Chapter 3
A Conceptual Model of the Metacognitive Activity

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Abstract This chapter makes a call for contributing to shape a theoretical and well sounded baseline concerning metacognition. It begins recognizing the fuzzy boundaries of the metacognition field and tailors a profile through a wide collection of related works. Particularly, this research focuses on an essential subject: metacognition models. Thus, a sample of proposals for describing the nature, components, and performance of the metacognition is summarized, and a proposal called Conceptual Model of the Metacognitive Activity (CMMA) is introduced. The CMMA is a conceptual model that depicts the metacognitive activity with the purpose of providing a functional view of how metacognition interacts with object-oriented cognition. Such a model takes into account basic aspects of neurology and biology sciences. Additionally, the autopoiesis property is considered to describe the autonomy and performance of the metacognition. Moreover, an analysis of metacognitive models is outlined and a comparison between them and the CMMA is made in order to shape an overall idea of what metacognition is, and the contribution of the CMMA. In this way, valuable topics are provided to encourage research oriented to build the metacognition basis.

Keywords Metacognition · Metacognition model · Metacognitive activity · Autopoiesis · Conceptual model of the Metacognitive Activity

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Abbreviations

AS	Autopoietic system
AO	Autopoietic organization
CMMA	Conceptual Model of the Metacognitive Activity
FOC	First-order cognition
LS	Living system
MS	Mechanistic system
NNS	Neuronal nervous system
SR	Self-regulation
SRL	Self-regulated learning
SWOT	Strengths, weaknesses, opportunities, and threats

3.1 Introduction

Metacognition, as a mental phenomenon that happens in the brain of human beings as well some species of animals [1], has been a research subject of cognitive developmental psychology. Although, metacognition basically means: *Cognition about cognition* or knowing about knowing [2], it concerns a variety of epistemological processes. Papaleontiou-Louca qualifies metacognition as: A kind of "second-order cognition" to highlight: thinking about thinking, knowing about knowing, regulating about regulation, and so on [3]. She infers: If "first-order cognition" (FOC) concerns understanding, memorizing, and so forth then, metacognition implies being aware of one's own comprehension, memory… Thus, diverse cognitions about cognitions might be named: metacomprehension, metamemory… with metacognition remaining the superordinate term.

Even though the essential concept given to the metacognition term is quite simple, its broad meaning and nature have been qualified as "fuzzy" [4]. In this regard, Veenman claims: One of problems with metacognition is the "fuzziness" of the concept and its constituents, as well as the proliferation of terminologies and disagreement about the metacognition ingredients and their interrelationships [5]. Furthermore, Zohar and Dori assert: "The 'fuzziness' in the metacognition definitions makes difficult to discuss several studies together in an integrated and clear way [6]. Moreover, Whitebread et al. [7] observe: "…metacognitive skillfulness is a rather fuzzy concept. It can be considered as a person's propensity to use these "basic skills" in everyday situations…".

Efklides and Misailidi [8] complain that: "…the distinction between cognition and metacognition is often hard to be made, and the diversity of metacognitive phenomena suggests that there is no single mechanism that can explain them all. Acevedo and Aleven [9] claim: "…there is a great need for theoretical clarity, including better definitions and descriptions of the metacognition components. Beran et al. [10] explain why they called their book "Foundations of

Metacognition": "Given that the term metacognition has acquired several different meanings in literature, a general definition of the term is no longer feasible".

This chapter is an essay on how the metacognitive community can contribute to develop a formal, holistic, and systemic theoretical baseline to ground metacognition. In pursuit of such a call, this chapter offers a conceptual view of the metacognition field that focuses on its background and development, as well as models that depict metacognition, including one that proposes sketching the metacognitive activity. So, the remaining of the chapter is organized as follows: In the second section the background and a sample of metacognition facets are outlined. In the third section several works explain the nature, composition, and activity of the metacognition. In the fourth section a conceptual model to sketch the metacognitive activity is introduced. The aim is to consider essential neuronal and biological aspects of the metacognitive activity. In the fifth section a discussion of the described models is given to sketch an integral view of the metacognition. The last section identifies strengths, weaknesses, opportunities, and threats (SWOT) of the metacognition, as well as the future work to be carried out to ground CMMA.

3.2 A Glance at Metacognition

In order to highlight essential elements to be considered for designing an integral baseline for the metacognition field, a conceptual view is outlined in this section. Thus, prior to recalling the appearance of the metacognition term, some research that makes up its roots is stated. Afterwards, a series of works published since the statement of the metacognition term up to the present is provided. Later on, several collections of works concerning different metacognition facets are identified to shape the nature of the field. Finally, several publications that unveil two of the main metacognitive actors are introduced, one for children and the other for nonhuman beings.

3.2.1 Previous Works

The metacognition historical roots are deep because they lie in works such as: "Principles of Psychology" published by William James in 1890 [11], the study on memory and the feeling-of-knowing experience made by Hart [12], and the Piaget School, where Flavell [13] made an incursion and contributed with his book "The Developmental Psychology of Jean Piaget" published in 1963.

However, the study of metacognition achieved widespread prominence in the 1970s through the research fulfilled on developmental changes in children's cognition about memory, understanding, communication, and problem solving by Tulving and Madigan [14], Flavell [15], Fischhoff [16], Brown [17], Wellman [18], Lachman [19], and other scientists.

3.2.2 The Birth of a Research Line

In 1976, Flavell coined the *metacognition* term to entitle his paper: "Metacognitive aspects of problem solving" [20]. In such a work, he provides a concept to show what metacognition is: "Any kind of cognitive transaction with the human or non-human environment, a variety of information processing activities may go on. Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in service of some concrete goal or objective".

Originally, Flavell recognized that metacognition consists of both monitoring and regulation aspects. In order to characterize such a viewpoint, Flavell [21] tailored a Formal Model of Metacognitive Monitoring in 1979. His model embraces four classes of phenomena: metacognitive knowledge, metacognitive experiences, tasks or goals, and strategies or activities. In addition, the interrelationships between these phenomena are drawn to explain how they interact to monitor and regulate cognitive activity.

In that moment a research line was born in the field of developmental and cognitive psychology, where scientists of diverse disciplines contribute to extend the theory, baseline, methods, and applications as is summarized in the followings two subsections.

3.2.3 A Chronicle of Metacognition Research Development

With the purpose of recognizing the evolution of the metacognition field, a sample of related works is introduced in this subsection. The works are organized according to the decade of their publication to reveal how the metacognition labor has evolved since the term was coined up to the present.

Once the metacognition term emerged, many partisans of the developmental psychology, cognitive sciences, neural sciences, pedagogy, education, and computer sciences contributed to extended the former achievements of the 1970s. For instance, during the 1980s a sort of relevant works were oriented to: study comprehension monitoring [22], cognitive knowledge and executive control [23], learning, remembering, and understanding [24], performance [25], metacognitive skills [26], reading comprehension [27], strategies [28], motivation [29], and cooperative learning [30].

