.
- Step 4: *Metacognitive Awareness of Task, Cognitive Faculties, and Processes*: Meta-level model of the task makes learners become aware of the characteristics of the task, their cognitive faculties, and state of their cognitive processing to tackle the task.
- Step 5: *Selection and Deployment of Cognitive Strategies*: Learners employ metacognitive knowledge, judgments, and feelings to select and deploy cognitive strategies to carry out cognitive task.

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- Step 6: *Execution of the Task to Achieve Cognitive Goal*: Learners carry out the cognitive task, supported by metacognitive regulatory strategies, and demonstrate the required behavior, perform the required action, and/or produce the required artifact, i.e. cognitive goal.

Note that whereas the cognitive-level model of the task would involve grouping of the plants as: All Plants = Group '?' + Group '?' + ... + Group '?'; the meta-level model would involve grouping of the plants as: All Plants + Criterion *x* = Group *x1* + Group *x2* + ... + Group *xn*; All Plants + Criterion *y* = Group *y1* + Group *y2* + ... + Group *yn*; or All Plants + Criterion *z* = Group *z1* + Group *z2* + ... + Group *zn*; where *x*, *y*, and *z* could be vegetative structure, vascular tissue, and leaf arrangement, respectively. In this task, 'grouping' is the activity that would lead to the development of a cognitive-model, i.e. *grouping of the plants*. However, the grouping shall have meaning when and if one or another criterion is employed. The metacognitive system accesses the cognitive-model of the task (i.e., its input) and applies metacognitive knowledge, feelings, and judgments and generates meta-level model, i.e., *criterion-based grouping of the plants*. In this regard, unlike the crude cognitive-level model, the refined meta-level model makes the learner aware of the possibility of having several groupings based on various criteria. Vascular tissues, vegetative structures, and flower structures can serve as criteria. At this stage, learners become aware of the characteristics of the task, their cognitive faculties, and the state of their cognitive processing in relation to the task. This awareness helps learners deploy effective cognitive strategies – assisted by their metacognitive knowledge, judgments, and feelings – to carry out the task. In the course of carrying out the task, metacognitive regulatory strategies will be employed in the planning, execution, and evaluation steps of the cognitive activity and its outcome.

It is also helpful to consider a second example with reading task and look into how the cognitive-metacognitive system works. For this purpose, let us consider reading Stephen Hawking's 'A Briefer History of Time' for understanding. 'Reading for understanding of A Briefer History of Time' represents a cognitive input (i.e., a reading task). It could be given to theoretical physicist or general booklover. Whereas the cognitive-level model of the task is "reading the book to understand its contents", the meta-level model is "reading the book by using higher order thinking (HOT) strategies to understand its contents". 'Reading' is the activity that leads to the development of a cognitive-model of the task, i.e., *reading of A Briefer History of Time*. The metacognitive system accesses the cognitive-model of the task and applies metacognitive knowledge, feelings, and judgments and generates meta-level model, i.e., *HOT strategies-assisted reading of A Briefer History of Time*. The meta-level model of the task makes the reader aware that understanding of the text shall require the use of HOT strategies (e.g., application of prior knowledge, concept mapping, summarizing, analyses, synthesis, evaluation, inference, prediction, and hypothesis). Here, it is important to note that HOT strategies, also known as critical thinking strategies, are not metacognitive strategies, as Dwyer et al.[41] claimed. They are cognitive strategies. Learners' abilities, experiences, knowledge, and skills in *identifying* and *deploying* appropriate HOT strategies are metacognitive, whereas the abilities, experiences, knowledge, and skills of processing of learning materials using HOT strategies are cognitive. Readers, thus, carry out the reading task by applying HOT strategies, where metacognitive knowledge, judgments, and feelings are employed in identifying and deploying appropriate HOT strategies. In the course of reading, metacognitive regulation will be employed in identifying and deploying sets of regulatory strategies and activities during the planning (pre-reading), monitoring (reading), and evaluation (post-reading) steps[18].

