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OVERVIEW

The developmental trinity of mind: Cognizance, executive control, and reasoning

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This paper summarizes research on how cognizance, that is, awareness of mental processes, interacts with executive control and reasoning from childhood to adolescence. Central positions are that (a) cognizance changes extensively with age; (b) it contributes to the formation of executive control, and (c) mediates between executive control and reasoning. Cognizance recycles with changes in executive and inferential possibilities in four developmental cycles: it registers their present state, yielding insight into their operation, allowing their better management; this catalyzes their transformation into the next level. Implications for theory of intellectual development and practical implications for education are discussed.

This article is categorized under:

Psychology > Development and Aging
Neuroscience > Cognition
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Philosophy > Consciousness

1 | INTRODUCTION

Consciousness is awareness of one's own existence and current relation with the world: "I know I am here and that the object I see is blue." Most aspects of an individual's functioning may enter consciousness, such as the mental and bodily functions, and emotions. Although a large part of cognitive activity is unconscious, such as the sheer functioning of all senses, there are two levels of consciousness (LOC; Dehaene, Lau, & Kouider, 2017): C1, awareness of one's own current object of thought (I know that I see a red apple) and C2, reflexive consciousness, which is awareness of one's own mental processes (I know that I see by my eyes), knowledge (I know I saw apples before), and abilities (I am good in remembering what I saw before). In this paper, we focus on cognizance, which is part of C2 consciousness involving awareness of cognitive processes. Cognizance draws on (a) self-monitoring, (b) reflection, and (c) meta-representation. Self-monitoring is the mind's eye turning to itself. For instance, "I try to balance on a seesaw," "I try to recall what she told me," "I try to learn how to add up numbers," and so on. Reflection is mentally re-enacting past experiences, memories, or thoughts to better understand events, actions, and thoughts and their relations: What, how, and why actually happened. Metarepresentation is encoding of the results of self-monitoring and reflection and tagging or redescripting them into new representations for future use (Karmiloff-Smith, 1992). Metarepresentation may occur in language, mental imagery, or a personally meaningful script. Cognizance unifies mental functioning across time, building links between past and present experiences and forging plans for future action. As such, it is the basic mechanism of mental time travel linking the present (perception) with the past (experience) and the future (problem solving) in many mental processes, simple, such as episodic memory, and complex, such as construction of the self. Thus, it allows individuals to learn actively and handle the unexpected (Beran, Brandl, Perner, & Proust, 2012; Carruthers, 2009; Demetriou, 2000; Michaelian, 2016; Piaget, 2001; Pillow, 2011).

Researchers studied various aspects of cognizance. Among others, reflective abstraction (revisiting past experiences to search for commonalities between them) (Piaget, 2001), metacognition (knowing about knowing) (Beran et al., 2012; Flavell, 1979; Pillow, 2008, 2011; Zelazo, 2015), and theory of mind (ToM; Wellman, 2014) (awareness about other person's mental states) are aspects of cognizance. Although there is research on the relations between these processes in development (Carruthers, 2009; Lyons & Zelazo, 2011; Schneider, 2008), there is no commonly accepted model for them. According to some authors, cognizance is a by-product of mental functioning. That is, as they grow older, children engage in activities and problem solving which require them to activate different mental functions, gradually gaining awareness about them. Others stress the social dimension of the discovery of the mind, assuming that it emerges from negotiating different points of view with other individuals (Wellman, 2014). Finally, others claim that it is an integral part of executive control that is adaptively important (Beran et al., 2012; Zelazo, 2015). We would suggest that all three approaches may be valid, with contribution of each factor varying between individuals and developmental phases.

This article examines the development of cognizance from infancy through adolescence and its role in the development of executive control, reasoning, and intelligence. These functions are related and complementary to each other. Executive control is deliberate adjustment of one's thoughts or actions in order to attain a goal (Zelazo, 2015). Obviously, executive control requires awareness of a goal and the steps needed to obtain it. Inference transfers meaning across representations on the basis of their commonalities and relevant rules (Johnson-Laird & Khemlani, 2014; Rips, 2001). Reasoning requires awareness of gaps in information (yielding a reasoning goal), of the representations to be integrated, and of truth standards needed to evaluate conclusions. Intelligence is a broader coordinating function employing the processes above, or other processes such as attention and memory, in order to understand what is going on at a given moment, acquire new knowledge and skills, make decisions, and solve problems in the best possible way (Carroll, 1993; Hunt, 2011; Jensen, 1998). It is noted that cognizance is not even mentioned in any of the classic theories of intelligence.

This paper comprises three sections. In the first section, we summarize research on the development of cognizance, executive control, and reasoning. Our aim here is twofold: to show how these three functions intertwine with each other in development and to uncover how each interacts with general cognitive ability in each developmental phase. The second section focuses on the mediating role of cognizance. The aim here is to highlight how cognizance carries influences from basic executive functions to reasoning and vice versa from reasoning to executive functions. Finally, the third section compares our model with other models of the cognitive development and intelligence.

2 | DEVELOPMENT OF COGNIZANCE, EXECUTIVE CONTROL, AND REASONING

Integrating over different traditions of research, Demetriou and colleagues suggested that cognitive development occurs in four cycles, with two phases in each (Demetriou et al., 2018; Demetriou & Spanoudis, 2017, 2018). Moving across cycles is associated with the emergence of new forms of representation; changes within cycles are associated with increasing awareness of them, skill in using them, and in their alignment and interlinking. In succession, the four cycles operate with episodic representations from birth to 2 years, realistic mental representations from 2 to 6 years, generic rules organizing representations into conceptual/action systems from 6 to 11 years, and overarching principles integrating rules into systems where truth and multiple relations can be evaluated from 11 to 18 years.