As for the 1990s, the metacognition research enhanced their lines and explored diverse subjects, such as: instruction [31], self-esteem [32], metamemory [33], metacognition models [34], metacognitive judgments [35], development of metacognition in children [36], frontal lobe supports to metacognitive activity [37], metacognitive theories [38], implicit memory [39], and prefrontal cortex supports to control and monitor memory processes [40].

Concerning the present century, an explosion of works concerning metacognition has been published; particularly books, edited books, specialized journals, conferences, and societies, such as: Metacognition: Process, Function… [41], Thinking and Seeing Visual Metacognition… [42], …Self-reflective Consciousness [43], Handbook of Metamemory and Memory [44], Metacognition [45], New science of Learning Cognition… [46], Trends and Prospects in Metacognition… [47], Metareasoning… [48], Metacognition in Science Education [49], Foundations of Metacognition [50], …Handbook of Metacognition… [51], Cognitive Development (since 1986) [52], Journal of Cognitive Neuroscience (since 1989) [53], Trends in Cognitive Sciences journal [54], Journal of Cognition and Development [55], Metacognition and Learning journal (since 1997) [56], Journal of Applied Research in Memory and Cognition [57], International Conference on Metacognition [58], International Association for Metacognition [59].

3.2.4 A Conceptual Shape of the Metacognition Through Its Works

In order to sketch an image of the metacognition, several of its facets are instantiated through a collection of recent works. The traits considered to make up the metacognition shape are the following: disciplines involved in the study, related paradigms, metasubjects, metacognitive facets, self-skills, and support to cognitive processes.

Some disciplines that study metacognition are the following: cognitive psychology [60], developmental psychology [61], educational psychology [62], neuroscience [63], cognitive neuroscience [64], science of learning [46], cognitive sciences [65], science education [49], autonomous artificial life form [66], memory [67] (e.g., amnesic [68], blank in the mind [69]), mental health [70], social psychology [71], social sciences [72], self-regulation (SR) [73], and computer-assisted learning [74].

A sample of work lines that make an explicit reference, or at least implicit in some sense, to metacognition as a "peer", "similar", "related", or "subordinate" construct, are the following: affect [4], cognitive processing [5], self-regulated learning (SRL) [75], executive control [76], critical thinking [77], theory of mind [78, 79], unawareness and uncertainty [80], cognitive load [81], and motivation [82].

The research in metacognition often demands a specialized study of a given subject that is labeled with the prefix "meta" to depict a kind of relationship, collaboration, or subordination such as: meta-metacognition [83], metacomprehension [84], metastrategic knowledge [85], meta-affect and meta-affective (compound term to adjective skill, experience, and knowledge) [86, 87], metamemory [67–69, 88], metarepresentation [89], meta-analysis [90], and meta-attention [91].

In addition, several functions, methods, strategies and techniques have been qualified by the adjective “metacognitive” to highlight its particular nature, such as: strategies [92], accuracy [93], judgments [94], prompts [95], instruction [96], tools [96, 97], inquiry [98], behavior [99], feelings [100], measures [101], scaffolding [102], and feedback [103].

Essentially, knowledge [104], regulation [104, 105], and experiences [106] have been considered the main “components” of the metacognition. However, some works recognize others components or functionalities, such as: skills [107, 108], control [109], monitoring [110, 111], reflection [112], and awareness [113].

Metacognition is involved with the reflective property of its components and other constructs to emphasize that the subject is aware and responsible for the performance of his/her mental activity, such as: metacognitive self-regulation [114, 115], self-esteem [115], self-efficacy [115, 116], self-monitoring [117, 118], self-confidence [118], self-explaining [102, 119], self-knowledge [120], self-perceived [121], self-correction [122], self-assessment [123], and self-management [123].

In spite of many works that relate metacognition with learning [124] and knowledge acquisition [125], metacognition is also involved in essential cognitive functions, such as: reading [126], understanding [127], questioning [128], pronunciation [129], spelling [130], decision-making [131], problem-solving [132], help-seeking [133], collaboration (e.g., co-regulation in learning) [134], and reasoning [135].

3.2.5 Metacognition Research on Children and Animals

Most of the metacognition research is oriented to young and adult people, who are involved in formal settings and long-life learning. However, some scientists are interested in exploring how metacognition is manifested in children and non-human beings. So, this subsection is reserved to highlight a sample of both research targets.

Metacognition is intricately linked to the human mind, including cognitive control, self-awareness, and consciousness. For this reason, it is acknowledged as one of the humans’ most sophisticated cognitive capacities, and it is widely accepted that humans are capable of metacognitive processing. Thus, a question is raised: When and how metacognition emerges and is developed? In order to respond to these questions, a collection of works provides an answer that asserts: metacognition evolves naturally (conscious and non-conscious) in informal and formal settings.

Some of the works that study metacognition in childhood are the following: Allwood [94] explores metacognitive judgments in children of 8–9-year-olds and 12–13-year-olds; Whitebread et al. [7] examine a broad variety of metacognition studies in different ranges of young children; Lyons and Ghetti [136] summarize different studies of metacognition in early childhood from 12 to 18 month old babies and from 3 to 5 years old preschool children; Misailidi [79] pursues to bridge the gap between metacognition and theory of mind based on a series of studies made with young children.

More related works about children metacognition are presented as follows: Renkl et al. [119] measure self-confidence and academic achievements in Primary-school children, while Kolić-Vehovec et al. [137] report developmental trends in metacognition and reading comprehension reached by children during elementary and high school (9–17 years) in Croatia; Csíkos and Steklács [138] highlight a similar research in Hungary with 10–11 years old children, whereas Sodian et al. [139] study metacognition in infants and young children. Esken [140] unveils forms of metacognition in children and Roebers et al. [121] examine associations between executive functioning, metacognition, and self-perceived competence in first grade children.

Other interesting works are introduced as follows: Kloo and Rohwer [141] compare the development of earlier and later forms of metacognitive abilities and Bryce and Whitebread [142] inquiry: whether developmental changes in children aged 5–7 years, reflect quantitative or qualitative improvements, and how metacognitive skills change with age and task-specific ability.

In addition, Krebs and Roebers [143] examine the influence of retrieval processes on 9–10 and 11–12 years old children's metacognitive monitoring and controlling; whilst, Barfurth et al. [144] examine metacognition in children and adolescents to consider the link between childhood giftedness and adult expertise, as well as understanding ways very able children and adults think and solve problems.

Historically, according to Morgan [145]: Homo sapiens alone were regarded as metacognitive, while animals were considered to have little by way of mental lives, and they were considered much more bound in their behavior to the stimuli that they encountered and the outcomes that they experienced [146]. Thus, a skepticism posture is placed on those who study non-human beings if claims of animal behavior should be considered as the result of metacognitive processes. A sample of works related to metacognition in animals is introduced as follows:

Beran et al. [146] offer evidence that counters that belief and some theoretical objections against the possibility that monkeys' performances reflect metacognitive abilities. Couchman et al. [147] reveal evidence for animal metaminds; Crystal [148] highlights several models of metacognition in animals; Fujita et al. [149] make the question: are birds metacognitive?; Call [150] seeks information in animals; Carruthers and Ritchie [151] study how metacognition emerges before demonstrations of affect and uncertainty in animals.