Finally, let us consider a third example on mathematical problem solving of linear equation – compute 3x + 2 = 5. 'Computing 3x + 2 = 5' represents a cognitive input (i.e., a mathematical task or problem). The cognitive-level model of the task is "computing 3x + 2 = 5" and the meta-level model of the task is "algebraic properties-assisted computing of 3x + 2 = 5". 'Computing' is the activity that leads to the development of a crude cognitive-model of the task, i.e., *computing 3x + 2 = 5*. The metacognitive system accesses the cognitive-model of the task and applies metacognitive knowledge, feelings, and judgments and generates a refined meta-level model, i.e., *algebraic properties-assisted computing of 3x + 2 = 5*. The meta-level model of the task makes the problem solver aware that solving of the problem shall require the use of algebraic properties; namely, property of additive inverse [i.e. 3x + 2 (– 2) = 5 + (– 2)], property of zero [i.e. 3x = 3], property of multiplicative inverse [i.e. ⅓(3x) = ⅓(3)], and property of 1[i.e. 1x = 1, then x = 1]. Problem solvers, thus, carry out the task assisted by their metacognitive knowledge, judgments, and feelings in selecting and deploying appropriate mathematical formulas and propositions. In the course of computing 3x + 2 = 5, metacognitive regulatory strategies will be

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employed during planning (e.g., establishing what is known and what is not), executing (e.g., computing what is required), and evaluation (e.g., checking, verifying for correctness) steps of the cognitive activity and its outcome.

As the cognitive-metacognitive system keeps operating to facilitate learning or knowing, it will be regulated by the monitoring and control systems of metacognition. In the above examples, the metacognitive system accesses the cognitive-level models of the task at Step 2 and generates meta-level model of the task at Step 3. The meta-level model of the task at Step 3 helps learners become aware of the task, their cognitive faculties, and processes at Step 4 (metacognitive monitoring). This awareness elicits the control system to take command. The control system, endowed with information generated as the result of meta-level model of the task and person variables at Step 4, controls the selection and deployment of cognitive strategies at Step 5 in one way or another (metacognitive control).

Here, it is not implied that the operation of cognitive-metacognitive system is always linear. It would also be important to note that the operation of the cognitive-metacognitive system cannot always be described as a cyclical processes as argued by Koriat and Shitzer-Reichert[24] and Nelson and Narens[33]. The cognitive task at Step 6 may serve as a cognitive input at Step 1 so that the process will be repeated in case learners fail to reach at their cognitive goals. In this case, the processes can be represented as cyclical. Note also that the cognitive goal achieved at Step 6 may or may not serve as a new cognitive input for initiating a new cognitive-metacognitive operation to run. In both cases, it is apparent that the cognitive-metacognitive system operates linearly.

Apparently, Step 4 and Step 5 represent the metacognitive monitoring and metacognitive control, respectively. Hence, in the process of monitoring, metacognitive knowledge, feelings, and judgments are employed. As metacognition knowledge and judgments are applied in the process of control, feelings may only influence the choice of cognitive strategies. In Step 6, where selected and deployed cognitive strategies are employed to process the task, metacognitive regulation plays the regulatory role during the planning, execution, and evaluation steps of the process and the outcome of the task. The generalized framework of the cognitive-metacognitive operation system is given below.

- Step 1: *Cognitive-Level Models of Cognitive Inputs*: Learners (thinkers) generate models of the cognitive inputs at hand at the cognitive-level.
- Step 2: *Metacognitive Awareness of the Cognitive-Level Model of Cognitive Inputs*: The metacognitive system accesses the cognitive-level models of the cognitive inputs.
- Step 3: *Meta-Level Models of the Cognitive Inputs:* Learners' metacognitive knowledge, feelings, and judgments are applied to generate meta-level models of the [accessed cognitive-level models] of the cognitive inputs.
- Step 4: *Metacognitive Awareness of Cognitive Inputs, Faculties, and Processes*: Meta-level models of the cognitive inputs make learners become aware of the characteristics of the cognitive inputs, of the learners' cognitive faculties, and state of their cognitive processing to process the cognitive inputs.
- Step 5: *Selection and Deployment of Cognitive Strategies*: Learners employ metacognitive knowledge, judgments, and feelings to select and deploy cognitive strategies to process the cognitive inputs.
- Step 6: *Processing of the Cognitive Inputs to Achieve Cognitive Goal*: Learners process the cognitive inputs, supported by metacognitive regulatory strategies, and produce the required cognitive outputs or cognitive goals (i.e., actions, artifacts, and behaviors).