Episodic representations are remembrances of actions and experiences preserving their spatial and time properties. Realistic representations are blueprints of episodic representations where spatial and time properties are reduced, associated with personal symbols, such as mental images, or conventional symbols, such as words. Rules are abstract mental schemes capturing relations between realistic representations and expressing them as concepts or categories of things, causal relations, and so on. Principles are higher-order rules specifying how generic rules are related or how they may be integrated. Changes within cycles occur at about their middle, at 4 years, 8 years, and 14 years, when representations become explicitly cognized so that their relations can be worked out, gradually resulting into representations of the next cycle (Demetriou & Spanoudis, 2017, 2018). Milestones in the development of cognizance, executive control, and reasoning across developmental phase and cycles are summarized in Table 1.

Notably, theories of intellectual development concur that major transitions in thought development occur at about the age of 2, 7, and 11 years and improvements in handling new acquisitions occur in between at 1, 4, 8, and 14 years (e.g., Case, 1985; Mascolo & Fischer, 2010; Piaget, 1970; Siegler, 2016), demarcating an early and a later phase in each period. We opted for "cycle" over "level" or "stage" for several reasons. First, this term indicates that each type of representation evolves through the same process of awareness building. Second, it indicates that reflection becomes sharper, more refined, and focused across cycles transforming the very nature of representations. Each new form of representation allows more refined executive and reasoning systems. Thus, practically speaking, developmental priorities change across cycles, transforming the

TABLE 1 Milestones in the development of cognizance, executive control, and reasoning across developmental phase and cycles

Age	Cycle	Cognizance	Executive control	Reasoning
0–1	Emerging episodic representations	Differentiate self from objects	Stimulus-action links, reinstituting circular reactions	Episodic expectations, for example, Mother calling, she is coming.
1–2	Integrated episodic representations	Self-recognition in the mirror Explicit awareness of stimuli and actions, implicit awareness of mental states	Perception initiated represented goals, for example, insert objects in same-shape holes.	Extrapolation of episodic sequences mimicking implication: for example, Dad came, mom is coming too.
2–4	Emerging realistic mental representations	Awareness of perceptual origins of knowledge, implicit awareness of representations, and one's own performance	Automation of self-initiated action episode: for example, Girl bathing her dol. Instruction-based goal execution, for example, bring my shoes.	Translation of representational ensembles into reasoning sequences: Ungle's car is outside, so he is in.
4–6	Integration of realistic representations	Explicit awareness of representations/implicit awareness of mental processes, ToM	Control of attentional focus: Shifting between actions according to instructions activating a represented plan.	Pragmatic reasoning: You said I can play outside if I eat my food; I ate my food; I go to play outside.
6–8	Emerging rule-based representations	Explicit awareness of representation/actions relations, Implicit self-evaluation rules	Rule-based action plans, such as turn-taking in games.	Scheme-based reasoning, modus ponens, conjunction, disjunction: There is a dog and a tiger; there is a dog, so there is a tiger.
8–11	Integration of rules into rule-based systems	Explicit awareness of mental processes, second-order ToM, logical necessity	Conceptual fluency allowing flexible shifting across conceptual systems: First recall fruits, then animals, then furniture.	Symmetric conditional reasoning: Integrated modus ponens–modus tollens: If there is an apple there is a pear; there is an apple, so there is a pear; there not a pear, so there is not an apple.
11–13	Emerging principle-based representations	Explicit awareness of mental processes; implicit self-evaluation principles	Automation of conceptual fluency programs: Complex everyday plans, such as homework planning.	Intuitive grasp of fallacies: If there is an apple there is a pear; there is a pear; I cannot know if there is an apple.
14–16	Integrated principles	Accurate self-representation and self-evaluation	Inferential relevance mastery program: Long-term plans, such as study choices for university.	Complete conditional reasoning: As above, also If there is an apple there is a pear; there is a not apple, I cannot know if there is a pear.

very nature of intelligence. In the terms of Siegler's (2016) wave model, representations of the previous cycle are gradually replaced by the representations of the current cycle as the primary units of thought, and the representations of the next cycle begin to emerge. Below, we focus on the development of the various processes in each cycle and their inter-relations (Demetriou et al., 2013, 2014).

2.1 | Episodic thought

Infants are mentalistic creatures (Baillargeon, Scott, & Bian, 2016): They represent themselves and others as representational beings. Infants differentiate themselves from objects by the age of 5–6 months (Rochat, 1998) and they recognize themselves in the mirror by 15 months (Gallup, 1982; Povinelli, 2001), suggesting that they compare what they see with representations of their invisible body parts. Infants talk to themselves about earlier experiences suggesting that they reflect on them before they are 2 years old (Vallotton, 2008). For example, they repeat instructions given to them earlier by an adult.

By 15–18 months, infants show awareness of systems of action they demonstrated before which include an executive sequence where past actions are intertwined with perceptions and current actions: When encountering a familiar object set, they intentionally restore the sequence which involves representation of past experiences (e.g., insert objects of various shapes in a box through same-shape holes) and projection into an action plan (e.g., "Grasp objects and look for same-shape holes," testing by trial and error if they do not get through). This is presorting episodic representation where perceptions, remembered representations, and actions reflected upon are used together to create intentional behavior patterns (Carey, 2009). Also, infants infer implicitly that someone who saw where an object was hidden will look for it at that place, as indicated by their looking pattern (Onishi & Baillargeon, 2005). Episodic reasoning involves reciting episodic representations and abstracting what runs through them. For instance, describing one's own actions prepares for conjunction. "I put this, and this, and this, all of them" is formally equivalent to a conjunctive argument: [all = this + this +this]. Recalling an episodic causal sequence prepares for implication: "Dad is going upstairs; he is going to get dressed" is formally equivalent to an implicative argument: if A then B.