3.3 A Sample of Models to Describe Metacognition

A second subject worthy to be taken into account for setting a theoretical baseline for the metacognition is the theoretical models. A model represents a conceptual viewpoint that describes the nature, components, and the way they interact in order to explain the metacognitive phenomenon. Therefore, a survey of fifteen works that characterize the metacognition is stated in this section.

3.3.1 Classic Models of the Metacognition

Research in metacognition is grounded on a wide variety of theoretical models, which provide essential concepts to describe its nature. Some of them are briefly described to highlight relevant attributes of the metacognition.

- Flavell's Metacognitive Monitoring Model: identifies four phenomena involved in metacognitive monitoring: knowledge, experiences, goals-tasks, strategies [21, 152]. Where, knowledge represents facts and beliefs that the individual holds about the factors that bias cognitive activities. Knowledge is characterized as person, task, and strategies variables. As for experiences, they are subjective internal responses of an individual to his/her cognitive performance. With respect to goals-tasks, they depict the results to be achieved by a task; whereas strategies are ordered processes set to control one's own cognitive activities and to assert that a cognitive goal has been fulfilled.
- Brown's [153] Knowledge and Regulation of Cognition Model: reveals two closely related categories: knowledge of cognition and regulation of cognition. The former means "*knowing that*" and represents activities that involve conscious reflection on ones cognitive abilities and activities. The later corresponds to activities triggered by self-regulatory mechanisms during an ongoing attempt to learn or solve problems. Such activities are unstable.
- Nelson and Narens's [154] Hierarchical Model: splits cognitive process into *meta-level* and *object-level*. The former sketches a cognitive model of the latter, which is updated as a result of the monitoring flow coming from the object-level. The meta-level reacts to such stimuli by producing control flows oriented to initiate, alter, or terminate mental actions being achieved at object-level.
- Norman and Shallice's [155] Executive-Object Model: embraces two levels named *executive system* and *instance*. The first depicts a view of the perceptual and cognitive functions existent at the instance level; whilst the second contains schemas that are basic units of action and thought. The model asserts the executive system modulates the instance level schemas according to an individual's intentions.
- Shimamura's [156] model: is based on the model proposed by Nelson and Narens [154], and Norman and Shallice [155] to map the meta-level and the object-level onto a hierarchical brain structure. Where posterior cortex supports object level to carry out task performance and prefrontal cortex performs the meta-level that is conceptualized as both monitoring and controlling the object level.

3.3.2 Declarative and Procedural Models of the Metacognition

Besides the "classic" models of metacognition, there are additional models of metacognitive skills that can be typified as either describing components or scheduling the processes involved in metacognitive behavior regardless of timing.

Descriptive Models of the Metacognition. Descriptive models highlight components, facets, and functionalities of the metacognition according to a particular viewpoint. In addition, a kind of conceptual, functional, or hierarchical relationship is linked in order to explain how they are organized and interrelated. A sample of this category is briefly presented as follows.

- Kuhn's [157] model: depicts metacognition as: "Any cognition that has cognition…as its object". It encompasses three components: metacognitive knowing (i.e., refers to one's base of declarative knowledge), metastrategic knowing (i.e., involves procedural knowledge), and epistemological knowing (i.e., individual's broader understanding of what knowledge and knowing are in general).
- Alexander and Schwanenflugel's [158] model: identifies three components of metacognition: declarative metacognitive knowledge (i.e., individual's knowledge about the contents of the mind), cognitive monitoring (i.e., individual's ability to read one's own mental states), and regulation of strategies (i.e., ability to strategically use metacognitive knowledge to achieve goals).
- Tobias and Everson's [159] Componential Model: considers monitoring prior learning as a prerequisite for metacognitive process. The model focuses on the ability to monitor, evaluate learning, select strategies, and make plans for one's learning, as well as the control of these processes. The knowledge monitoring is the ability to know: what you know and knowing what you do not know.
- Schraw et al. [84] framework: sketches a hierarchy to split metacomprehension into metacognition and metamemory. Because metacognition refers to knowledge about cognition and cognitive processes, it recognizes them as its essential components, which are also respectively named metacognitive knowledge and metacognitive skills. Where, the former holds three sorts of knowledge: declarative, procedural, and conditional. Whilst, the latter considers two additional skills (information management and debugging) to the classical ones (planning, monitoring, and evaluation).
- Zohar's [85] Metastrategic Knowledge Model: reveals general knowledge about higher-order thinking strategies. It maps the traits of the models proposed by Flavell [21, 152], Schraw [84], and Kuhn [157] prior stated. Where metastrategic knowledge corresponds to three kinds of knowledge about: persons, tasks, and strategies.
- Efklides's [4] model: defines two functions of the metacognition: monitoring and control. The first is manifested by metacognitive knowledge and experiences; whilst the second is expressed by metacognitive skills. The metacognitive knowledge is associated to facets: ideas, beliefs, theories of goals,

task, person, cognitive function… Metacognitive experiences concerns with the facets: feelings of familiarity, difficulty, knowing… and judgments of learning, estimate of effect… Metacognitive skills are related to the facets: conscious for effort and time allocation.

Procedural Models of the Metacognition. Procedural models characterize metacognition as a sequence of stages or processes, which evolves during the time the individual matures. Some of these models are outlined next:

- Veenman's [160] model: extends the model of Nelson and Narens [154] to depict a dynamic bidirectional flow. Where metacognition is seen as both bottom-up and top-down processes. As for the former, anomalies in task performance trigger monitoring activities, which in turn activate control processes on the meta-level. Whereas for the latter, apart from being triggered by task errors, the top-down process is also triggered as an acquired program of self-instructions, whenever the individual is faced with performing a task he/she is familiar with a certain extent. Such a program of self-instructions could be represented by a production system of condition-action rules [161].
- Zelazo conscious awareness model: traces an information processing account through the next stages: (1) at birth, children reveal minimal consciousness because they are aware only of the input stimuli; (2) around the first year, infants unveil recursive consciousness due to they are able to bring back to mind stimuli which are no longer in the environment; (3) around the second year, children are self-conscious as they are accustomed to reflect about the stimuli brought back to their mind; (4) during the proceeding years additional levels of conscious awareness are reached as children progress through further iterative recursions, bringing to mind and reflecting upon the contents of their mental activity from lower levels of consciousness [136, 162].
- Flavell's awareness of uncertainty model: considers children deal with uncertainty through four stages: (1) at birth, babies may not have any experience of uncertainty; (2) young children may have subjective experiences of uncertainty, but fail to be consciously aware of it; (3) children may be consciously aware of the subjective experience of uncertainty, but may not attribute it as such; (4) later, children are consciously aware of their subjective experiences of uncertainty and recognize them as uncertainty [136, 163].
- Efklides's [164] metacognitive and affective model of self-regulated learning: joins metacognition and motivation/affect as two levels of functioning in SRL, *person* and *task x person*. At the first level, person interactions between trait-like characteristics (e.g., cognitive ability, metacognitive knowledge and skills, self-concept, perceptions of control, attitudes, emotions, and motivation in the form of expectancy-value beliefs and achievement goal orientation) are supposed to happen and such person traits guide top-down SR. At the task *x* person level (i.e., the level at which SRL events occur) metacognitive experiences (e.g., feeling of difficulty) and online affective states play a major role in task motivation and bottom-up self-regulation. The stimuli represented by a cognitive task activate person and task *x* person levels, as well as reciprocal relationships between

them and their respective components. This means, person traits interact with each other at person level; whereas at task *x* person level, reciprocal relationships between cognition and metacognition–affect, as well as metacognition–affect and SR of affect/effort are triggered.