At this juncture, it is important to ascertain that the metacognitive monitoring of the cognitive-metacognitive operation system and the cognitive monitoring of the cognitive system are not one and the same. In other words, the metacognitive monitoring addressed in the works of Nelson and Narens[33] and revised in this article, and the one addressed in the works of Brown[4] and Desoete[42] are not the same. Unfortunately, the monitoring process that is thought to be evident during the execution of a cognitive task is treated as metacognitive by many researchers working on metacognition (e.g., Nietfeld et al.[36]; Pieschl[43]). In fact, not only the monitoring of cognitive processing but also the planning for cognitive endeavor and the evaluation of cognitive processes and outcomes are regarded as metacognitive (e.g., Desoete[42]). Planning of a certain task, monitoring of its execution, and evaluation of cognitive processes and their outcomes are purely cognitive (e.g., Manlove et al.[44]). What represent metacognitive in these cases are the: (a) awareness of the characteristics of tasks and one's cognitive faculties (i.e. metacognitive knowledge), and (b) identification and deployment of appropriate information, strategies, and tools based on that

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awareness required in the planning, monitoring, and evaluation of the cognitive endeavor and its outcomes (i.e., metacognitive regulation).

Conclusion

The generalized framework of the operations of the cognitive-metacognitive system passes through six steps to promote learning. The framework clearly shows the roles of the three components of metacognition in promoting the efficiency of the cognitive system, thus learning. It has also clarified how the metacognitive monitoring and metacognitive control systems play their roles. Nonetheless, it is quite apparent that the operations are somewhat abstract for teachers and practitioners to deal with and make use of metacognition. Critical examination of the steps of the cognitive-metacognitive system reveals that the metacognitive system carries out its role of augmenting and complementing the cognitive system by: (a) generating refined and manageable meta-level models of cognitive inputs for cognitive processing; (b) identifying and deploying appropriate and effective strategies and tools of cognitive processing, and (c) identifying and deploying regulatory strategies and/or initiating regulatory activities to regulate cognitive processing. Previous works in metacognition have extensively established the role of the construct in identifying and deploying appropriate and effective strategies and tools of cognitive processing, and deploying regulatory strategies and/or initiating regulatory activities during planning, execution, and evaluation steps of cognitive endeavors.

The present work has tried to clarify the relations of the cognitive and metacognitive systems in processing cognitive inputs to reach at cognitive goals. It demonstrated that the effectiveness of the cognitive-metacognitive system in promoting cognitive processing, thus learning, depends primarily on the ability of one's metacognitive system in generating refined meta-level models of cognitive inputs. Where meta-level models of cognitive inputs can be generated, the cognitive processing of the inputs and the metacognitive regulation of their executions, the present author contends, depend on the knowledge and experiences of learners in deploying appropriate and effective strategies and tools of cognitive processing as well as in deploying appropriate and effective metacognitive regulatory strategies during planning, execution, and evaluation steps of the cognitive processing. Therefore, it is fair to recommend that teachers and other practitioners – along educational levels and across disciplines – who attempt to make use of metacognition in instruction have to focus on helping their students to be capable of: (a) generating refined meta-level models of cognitive inputs; (b) identifying and deploying appropriate and effective cognitive strategies and tools, and (c) identifying and deploying regulatory strategies and/or initiating regulatory activities.

Notes

Running head: Cognitive-metacognitive system

Type of Research: Theoretical article.

Statements and Declarations

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Conflicts of Interest

The author declares no competing interest.

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