2.2 | Realistic representational thought

Representations at 2–3 years of age are reduced mental projections of episodic representations with a component of implicit awareness. There is evidence accruing in the recent years that children have some awareness of their own mental states from about 3 years of age. Paulus, Proust, and Sodian (2013) trained 3.5-year-old children to associate individual animals with specific objects. They showed them short videos of an animal doing something (e.g., an elephant who likes watching TV). Sometime later they showed the probe animal (e.g., the elephant) and they tested if children remembered the object associated with it (a TV). They also asked the children to indicate how confident they were for their judgment. Confidence ratings for correctly remembered items were higher than ratings for incorrectly noted items, suggesting an awareness of representations stored earlier in memory. Also, children at this age are aware that when one saw an object one knows about it (Flavell, Green, & Flavell, 1995). This makes ToM possible. Children are supposed to have a ToM when they understand that one's actions relate to one's own representations which derived from one's own perception (Wellman, 2014): "I know that smarties are in Box B because I saw them moved there from Box A; however, you only saw them placed in Box A and you didn't see them moved; so you believe what you saw as I believe in what I saw." Obviously, the explicit representation of belief here is to be contrasted to the implicit episodic belief mentioned above.

By the age of 4–5 years, preschoolers are sophisticated enough to setup action plans requiring shifting between actions according to a probe. For instance, children at this age can successfully follow instruction involving shifting between two rules: "Sort objects according to color when a red tag is on and according to shape when a square tag is on" (Vendetti, Kamawar, Podjarny, & Astle, 2015; Zelazo, 2004). In other words, executive control at this phase is guided by a "focus-recognize-respond" program allowing children to represent a major goal (e.g., sort objects in piles), its alternative realizations (color if red, shape if square), and shift between them as specified. Obviously, this task involves awareness of representations one may focus on and choose from, organizing action beforehand. However, cognitive flexibility is still not very coherent in this cycle. For instance, flexibility between rules as described above is not related to flexibility in shifting between words according to the properties indicated by each word (Deak & Wiseheart, 2015).

By this age, reasoning progresses from reciting or reading episodic sequences of events to pragmatic deals: "You said I can play outside if I eat my food; I ate my food; I go to play outside" (Kazi, Demetriou, Spanoudis, Zhang, & Wang, 2012). This sequence is basically an inference locking two representations ("A occurs" and "B occurs") together into an inductive sequence (i.e., "When A occurs, B also occurs). Children may consider inductive options (i.e., "no eating-no play" and "eating-play") because their executive control program allows envisaging alternative choices.

BOX 1

CAPTURING CHANGE IN SPECIFIC MENTAL PROCESSES AS A FUNCTION OF GENERAL DEVELOPMENTAL ABILITY

Change in the rate of change of a specific mental process M would alter its relations with other processes if the rate of change across them is not the same. By implication, this would be reflected in changes in the relations between this particular process M and general mental ability; technically, general mental ability is represented by a composite index, the g index, which stands for performance on all processes used in a study. These may include processing speed, working memory, reasoning, and cognizance. The model of nonlinear logistic growth describes the development of most mental abilities. This model posits that change is slow when an ability emerges, accelerates later, attaining maximum rate around the middle of its course, slowing afterward as it approaches its final level, when a new cycle will start anew. This relation is formally illustrated in Figure 1. One may assume that the relations between a specific process and g in each phase strengthen in the middle of the phase to reflect that this ability is incorporated in g, thereby coming under its control.

One might object that the relations above between cognizance, executive control, and reasoning are conjected rather than evidenced. We ran a series of studies designed to explore how these processes merge to form general mental ability in each phase and how they differentiate from or intertwine with it as it evolves with age (Demetriou et al., 2017). In one of these studies, participants from 4 to 16 years of age ($N = 662$) completed a large number of tasks addressed to information processing speed (e.g., recognize if an object is in the left or the right half of the screen), attention control (e.g., recognize the ink color of a color word written in a different color—the word RED written in green, say green), verbal (recall of words in presentation order) and visual–spatial working memory (recall of shape, position, and orientation of geometric figures), and reasoning (inductive, deductive, spatial, and quantitative reasoning). We created a composite index for each of these processes. We ran specific analyses which abstracted a general factor underlying all processes and specified how each process related to it across age phases. This general factor captured what was common between all processes. We found that all three processes standing for some aspect of executive control, that is, speed, attention control, and working memory, intertwined strongly with this general factor in the 4–6 years phase; this relation weakened

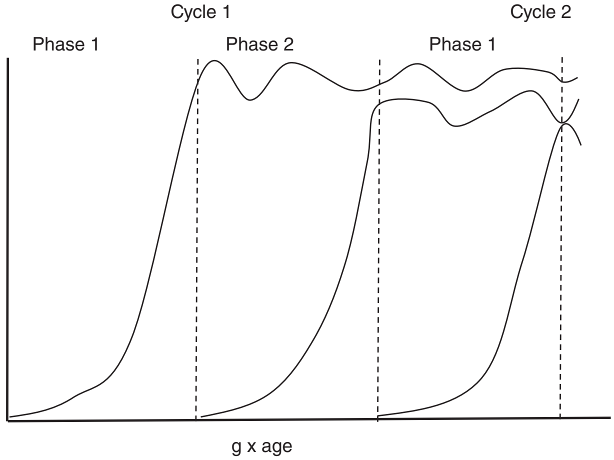

FIGURE 1 Idealized curves of the integrated integration–differentiation logistic growth model

in the following phase. This relation is nicely illustrated in Panel A of Figure 2. The rationale of this method is explicated in Box 1. It can be seen in Panel A of Figure 2 that change in attention control was very steep in the 4–6 years phase tightly correlating with changes in general ability. In the next cycle, change in attention control slowed down and the relation with changes in general ability diminished. Obviously, reasoning was not a major marker of general cognitive ability in the representational cycle. However, executive control was a major marker of the buildup of general cognitive ability in this cycle. However, it can be seen in Panel B of Figure 2 that when change in attention control decelerated, change in inferential awareness accelerated, strongly intertwining with general ability in the 6–8 years phase.