3.4 A Conceptual Model of the Metacognitive Activity

In order to participate in grounding the metacognition basis, a Conceptual Model of the Metacognitive Activity (CMMA) is proposed in this section. The CMMA includes concepts of the neurology and biology inspired in [165–169]. They provide a theoretical context of neurological structures and biological systems that support the development of cognition, and specifically metacognition. Thus, diverse concepts, premises, and hypothesis are stated to describe the nature of cognition and metacognition.

3.4.1 A View of the Nervous System

Cognitive activity is immanent to living beings. Daily, the *nervous system* of human beings performs cognitive activity to fulfill mental and physical tasks (e.g., thinking, eating…), besides automatic and routine tasks (e.g., breathing, sleeping…). Therefore, the cognitive activity, and more specifically the metacognitive activity, is a daily process of the nervous system.

Multi-cellular animals, such as human beings, have a neuronal nervous system (NNS); whereas unicellular living systems have a molecular nervous system. NNS is organized as a *closed network of neurons* that tailors changing activity relationships. The NNS exists in structural intersection with a larger system, the *organism*, and at the *sensory* and *effector* areas that are used to interact in a medium that is a dynamic totality. Based on the work achieved by Maturana, some operational consequences concerning the manner that the nervous system is constituted and several properties of the NNS are outlined in this section [165–169].

Organism and NNS exist operationally in different non intersecting domains. The organism operates in the domain in which the living system (LS) exists. The NNS operates in the domain in which it is found as a closed neuronal network of changing relations of activities. The interrelation between both domains occurs at the sensory and effector items where organism and NNS are in structural intersection.

The NNS does not interact with the medium, neither act on representations of the medium. Its structure is not fixed; it continuously changes due to the following reasons: (1) the structure of the NNS follows a path of change that is contingent to the flow of the interactions of the organism in the realization and conservation

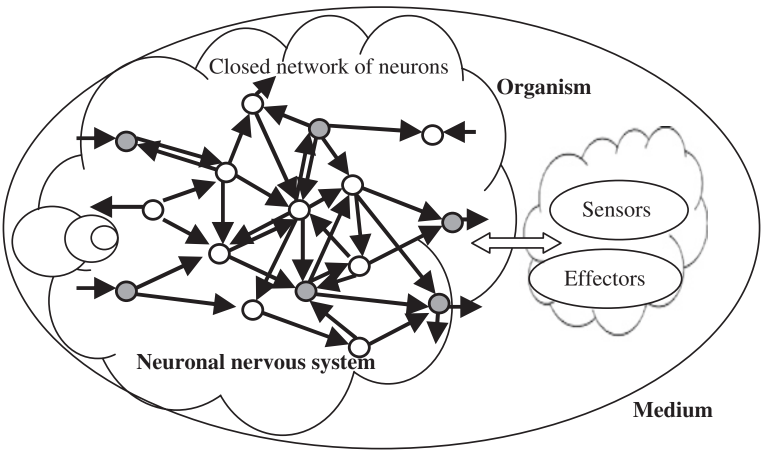


Fig. 3.1 A conceptual view of the neuronal nervous system according to the CMMA

of its life; (2) the structural changes triggered in neuronal items that intersect with internal and external sensory/effectors of the organism as a result of the organism interactions in the external medium; (3) by structural changes triggered in the neuronal items by hormones secreted by the organism endocrine cells; (4) by recursive structural changes triggered in its neuronal components as a result of their participation in its operation as a closed network of changing activity relationships.

The NNS intersects structurally with the sensors and effectors of the latter's sensory and effector surfaces. So, the sensors and effectors of a multi-cellular organism have a dual character and operate both as components of the organism and the NNS. As regards the former, sensors and effectors operate in the interactions of the organism in its existence domain as its sensors and its effectors. For the latter, sensors and effectors operate in their closed dynamics of changing activity relationships, as well as other neuronal elements. A conceptual view of the NNS is drawn in Fig. 3.1 to illustrate the CMMA.

3.4.2 A View of the Biological Context

Human and non-human beings are biological LS, whose cognitive and metacognitive activities are fulfilled through neuronal structures and neuronal activity. Neurons are cells that establish synaptic connections to shape networks of neurons. The neuronal structures facilitate the interchange of chemical and electrical flows as a way to perform neuronal activity. Thus, in order to complement the CMMA baseline, it is pertinent to take into account a biological view to consider metacognition as a LS, specifically an *autopoietic system* (AS), based on the following concepts:

- LS: it is a structure determined system, whose structure defines how the LS is made at any instant. All that happens to the LS at any instant depends on its structure. Any agent impinging on the LS only triggers structural changes determined in it [165]. So a LS is a kind of molecular machine that operates as closed networks of molecular productions. The molecules produced through their interactions generate the same molecular network that produced them, specifying at any instant its extension. Such a phenomenon reveals a recursive property.
- Living organization: is a property to support the belief that all LS must share a common organization. A living organization can only be characterized unambiguously by specifying the network of interactions of components which constitute the LS as a whole, that is, as a "*unity*". Varela et al. [166]. inquiry: "What is the necessary and sufficient organization for a given LS to be a living unity?"
- Unity: is treated from two views: (1) as an analyzable whole endowed with constitutive properties which define it as a unity; (2) as a complex system that is realized as a whole through its components and their mutual relationships. Where a complex system is defined as a unity by: The relationships between its components (which realize the system as a whole) and its properties, which determine the way the unity is defined [166].
- Classes of unities: they are LS determined by the same organization in spite of having different kinds of components, as long as these components have the properties which realize the required relationships. Some classes of unities are labeled as *mechanistic systems* (MS) because their organization is specifiable only in terms of relationships between processes generated by the interactions of their components. This is the case of LS whose living organization is considered to be a MS.
- MS: is a system whose components' properties are capable of satisfying certain relationships that determine the unity of the interactions and transformations of these components. It means the system under study only behaves as it does because all its components contribute. So a mechanistic viewpoint necessarily needs a decomposition of the system into components and their interrelations [167]. There are some MS defined as unities by a specific organization called *autopoietic organization* (AO). Such MS is different from others in the sense the product of its operation as a system is necessarily always the system itself. If the network of processes that constitutes this kind of MS is disrupted, the system disintegrates.
- AO: is defined as a unity by a network of productions of components which satisfies two constrains: (1) components recursively participate in the same network of productions of components that produced them; (2) tailor the network of productions as a unity in the space in which the components exist. This is the case of a cell, which is a network of chemical reactions that produce molecules that realize the cell; and such reactions interact and recursively participate in the same network of reactions which produced them [166].
- AS: is a mechanistic system that exhibits the AO. Biological evidence shows that LS belong to the class of AS [168]. The LS is a molecular AS open to the flow of matter and energy. The AS is a LS closed in its states dynamics

in the sense that it is alive only while all its structural changes conserve their autopoiesis [169]. The AS holds an *autonomy* property of an AO, where the realization of the AO is the product of its operation. As long as an AS exists, its organization is invariant. If the network of productions of components which defines the organization is disrupted, the unity disintegrates. So an AS has a domain in which it compensates perturbations by the realization of its autopoiesis, and it remains a unity.

3.4.3 Nature of the Cognition

Besides the neurological and biological essentials, the CMMA also considers the nature of the cognition. In this section a series of concepts is stated to provide key definitions of several constructs. In addition, the learning ability is chosen to provide an example of the conceptual view of cognition, which is similar to Fig. 3.1.

Essential Concepts about Cognition. The brain is the seat of cognition. Cognition literally means: "to know". Cognition has to do with how a person perceives, understands, and behaves in the world. Cognition claims the acquisition, development, and exploitation of a wide sort of knowledge and cognitive activities.

As for knowledge, it can be seen as memories formed from the manipulation and assimilation of raw input (i.e., information perceived via our senses of sight, hearing, taste, touch, and smell), as well as the result of our daily cognitive activity (e.g., thoughts, reasoning, recalls, learning, mental experiences, cognitive outcomes…).

A large part of cognition involves the organization of our knowledge into associations or categories. These might range from facts (e.g., things one might find in a place) to beliefs (e.g., suppositions about how some people behave). Simple symbols (e.g., dollar currency $) are used to group more complex learned associations such as those between noses, lips, eyes, and smiles. Using knowledge to direct and adapt action towards goals is the foundation of the *cognitive activity*.

In regards cognitive activity, it represents the manifestation of cognition achieved in the brain. People perform cognitive activity to fulfill nearly every human action, from the simplest task to the most complex. Cognitive activity is embodied into *cognitive abilities* to guide their organization, practice and control to accomplish specific cognitive purposes. For instance, answering the phone involves at least: perception (hearing the ring tone), decision making (answering or not), motor skill (lifting the receiver), language skills (talking and understanding language), and social skills (interpreting tone of voice and interacting properly with another human being).

C*ognitive abilities* (e.g., brain or mental functions) are neural processes, which are represented and performed in the brain. They constitute the ownership of the means to achieve something, or the faculty for practicing a natural or mastered skill needed to do something. They are based on specific constellations of brain structures (e.g., memory skills rely mainly on parts of the temporal lobes, next to the temples, and parts of the frontal lobes, behind the forehead). Cognitive abilities are neural processes, which are represented and performed in the brain. The cognitive abilities are overlapping and not always clearly distinct. Keeping this in mind, the concept of cognition is broken down into some of its more widely cognitive abilities, such as: perception, attention, reasoning, speaking, planning, learning…

Representation of Cognition according to the CMMA. In order to show how the CMMA characterizes the cognition, the *learning* ability is picked to apply the neurological and biological previously stated baseline. Therefore, a series of concepts and a graphical representation are outlined as follows.

Learning is a ordinary cognitive ability that demands a dynamic structure determined by neural networks. It triggers the interchange of information, depicted as chemical and electrical flows, with the NNS, the sensors and effectors, and the organism. The mechanism of *synaptic plasticity*, stated in the Hebbian theory, reveals that an increase in synaptic efficacy arises from the pre-synaptic cell's repeated and persistent stimulation of the postsynaptic cell [170]. This mechanism claims the adaptation of neurons in the brain during learning. The theory claims: "Cells that fire together, wire together". It attempts to depict associative learning, in which simultaneous activation of cells leads to pronounced increases in synaptic strength between those cells.

According to the CMMA, learning can be conceptually characterized as is shown in Fig. 3.2. The model presents a *closed network of components* such as cognitive activities and knowledge. They are sketched as a network of black and white nodes to respectively depict cognitive activities and knowledge. They hold relationships for transferring stimuli between them. The direct relationships are drawn as thin links, the recursive flows are pictured as thick links, and the feedback flows are depicted as dotted lines. The arrowheads of the links reveal direct sense of stimuli transference.

The closed network of components is organized as a structure determined system oriented to accomplish *ordinary cognitive* processes. The processes progressively master new and current knowledge, as well as new and current cognitive skills. The structure determined system operates and evolves throughout several cycles.

During a given cycle, several kinds of outcomes are produced, such as: new or transformed components (e.g., cognitive *activities* and *knowledge*), ordinary cognitive *processes*, new knowledge, and *skills*, where these products are respectively identified in Fig. 3.2 by *A*, *K*, *P*, and *S* ovals, which appear inside the smallest cloud. In consequence, feedback and recursive flows transfer the outcomes as inputs to trigger the next cycle. In this way, the closed network evolves like a spiral along the time. The closed network and the set of outcomes hold bidirectional flows to transfer stimuli with the sensors and effectors. They are the mediators between the NNS, shaped as the largest cloud in Fig. 3.2, and the organism, sketched as an oval.

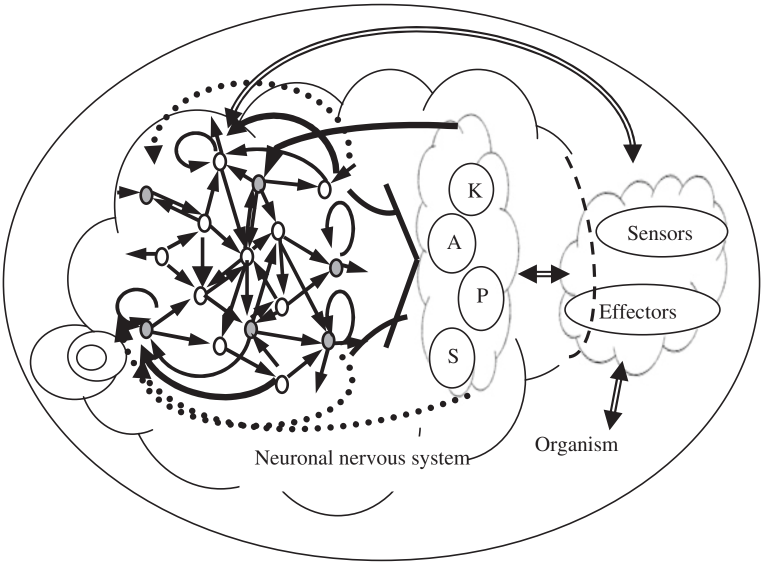


Fig. 3.2 A conceptual view of the learning cognitive ability according to the CMMA

3.4.4 Nature of the Metacognition

Once the neurological, biological, and cognitive baseline has been stated, it is time to explain how the CMMA represents the metacognition. Firstly, key concepts are defined to shape a theoretical reference. Later, a sample of how to depict the metacognition to support learning is outlined in accordance with the previous representations.