2.3 | Rule-based thought

At 6–8 years, children are explicitly aware of mental representations and their relations with their own actions. For instance, they differentiate between easy and difficult memorization tasks, suggesting awareness of the relation between complexity of representations and learning. However, at this age, children do not yet explicitly differentiate between mental functions, such as memory and reasoning, nor do they explicitly associate each with specific processes, such as rehearsal for memory and inference for reasoning (Paulus, Tsalas, Proust, & Sodian, 2014; Spanoudis, Demetriou, Kazi, Giorgala, & Zenonos, 2015; Tsalas, Sodian, & Paulus, 2017). Also, children at 6–8 years do not prepare sufficiently to cope with a forthcoming task because they are not explicitly aware that different tasks require relevant preparation (Chevalier & Blaye, 2016).

A differentiation between mental processes is possible at 8–10 years. In this phase, awareness of different mental processes allows children to shift flexibly between them (e.g., to remember you need to observe carefully and rehearse; to sort you need to follow a sorting rule; Demetriou et al., 2018; Kazali, 2016). Children in this phase understand that more difficult items require more study time, if they are to be successfully stored and recalled (Tsalas et al., 2017). Also, in this phase, children differentiate between the metaphorical and literal meaning of verbal statements. For instance, Carpendale and Chandler (1996) showed that understanding the interpretative nature of mind (e.g., that different characters may interpret the phrase

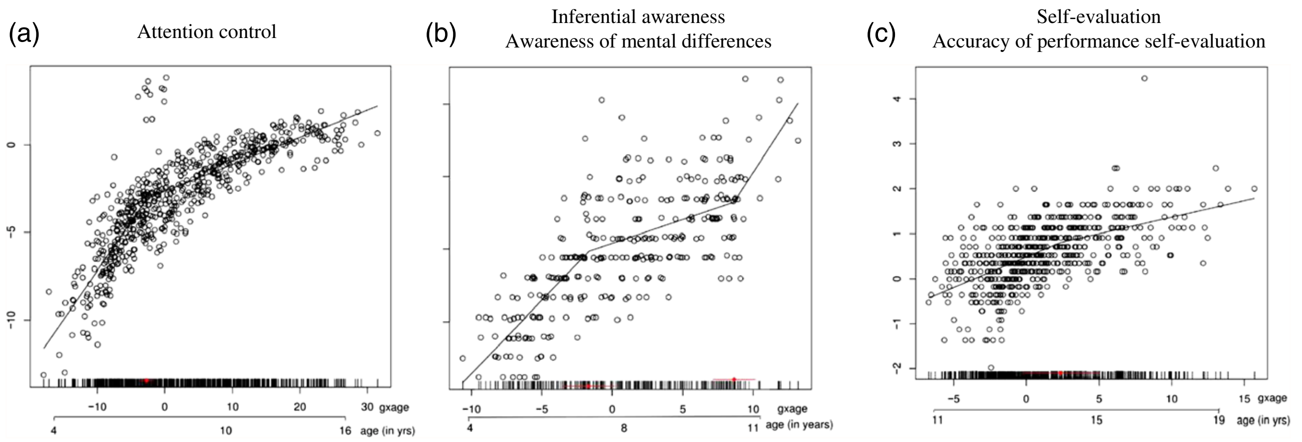

FIGURE 2 Relations between development of general cognitive ability (g × age) and special processes across cycles. *Note.* Developmental general cognitive ability is the product of an individual's age (in years) and his/her factor score on the first principal component abstracted from performance on the processes included in each study. Models of relations were estimated by segmented regression analysis

"wait for a ring"—a phone call or a diamond ring—differently depending upon the information they have) is attained at the age of 7–8. Also, at this age, they master higher-order ToM (e.g., "I know that George knows that Mary knows that …"; Wellman, 2014), recognize that gaps in knowledge may be filled by inference (e.g., "He sorted by color, so blue objects would be in the blue box"; Spanoudis et al., 2015).

Thus, in this phase, executive control is upgraded into a *conceptual fluency program* allowing children to shift between mental processes (e.g., memory vs. inference) or conceptual domains (e.g., they recall words belonging to different categories—fruits, animals, furniture—following a probe) (Brydges, Reid, Fox, & Anderson, 2012). Compared to the previous "focus-recognize-respond" executive program, the current program involves analytic representations of conceptual spaces.

In addition, 8- to 9-year-olds implicitly use rules specifying how different types of inference are interrelated. For instance, if accepted that "A implies B" then two possibilities are necessarily true: When A occurs then B occurs too and when B does not occur then A did not occur either (Christoforides, Spanoudis, & Demetriou, 2016). Therefore, awareness of underlying relations allows moving across rules so that they may then guide executive control and reasoning. Grasp of logical necessity in this phase is a strong sign of this awareness (e.g., "All balls in the box are red, so the next to be drawn out MUST be red"; Miller, Custer, & Nassau, 2000).

Another set of studies investigated the relations between general mental ability and specific processes in the period of transition from representational to rule-based thought with an emphasis on the role of various aspects of cognizance in this transition. In these studies, 4- to 11-year-old children were examined on various aspects of processing speed, executive control, working memory, reasoning, and awareness of the perceptual and inferential origins of knowledge and similarities and differences between different reasoning processes. In the perceptual awareness tasks, children saw a person placing objects in same color boxes according to their color and heard this person describing what she did before. Children were then asked to specify the location of objects based on what they saw and heard before. In the inferential awareness tasks, children saw the same person hiding objects in same color boxes but they were subsequently asked to locate objects of a different color not shown before. Thus, this condition addressed awareness of inductive inference as a source of knowledge. That is, that this not-seen before object must be in a same-color box, given that the person was sorting objects in same color boxes (Kazali, 2016; Spanoudis et al., 2015).

To test awareness of cognitive processes, children saw pairs of persons solving similar (e.g., two persons adding up numbers) or different tasks (e.g., a person adding up numbers and another putting the pieces of an object together). Children were asked to reflect on (a) the similarity (i.e., "Is the job of *this* child the same as the job of *this* child? Why do you think so?") and (b) the relative difficulty of mental processes activated ("Who of the two children is doing the *easier* job? Why do you think so?") (Kazi et al., 2012). Notably, of the various processes, only increases in perceptual awareness were significantly and positively related with increases in general cognitive ability from 4 to 6 years of age. In the 7–11 years, phase increases in both perceptual and inferential awareness intertwined with increases in general cognitive ability. Interestingly, in this later phase, both awareness of similarities and differences between cognitive processes but also advanced inductive reasoning, as in some demanding Raven matrices, and deductive reasoning of intermediate complexity, as noted above, emerged as strong markers of general cognitive ability. In the rule-based cycle, inductive reasoning and inferential awareness are the primary markers. Panel B of Figure 2 (see Demetriou et al., 2017, Studies 2, 3, and 4) shows the development of inferential awareness in this cycle (Demetriou et al., 2017).

2.4 | Principle-based thought

At 11–13 years, adolescents form accurate maps of mental functions and of their own strengths and weaknesses (Demetriou & Efklides, 1989; Demetriou & Kazi, 2006; Makris, Tahmatzidis, & Demetriou, 2017). As a result, they evaluate their own performance on cognitive tasks with increasing accuracy. For instance, they know where in school they are strong and where they are weak. Also, they cognize the constraints of different inferential processes; for instance, they recognize that it is easier to execute mental rotation than to calculate mathematical relations (Demetriou & Efklides, 1989; Demetriou & Kazi, 2006). They can even ground inference on truth and validity rules. That is, they explicitly understand that accepting certain conditions (e.g., birds fly; elephants are birds) imposes constraints on inference (i.e., elephants fly) even if a statement is admittedly wrong (elephants are not birds). This achievement allows consistency in reasoning. By the age of 13–14 years, "reasoners have a meta-representation of logical validity that can be used to inform them of the accuracy of their logical deductions, at least when reasoning about abstract materials" (see Markovits, Thomson, & Brisson, 2015, p. 691). This protects them from drawing false conclusions. Specifically, they understand that accepting that "If A then B" does not allow drawing any conclusion about A if only knowing that B occurred or drawing any conclusion about B if only knowing that A did not occur because B may be caused by causes other than A. For instance, knowing that "if one has fever one feels bad" does not allow inferring that one has fever if one feels bad or that one does not feel bad if knowing that one does not have fever. Therefore, the *inferential relevance mastery program* explicitly places truth weights on the various alternative choices that may be deduced from a logical argument (Christoforides et al., 2016; Moshman, 2004). Control in this cycle is much more complicated that the executive control attained in the previous cycles. It is based on a suppositional-generative program enabling adolescents to coactivate conceptual spaces, evaluate them against each other and personal preferences, and form long-term life plans, such as choosing a course of studies rather than locally control action vis-à-vis a particular stimulus or rule-based set up (King & Kitchener, 2002).

We ran several studies aiming to map what are the main markers of general cognitive ability from early adolescence to late adulthood (see Demetriou et al., 2017, Studies 5–8). Overall, in these studies, participants solved several tasks of principle-based inductive and deductive reasoning in several domains, including mathematical (e.g., estimating mathematical proportional relations), spatial (e.g., performing mental rotations to predict how objects would like if rotated), and social relations (e.g., make choices about disputed solutions to social problems). Also, they were asked to evaluate how successful their solutions were, after solving each of task participants. Actual performance and self-evaluation scores were combined to create self-evaluation accuracy scores, reflecting the degree of concordance between performance and self-evaluation. Specifically, both low performance and low success evaluation and high performance and high success evaluation resulted into a high concordance score. Low performance but high self-evaluation or high performance but low self-evaluation resulted in low concordance scores. Modeling changes in the relations between general mental ability, specific processes, and accuracy in self-evaluation from 11 to 45 years revealed three major markers of development: advanced deductive and advanced mathematical proportional reasoning together with accuracy in self-evaluation, all spurted at 14–15 years, strongly marking g in this phase. Panels C of Figure 2 shows the development of self-awareness in this cycle.