Essential Concepts about Metacognition. Most of the cognitive activity, such as all the cognitive abilities introduced in the prior subsection, is considered as FOC due to people daily practicing to accomplish a mental or a physical goal (e.g., acquiring new knowledge, watching an advertisement…), and to interact with others and their environment (e.g., speaking with somebody…). However, there is a category of cognitive activity that pursues to trigger, supervise, evaluate, exert, and take over FOC activity, such a category is called: *metacognition*. Essentially, *metacognition is cognition* and aims at gaining, stimulating, and practicing several kinds of knowledge and activities, which are labeled as *metacognitive*.

For instance, *metacognitive knowledge* is knowledge of cognition. It refers to what individuals know about cognition and their own cognition strengths and weaknesses. Moreover, it accounts for experiences, strategies, and conditions under what some kind of activity is preferred more than others. Furthermore, it shapes a model of the current FOC activity, which is the target of the metacognitive activity.

As regards *metacognitive activity*, it is also the manifestation of neural processes and is supported by brain structures (e.g., metacognitive monitoring and control have been viewed as a function of the prefrontal cortex, which monitors sensory signals from other cortical regions and through feedback loops implements control [44]). Metacognitive activity reveals the practice of metacognitive strategies, processes and skills currently performed in the brain.

Metacognitive activity is guided by *metacognitive strategies*. Such strategies are sequential processes devoted to monitor and control FOC activities and to ensure the fulfillment of a cognitive goal. The organization of metacognitive activities, processes, and strategies to accomplish a metacognitive purpose is named "metacognitive skill".

The repertory of *metacognitive skills* is quite extensive, and nearly includes all the ordinary cognitive abilities. Furthermore, the prefix *self* produces a special version of the former skill term. For instance, metacognitive regulation is the monitoring of one's cognition and includes planning activities, awareness of comprehension and task performance, and evaluation of the efficacy of monitoring processes and strategies [171]. Whereas, metacognitive self-regulation is defined as: self-regulated thoughts, feelings, and behaviors that are oriented to attaining goals. It follows three stages: forethought, performance, and self-reflection.

Characterization of Metacognition according to the CMMA. Based on the prior neurological, biological, and cognitive concepts and practices of representation, this subsection explains how the CMMA characterizes metacognitive activity.

Metacognitive activity is considered a neurological, biological, and LS. The view provides an idea of the nature of the metacognition and how the activity is accomplished according to the support of the NNS. Based on the arguments presented in Sect. 3.4.2, it infers that metacognition is a kind of AS, illustrated in Fig. 3.3.

The meaning of the representation stated by the CMMA for the metacognition in Fig. 3.3 takes into account the prior description given for the common shapes (e.g., direct, feedback, and recursive relations are respectively sketched through thin, thick, and dotted lines…) in Fig. 3.2. In addition, the following observations are pointed out:

The square depicts the *organism*; the oval sketches the *NNS*; the big cloud at the left shows the *metacognition*; the middle cloud corresponds to the *FOC activities*; the smallest cloud concerns the *sensor* and *effectors* items.

The metacognitive image holds three elements: a *closed neuronal network* is illustrated at the left (e.g., where the black and white nodes represent metacognitive activities and metacognitive knowledge respectively); at the center is shown a cloud with ovals to label metacognitive *processes* (e.g., *P1*, *P2*…); at the right, the wide arrows show metacognitive *strategies* (e.g., *S1*, *S2*…).

As for the FOC picture, it shapes a *closed neuronal network* (e.g., where the black and white nodes depict cognitive activities and cognitive knowledge); whilst several cognitive activities labeled as *A1*, *A2*… are outlined like ovals at the right.

Metacognition is performed by the structure and activity of the NNS. The NNS structures are characterized as a closed network of neuronal elements that

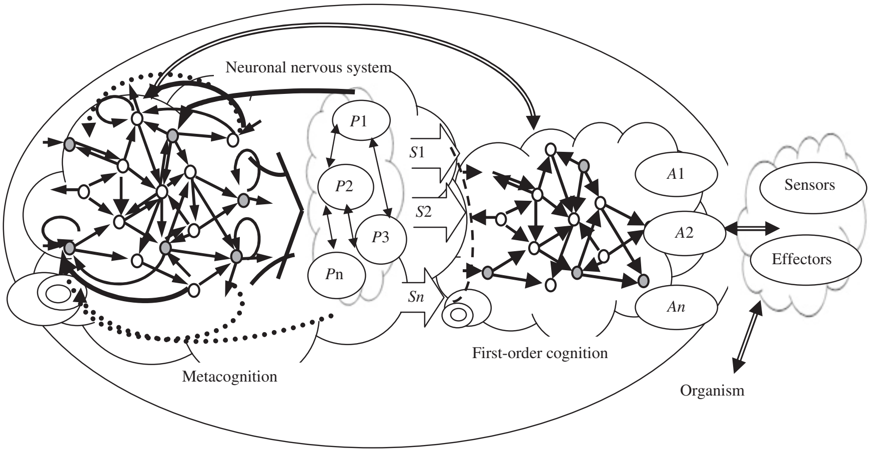


Fig. 3.3 A conceptual view of the metacognition according to the CMMA

establishes changing activities relationships. The NNS provides a mediated structural intersection with the organism by means of the participation of FOC activities. They transfer and receive communication with sensory and effector items. Such items make up the structural intersection between organism and NNS. The organism operates in the domain in which human being exists; whereas, the metacognition operates in the domain in which it exists as a closed neuronal network of changing activity relationships.

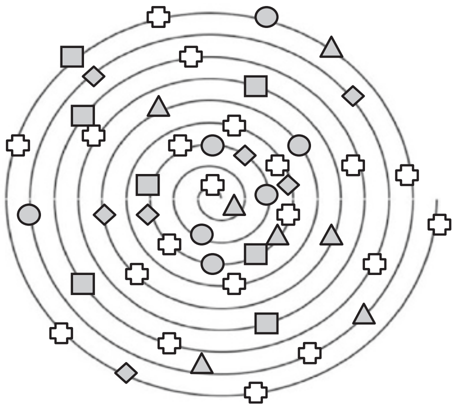
Metacognition, as a manifestation of cognition with a given purpose, monitors and controls the performance of FOC activities. It is considered a kind of *LS* that holds a living organization. Metacognition is thought as a closed network of interactions of basic components (e.g., metacognitive knowledge and metacognitive activities).

The closed network establishes direct, feedback, and recursive relationships between the basic components. As a result, several kinds of metacognitive processes are fulfilled. In this manner, different sorts of metacognitive skills are realized. Both, processes and skills hold feedback relationships with each other, and also with the basic components. This dynamic schema constitutes the metacognition as a whole LS that is, a *unity*!