3 | CAPTURING THE MEDIATING ROLE OF COGNIZANCE

The relations between cognizance, executive efficiency, and reasoning vary with developmental phase. Each new form of representations is acquired in the first phase of each cycle; representations are then interconnected into more complex ensembles in the second phase. Awareness of the new form of representation is implicit in the first phase of each cycle and it becomes explicit in the second phase yielding insight about underlying relations which will generate the representations of the next cycle. In the episodic cycle, awareness of actions and action-object relations is explicit but awareness of intervening representations is implicit. Revisiting episodic blocks allows the infant to abstract action patterns, inter-relate them, and represent them in language or other representations, generating the realistic representations of the next phase. By the age of 3–4 years, children become explicitly aware of representations but not of underlying mental processes. Thus, they can focus on, compare, and shift between representations according to a goal. In this phase, children can hold in working memory 2–3 instructions, understand the intentions of others, and reason pragmatically. However, comparing representations generates relations; when explicitly represented, these relations yield the rules of the next cycle at 6–8 years. These attract attention to underlying processes, which are first implicitly and later explicitly represented, at age of 8–9 years, culminating in the *conceptual fluency program* of rule-based thought. Cognizing similarities and differences between rules eventually yields general principles bridging rules into multidimensional thought at 11–13 years and meta-logic and the epistemological stance that goes with principle-based cognition at 14–16 years.

Several studies modeled how cognizance mediates between processing and executive efficiency on one hand and reasoning on the other hand. In these studies, we tested participants from 4 to 17 years of age. To test cognizance, participants were examined on their awareness of similarities and differences between mental processes. It is reminded that they were asked to infer an observer's knowledge based on an actor's activity (e.g., seeing, hearing, sorting, etc.), and evaluated task difficulty and their own performance on it. Participants were also tested on executive control (i.e., examples above), working memory (e.g., recall number digits or words), and inductive, deductive, and spatial reasoning (Kazi et al., 2012; Spanoudis et al., 2015).

We tested several models aiming to examine if cognizance mediates between executive and inferential processes and if mediation operates bottom up from executive to inferential processes or top-down, from inferential to executive processes. Answering this question requires pitting against each other a bottom-up and a top-down model where the direction of effects is precisely specified. In the bottom-up model, the following relations were built. First, the four executive factors (i.e., speed, stimulus recognition speed, attention control, and working memory) were taken as the background factors which were directly regressed on age. Cognizance was regressed on all four of these executive factors. The three reasoning factors were regressed on a common reasoning factor, which stands for fluid intelligence (Gf). This Gf factor was regressed on cognizance, which was thereby upgraded into a mediating factor carrying the effects of the executive factors to the reasoning factors. In the top-down model, the reasoning factors (i.e., inductive, deductive, and spatial reasoning) were taken as the background factors which were directly regressed on age. Cognizance was then related to each of these factors. The four executive factors (speed, stimulus, attentional control, and working memory) were regressed on a common factor that stands for executive control. This executive control factor was regressed on the cognizance factor that carries the effects of the reasoning factors onto the executive factors. These models are depicted in Figure 3.

These two models were first tested in a multiple-group analysis where the first group involved the 4- and 5-year-olds, the second group involved the 6- and the 7-year-olds, and the third group involved 8- to 10-year-olds. Inspection of Figure 3 shows that cognizance mediates between executive control, on one hand, and reasoning, on the other hand throughout this age period. This mediation is cycle-specific, exerted through the processes underlying the management of representation in each cycle: perception-based aspects of representation in the representational cycle and rule-based inferential processes in the rule-based cycle. Also, overall, bottom-up mediation is stronger early in development. Top-down mediation appears from late childhood onwards. In other words, in the period from about 4 to 7 years, lower level executive processes, attention control and working memory in particular, generate awareness of mental processes that is used in sake of managing reasoning. Later, at 8–10 years, awareness emerging from reasoning as such is transferred top-down to executive control, enhancing its scope and flexibility (Papageorgiou, Christou, Spanoudis, & Demetriou, 2016; Spanoudis et al., 2015).

Several learning studies examined whether training cognizance accelerates transitions across phases in the way it does in spontaneous development. In one of these studies, we trained 8- and 11-year-old children to become aware of the logical schemes of conditional reasoning explicated above. Moreover, we examined how change as a result of training relates to executive and processing efficiency. We found that enhanced awareness of logical schemes and underlying inference pulled children up by an almost full developmental phase. For instance, trained third graders handled problems at the level of principle-based reasoning. Also, initial facility in executive control facilitated awareness of underlying inferential processes and adoption of the *suppositional stance* of principle-based cognition. Notably, 1 year later, training effects on the process trained did weaken but remained significant. However, they transferred to not trained processes, such as working memory and attention control. This implied that improving the central control mechanism of thought improves more specific executive processes (Christoforides et al., 2016; Papageorgiou et al., 2016).

4 | RELATIONS WITH OTHER THEORIES

Cognizance, executive control, and reasoning are tightly intertwined in development. To cognize a representation or process, thinkers must focus on, monitor, record, and compare it with other representations or processes. In fact, reflecting on mental objects requires executively varying them and reasoning about these variations. This trinity develops through several cycles of raising implicit mental content into increasingly explicit representations, opening a new cycle of awareness, executive control, and reasoning. Although all cycles involve awareness of and reflection on representations, representations change, reflecting the varying priorities in the formation of general mental ability. The major priority in the episodic cycle is the shift from the "here and now" of present action and perception to the mental and the representational. The major priority in the representational cycle is attentional control and flexibility. Awareness of perceptual processes and the perceptual origins of