Metacognition is a kind of mechanistic system whose organization is specifiable in terms of relationships between metacognitive processes generated by the interactions of their components. As a consequence, the product of the metacognition operation as a system is *always metacognition*!

In this sense, metacognition holds an *AO* due to it being defined as a *unity* by a network of productions of basic components organized as a structure determined system. The metacognitive components recursively participate in the same network of productions of components that produced them (i.e., new metacognitive

Fig. 3.4 A graphical evolution of the metacognition according to the CMMA



knowledge and metacognitive activities are produced) and realize the network of productions as a unity in the space in which the components exist.

Based on the stated arguments, metacognition is an *AS*. Therefore, it is a system closed in its states dynamics. In the sense that it is alive only while all its structural changes are structural changes that conserve their autopoiesis.

Metacognition, as a kind of cognitive activity, operates and evolves in a spiral way, as is pictured in Fig. 3.4. During a given cycle, different outcomes are produced (e.g., new or transformed metacognitive activities, knowledge, processes, and skills, and new or altered FOC activities and abilities) as well as feedback and recursive flows are triggered.

For instance, *monitoring* is one of the triggered skills (e.g., it is pictured through gray circles in Fig. 3.4). In addition, other functionalities are concurrently or sequentially fulfilled (e.g., they are sketched as the cross symbol in Fig. 3.4). One of them corresponds to the *regulation*, which is drawn as a gray square in Fig. 3.4. As a result of the activation of several functionalities, *awareness* (e.g., it is shaped as a diamond) is developed to get consciousness of the FOC activities being fulfilled to deploy the FOC ability of learning. In order to support the execution of those functionalities *knowledge*, illustrated by a triangle in Fig. 3.4, is retrieved. In reciprocity new knowledge is added, and current knowledge is updated and deleted.

3.5 Analysis of Metacognition Models

Once a series of classic, descriptive, and dynamic models of metacognition, as well as the propose CMMA, have been described, a comparative analysis of the traits they represent is outlined in this section. The aim is to provide another conceptual element for contributing to develop a holistic baseline of the metacognition field.

3.5.1 A Comparative Profile of Metacognition Models

In order to facilitate the comparison of the fifteen models stated in Sect. 3.3, a profile is tailored to characterize their main traits. Such a profile is presented in Tables 3.1, 3.2 and 3.3; where the left column identifies the attributes and the remaining unveil the characteristics of their respective model.

3.5.2 An Analysis of the Metacognition Models

Based on the description given for the fifteen models in Sect. 3.3 and in Tables 3.1, 3.2 and 3.3; an analysis of their nature is stated in this subsection. The purpose is to summarize the attributes used to model metacognition. In addition, a comparison of such pattern of traits versus the CMMA is also achieved. The aim is to continue the provision of conceptual items to shape a theoretical baseline for the metacognition arena.

With relation to the sample of classic metacognition models, psychology and neurology are the disciplines taken into account. The object to study is metacognition and some facets. Most of the models only identify and depict facets; whilst a few also explain how the components interact. The relationship between components is diverse without a prevalent type. Also the main components are heterogeneus; some are metacognitive facets, others are conceptual components or brain areas. The subcomponents are also diverse (e.g., variables, facets, and conceptual items).

Table 3.1 A comparative profile of classic metacognitive models

Trait	Flavel [152]	Brown [152]	Nelson and Narens [154]	Norman and Shallice [155]	Shimamura [156]
Baseline	Psychology	Psychology	Neurology	Neurology	Neurology
Target	Monitoring	Metacognition	Metacognition	Attention–perception	Metacognition
Nature	Descriptive	Descriptive	Descriptive–dynamic	Descriptive–dynamic	Descriptive
Relationship	Relational	Hierarchical	• Bottom-up	• Bottom-up	• Spatial
Components	• Knowledge	• Knowledge	• Meta-level	• Executive system	• Prefrontal cortex
	• Experiences	• Regulation	• Object-level	• Instance–level	• Posterior cortex
	• Goals-tasks				
	• Strategies				
Sub-components	Variables:	• Person	• Monitor	• Schemas	• Monitoring
	• Person	• Task	• Object model		• Control
	• Task		• Control		
	• Strategies				

Table 3.2 A comparative profile of descriptive metacognitive models

Traits	Kuhn [157]	Alexander and Schwanenflugel [158]	Tobias and Everson [159]	Schraw et al. [84]	Zohar [85]	Efklides [4]
Baseline	Psychology	Psychology	Psychology	Psychology	Psychology	Psychology
Target	Metacognition	Metacognition	Monitoring	Metacomprehension	Metastrategic knowledge	Metacognition
Nature	Descriptive	Descriptive	Descriptive–dynamic	Descriptive	Descriptive	Descriptive–dynamic
Relationship	Hierarchical	Hierarchical	Bottom-up	Hierarchical	Hierarchical	Hierarchical
Components	Metacognitive: • Knowing • Metastrategic • Epistemological	• Declarative knowledge • Cognitive monitoring • Regulation of strategies	• Monitoring • Evaluation • Selection • Make plans • Control	• Metacognition • Metamemory	Knowledge: • Persons • Tasks • Strategies	• Monitoring • Control
Sub-components				Knowledge: • Declarative • Procedural • Conditional Skills: • Information management • Debugging • Planning • Monitoring • Evaluation		Monitoring: • Knowledge • Experiences Control: • Skills

Table 3.3 A comparative profile of procedural metacognitive models

Traits	Veenman [160]	Zelazo [136, 162]	Flavell [136, 163]	Efklides [164]
Baseline	Psychology	Psychology	Psychology	Psychology
Target	Metacognition	Conscious–awareness	Awareness –uncertainty	Metacognition, affection, SRL
Nature	Dynamic	Evolutionary	Evolutionary	Dynamic
Relationship	• Bottom-up	Sequential	Sequential	• Bottom-up
	• Top-down			• Top-down
Components	• Meta-level	• Conscious	• Awareness	• Person
	• Obeject-level	• Awareness	• Uncertainty	• Task *x* person
Sub-components	• Task performance			Person:
				• Cognitive ability, self-concept
	• Monitoring			• Metacognitive knowledge–skills
				• Perceptions of control, attitudes
	• Control			• Emotions, and motivation
				Task *x* person:
	• Program of self-instructions			• Metacognitive experiences
				• Online affective states
Sequence or stages	1. Task performance	1. At birth: minimal consciousness	1. At birth: non experience of uncertainty	1. Task activates person and task *x* person
	2. Monitoring			
	3. Control	2. 1st year: recursive consciousness	2. Young children: unaware of subjective uncertain experiences	2. Reciprocal relationships between person and task *x* person
	4. Program of self-instructions	3. 2nd year: self-consciousness		
		4. Proceeding years: conscious awareness	3. Children: lightly aware of uncertain experiences	3. Reciprocal relationships between person facets
			4. Later: children are aware of uncertain experiences	4. Later: reciprocal relationships between task *x* person facets
				• Cognition/metacognition–affect
				• Metacognition–affect/SR of affect–effort

In resume, the classic models offer different viewpoints to depict metacognition and consider its components. Thus, they lack an evident pattern to characterize them.

Concerning the descriptive metacognition models, psychology is the only discipline; whilst besides the metacognition several facets are the object to model. Most of the models are only descriptive and a pair includes dynamic aspects. The typical relationship between components is hierarchical. Diverse kinds of metacognitive knowledge are prevalent, as well as monitoring and control. Also, as subcomponents, they appear as the most considered. As a summary, the sample of descriptive models offers an essential pattern of traits that suggest a common study target, as well as a viewpoint to characterize metacognition.

In another vein, procedural models of metacognition are characterized as founded on psychology, considering metacognition and awareness as their target. The models are expressed as dynamic and evolutionary; while bottom-up and sequential are the classic relationships between components. Awareness and abstract concepts are the typical components; whereas metacognitive facets are the typical subcomponents. Two views are considered to explain how metacognition is achieved: one corresponds to conceptual interaction of metacognitive components; whilst the other to the natural maturing of the individual whose awareness is increasing whilst the person grows up. As a synopsis, procedural models are psychological representations of metacognition, and particularly awareness. They focus on conceptual workflows or chronological maturity of the individual.

Finally, the CMMA is contrasted against the three types of models to highlight its contribution to the metacognition field. The CMMA offers a different perspective: It takes into account the biological viewpoint to characterize metacognition. It depicts a cyclical workflow, where components of a closed network interact through direct, feedback, and recursive relationships. Moreover, conceptual relationships are established between metacognitive components, processes, and strategies, as well as FOC activities. Thus, instead of specifying particular metacognitive facets, the CMMA includes all the possible manifestations of metacognition. The sequence of stages is characterized as a closed and permanent AS.

3.6 Conclusions

This work is an attempt to deal with the fuzziness of the metacognition concept and the lack of a theoretical and well sounded baseline for the metacognition field. It provides some reasons that reveal the complexity of the concept through a revision of research in the metacognition field and models oriented to describe metacognition. Furthermore, a conceptual model, named CMMA, to characterize the metacognitive activity has been introduced. Moreover, an analysis of the surveyed models is made and a comparison between them and the CMMA is fulfilled to highlight the contribution of the proposed model. Thus, this work concludes with a summary of its achievements, a series of observations about the metacognition field through a brief SWOT analysis, and the identification of future work to ground the CMMA.

An Account of the Achievements. The starting point tackled in the work concerns the fuzziness of the metacognition concept; particularly, its real meaning, nature, traits, performance, application, scope as well as its interrelationship with other constructs are just a sample of issues. Such a claim has been illustrated by the exposition of related works that highlight the background, appearance of the term, development, profile, and two polemic study targets of the metacognition.

As a second step towards an integral foundation, a survey of works oriented to shape three kinds of metacognition models has been outlined. The idea is to show the traits of the metacognition, its components, structure, and way of interaction. The sample includes well-known classic, descriptive, and procedural models in order to provide diverse perspectives of modeling and study.

The third step has contributed by means of introducing a new model, named CMMA, to tailor a holistic metacognition ground. It offers a conceptual shape of the metacognition activity from the neurological and biological perspectives. The proposed model conceives metacognition as an AS, whose components are able to produce new ones as well as interact with FOC activity. The metacognition activity is shaped as a closed network of components that interact to fulfill metacognitive processes and develop metacognitive skills oriented to monitor and regulate ordinary cognitive activities such as learning.

A fourth step to provide conceptual elements for the metacognition basis corresponds to an analysis of the traits that characterize the sample of surveyed works. In addition, a comparison of the models attributes against the ones of the CMMA has been made to reveal the contributions of the proposed model.

A SWOT Analysis of the Metacognition Arena. With the purpose of describing the status of the metacognition field, some strengths, weaknesses, opportunities, and threats are presented as part of the conclusions. As for the *strengths*, metacognition is based on well-sounded disciplines: psychology and neurology. Mature research in progress is being carried out. Scientists of diverse fields have been working on metacognition and contributing to extend the scope. New ways to improve knowledge acquisition in formal and long-life settings are being explored. Applications of the metacognition are varied, not only for learning and education purposes, but also for health sciences, business, marketing, and social networks. Results of empirical studies are frequently published to share findings. Stimulation and measurement of metacognition is supported by computer-based tools.

With relation to the *weakness*, the first two are the complexity of the mind and the challenge that represents to organize its components and performance in diverse tiers. Another is the difficulty faced by human beings to think about their thoughts and the mental overload produced when people are aware of their ordinary cognition prior, during, and after it happens. Other issues include: the lack of an interdisciplinary study to provide the theoretical and well-sounded basis of metacognition; the diversity of viewpoints applied to carry out research; the plurality of metacognitive jargons used for the practitioners to define their research; the methods, instruments, and criteria for developing research are quite heterogeneous, so it is difficult to transfer their application in other settings. Another weakness is the complex interactions between cognitive, metacognitive, motivational, and emotional processes that bias individual's behavior and cognitive achievements.

Concerning the *opportunities*, metacognition field has the chance to receive the formal acknowledgment of educational programs interested in improving the teaching-learning processes by including metacognitive practices in their curricula. Pedagogues, educators, and teachers interested in enhancing their labor are the potential users to be trained in metacognitive practices. The demand for upgrading the quality and practices of education represents an opportunity to include metacognition as a normal guide for all. Learners are the main target for study, stimulation, and assessment of their outcomes through metacognitive behavior that are useful in formal and informal settings. The application of experiences gained in diverse fields of study provides a valuable source of knowledge. The call for teaching metacognitive skills is considered one of the main implications for instruction.

Regarding the *threats* some of them are: the unsatisfied need for theoretical clarity and well-known accepted definitions and descriptions of the components of metacognition. Others consist in the widespread proliferation of terms, constructs, methods, and processes that are used in literature. The incompetence of current metacognition baseline, theories, frameworks, models, and methods to tackle issues such as level of granularity, collaboration, descriptiveness, social networking, ubiquitous learning, comprehensiveness, and dynamic processes. Although researchers have been engaged in a considerable amount of research, to date there is still no work that examines this body of research. Theoreticians in the field of metacognition endorse different theoretical perspectives. Some of these perspectives reflect the prevalent "fuzziness" in the field. Others may be internally clear, but they have not been well understood how the various perspectives relate to each other.

Future Work to Support the CMMA. The proposed model pursues to characterize and explain how the metacognitive activity is accomplished. However, more theoretical work is needed to enhance the neurological and biological basis, as well as the psychological constructs. In addition, a formal characterization is also required to provide a mathematical representation of the structure, performance, and outcomes.

Moreover, experimental trials are claimed to provide empirical evidence to support the concepts, statements, and suppositions stated by the CMMA. The consideration of other disciplines such as system engineering is needed to develop a systemic and holistic model of the metacognition. Finally, the implementation of a computer-based system to provide metacognitive stimuli based on the CMMA is required.

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