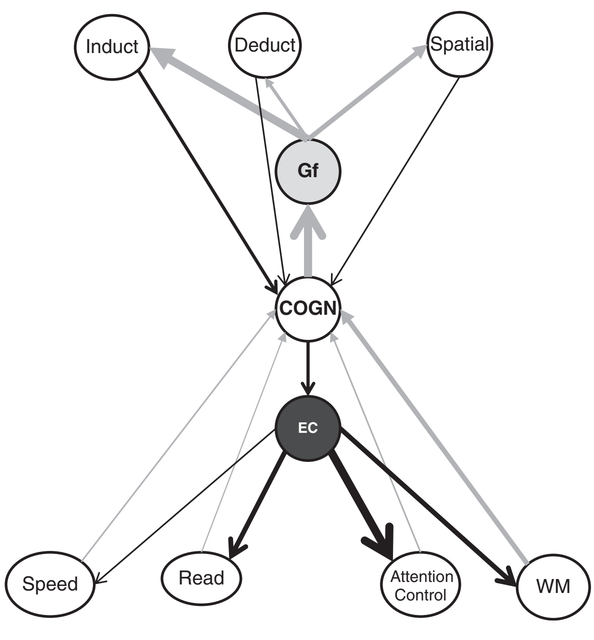

FIGURE 3 Models of the mediation of cognizance between executive and reasoning processes. *Note.* COGN and EC stand for cognizance and executive control, respectively. Induct, deduct, and spatial stand for inductive, deductive, and spatial reasoning, respectively. Speed, Read, and WM stand for processing speed, reading speed, and working memory, respectively. Width of arrows indicates strength of relations. Gray arrows indicate bottom-up relations and black arrows indicate top-down relations

knowledge are thus the major markers of the formation of general mental ability. In the rule-based cycle, the major priority is control of the inferential process; thus, inductive inference and related awareness are the major markers of g expansion. Finally, in the cycle of principle-based thought, control of the relations between principles and value spaces is the major priority; thus, grasp of logical constraints framing inference, explicit awareness of mental processes, and criteria for inference are the major markers of g.

The differing priorities above yield a different stance to reality in each cycle. The episodic mind is captive of environmental variation, guided by it as much as it errs because of it. The realistic representational mind blurs boundaries between imagination and reality, enjoying the imaginary world as much as it may be deceived by it. The rule-based mind allows a well-organized representation of the world which often lacks cohesion and logical validation. The principle-based mind adopts a suppositional stance allowing a kaleidoscopic but systematic viewing of the world, although, at the beginning, it may lack a dialectic approach allowing selection of value systems.

In emphasizing cognizance, the model summarized here shares a fundamental postulate with Zelazo's (2015) and LOC model (Vendetti et al., 2015). They both ascribe change to self-reflection which generates increasingly higher levels of awareness. These "… are brought about by a type of reflection or re-entrant processing that permits the contents of consciousness at one level to be considered in relation to other contents at that same level, resulting in a more complex conscious experience." (See Zelazo, 2004, p. 13). Lyons and Zelazo (2011) argued that these changes in awareness underlie changes in executive control and metacognition. The present theory goes beyond LOC in that it models development at a wider age range, accommodating changes in reasoning and other aspects of mental processing, such as working memory and intelligence.

An epistemologist would see several psychological realities in the patterns abstracted by the approach adopted here. We will name these realities after great psychologists or philosophers. First, there is definitely a Piagetian reality. There are four developmental cycles with two phases in each that for many would be quite close to the four Piagetian stages of cognitive development (sensori-motor, preoperational, concrete and formal operational intelligence). These cycles are primarily representationally rather than logically defined. That is, they are distinguished from each other in reference to the type of representation dominating in each cycle (i.e., episodic schemes, mentations, rules, and principles) and by the relations connecting representations (i.e., spatially and time-based associations, representational mappings, inferential links, truth- or validity-based inferential constraints). Also, although overlapping in time, these cycles follow a necessary sequence and each next cycle integrates all earlier ones. Thus, in a sense, development is Gödelian in nature. That is, each cycle comes to a closure only when moving into the next cycle. Specifically, episodes can be autonomously and independently examined only in the representational cycle when representation allows the child to revisit them beyond "here and now." Realistic representations come to a closure only when rule-based thought allows organizing and intentionally activating them for purposes other than the events or episodes that gave birth to them. Rule-based thought comes to a closure only in principle-based thought allowing their evaluation vis-à-vis multiple standards and their orchestration into long-term plans. Finally, principle-based thought comes to a closure in a meta-principle (epistemologically-based) environment where principles are meta-theoretically arranged on the basis of value-based systems related to the nature of knowledge or the importance for society (Mascolo & Fischer, 2010).

There is a neo-Piagetian reality as well, which we call a Pascual-Leonian reality, after Pascual-Leone (Arsalidou & Pascual-Leone, 2016; Pascual-Leone, 1970) who initiated the neo-Piagetian movement. Specifically, development through the cycles is associated with increasing complexity of executive control structures (Case, 1985) or abstraction (Mascolo & Fischer, 2010) in the structures of information that may be grasped and dealt with. Halford, Wilson, Andrews, and Phillips's (2014) notion of relational complexity may be a tool for specifying constraints on the concepts that can be grasped in each cycle. Specifically, the relational complexity of a task corresponds to the number of dimensions which must be simultaneously represented if a particular construct is to be understood (e.g., modus ponens requires three dimensions). We stress, however, that we take relational complexity as a tool for analyzing the representational dimensionality of concepts rather than the representational capacity of the individual. Eventually, in line with Pascual-Leone, a meta-subjective account of this sequence would have to be stated. That is, we would have to account for the internal constraints that make the emergence of each next level from the preceding level causally necessary, from the point of view of the cognizer (Arsalidou & Pascual-Leone, 2016). This may drastically change the very notion of complexity (and subjective difficulty) because consolidation of each level largely rescales complexity (and difficulty) at the same subjective metric: manageable.

The findings summarized here strongly suggested that changes in reasoning are not driven by changes in working memory but by changes in the representational resolution of mental representations, allowing more refined processing. In line with this approach, Shipstead, Harrison, and Engle (2016) maintained recently that working memory and Gf involve processes that are not causally related but they are organized around top-down processing goals in problem solving. The first allows the person to represent information so that solutions can be envisaged. The second involves the ability to disengage from rejected solutions and envisage new ones. This explicates why the role of cognizance and inference strengthens with development: increasing resolution of cognizance allows more focused scanning and identification of dimensions in information structures and more precise alignment and encoding into new concepts.

There is also a Spearmanian reality, suggesting that general mental ability is much broader than the handling of complexity. The level of general mental ability available at a given time conditions how specific mental processes are constrained by it. Consolidated processes may differentiate and vary rather freely in more able (often older) persons. However, change in general mental ability is by definition developmentally constrained. Individual differences in this regard are actually differences in rate of attainment and infusion of g by processes specific to a particular phase.

Finally, there is also a Kantian reality. "The highest principle of Kant's theoretical philosophy is that all cognition must 'be combined in one single self-consciousness" (Kitcher, 2011). We showed here that there is a powerful cognizance mechanism that generates and transforms self-awareness of cognitive processes throughout the cycles above. In fact, to a large extent, this awareness defines the subjective aspect of mental functioning, raising it from simple computation to representation where information and mental functioning is subjectively meaningful. The Kantian reality of the mind may of course interact with its Freudian reality, dealing with the interplay between unconscious and conscious processing. However, dealing with this interplay is beyond the present space limitations.

It is notable that brain research suggests that the development of networks of increasing complexity in the brain match the cognitive levels described here. Specifically, the dominant networks associated with the four cycles are located in the sensory and the motor cortices, which first intertwine with reticular and parietal, and then with a succession of regions in the prefrontal cortices. According to Luna and colleagues, the consolidation of sensory networks precedes parietal and prefrontal networks and the tuning of sensory parietal cortices with dorsal prefrontal cortices is complete by adolescence; however, there is also a second phase, ignored by previous research, in which the networks linking the ventral and medial prefrontal cortex to limbic and temporal regions continue to change into young adulthood. It seems that the top-down control network is fully established only in late adolescence and early adulthood (Luna, Marek, Larsen, Tervo-Clemmens, & Chahall, 2015). This last network may underlie the metacognitive module which may exist in the brain as suggested by Anderson and Fincham (2014). This module "creates, modifies, and rehearses declarative representations of cognitive procedures" (p. 25), intervening at any of the steps involved in problem solving (encoding, planning, solving, and responding), thereby creating and inter-relating new representations. There is a crucial commonality between representational and neural expansion: in the fashion that the representational program of each cognitive developmental cycle is embedded and enhanced in the next cycle, underlying brain networks of each cycle integrate and extend the brain network of the previous cycle by laying extra paths between local networks and higher-level control and abstraction networks. Thus, further representational and inferential possibilities come within reach because further brain lines are there to support them (Demetriou & Spanoudis, 2018; Papageorgiou et al., 2016).

This model solves two thorny problems in developmental and psychometric theory: Why are (a) later levels of intellectual development more difficult to attain than earlier levels and (b) higher scores of intelligence rarer? The first is due to the fact that reflection and meta-representation become increasingly difficult to perform because each next cycle's representations are more difficult to visualize by the mind's eye (e.g., compare episodic representations with principles) and they are semantically richer. Therefore, integrating representations into higher levels of executive control and reasoning becomes increasingly difficult because options increase exponentially, rendering fluid functioning less easy to upgrade and mistakes more likely. The second comes from the very nature of intelligence tests: Higher intelligence scores require solving problems associated with later developmental phases. Therefore, high scores are constrained by developmental constraints (Demetriou et al., 2018).

This theory also has educational and clinical implications. Learning must capitalize on cognizance in developmentally specific ways. In infancy, it must build awareness about the perceptual origins of knowledge and facilitate mapping actions onto objects and their representations. At preschool, children must become aware of representational constraints of thought and knowledge by tuning into their and others' representations and related knowledge. In primary school, children must refine their understanding of the process- and rule-specific constrains of knowledge and inference. Adolescents must practice inferential relevance mastery by evaluating conceptual spaces for truth and refining the suppositional stance vis-a-vis different knowledge and inferential domains. In populations with special learning difficulties, learning must compensate for what is lacking because of impairment. For instance, learning programs for the blind must build the awareness needed for cognitive change by turning reflection on other (e.g., auditory) sources of information and knowledge (Demetriou & Spanoudis, 2018).

5 | CONCLUSION

The studies summarized in this article suggest that the relation between specific processes and general mental ability vary with developmental cycle and phase. New acquisitions in each cycle get increasingly integrated into general ability, at the phase when they infuse g, impregnating it with their properties. Later, they may differentiate from it, according to interests and practice. Control of attentional focus dominates in the cycle of reality-based representations. Awareness of the perceptual origins of knowledge also contributes in the second phase of this cycle. In the next cycle of rule-based thought, inductive reasoning dominates. Awareness still actively infuses ability with its properties but it mutates from perceptual to the inferential aspects of representations. In the next cycle, deductive reasoning dominates as the major source of infusion of new properties into general ability. In this cycle, awareness continues to be powerful but it is individualized as it is tuned to one's own personal strengths and weaknesses. Attention is also drawn to the fact that the mediation of cognizance between executive and reasoning processes is cycle-specific. That is, in each cycle, it is exerted through the processes underlying the management of representation in each cycle. This is the perception-based aspects of representation in the representational cycle, rule-based inferential processes in the rule-based cycle, and abstract semantic processes in the principle-based cycle. Therefore, cognizance is a higher-order monitoring process that registers the representations and the sources of knowledge available. When new higher-order representations enter onto stage, cognizance turns onto them, often letting earlier representations go unnoticed, as they are automated and thus in no need of supervision.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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