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Executive Functions and Improvement of Thinking: An Intervention Program to Enhance Deductive Reasoning Abilities

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Abstract. Empirical and theoretical advances and application to society are moved at different speed. Application work is frequently developed later because it requires the integration of knowledge from different research areas. In the present paper, we integrate literature coming from diverse areas of research in order to design a deductive reasoning intervention, based on the involved executive functions. Executive functions include working memory (WM)'s online executive processes and other off-line functions such as task revising and planning. Deductive reasoning is a sequential thinking process driven by reasoners' meta-deductive knowledge and goals that requires the construction and manipulation of representations. We present a new theoretical view about the relationship between executive function and higher-level thinking, a critical analysis of the possibilities and limitations of cognitive training, and a metacognitive training procedure on executive functions to improve deductive reasoning. This procedure integrates direct instruction on deduction and meta-deductive concepts (consistency, necessity) and strategies (search for counterexamples and exhaustivity), together with the simultaneous training of WM and executive functions involved: Focus and switch attention, update WM representations, inhibit and revise intuitive responses, and control the emotional stress yielded by tasks. Likewise, it includes direct training of some complex WM tasks that demands people to carry out similar cognitive assignment than deduction. Our training program would be included in the school curriculum and attempts not only to improve deductive reasoning in experimental tasks, but also to increase students' ability to uncover fallacies in discourse, to automatize some basic logical skills, and to be able to use logical intuitions.

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During the last decades theoretical and empirical advances in experimental psychology and cognitive neuroscience have yielded an important increase in our knowledge of the processes and mechanisms underlying human higher-level cognition, as well as the recognition of its limits and restrictions. There are multiple evidences confirming that comprehension, thinking and problem solving are complex behaviors which involve different levels, are carried out through the construction of representations and need the active use of working memory's (WM) storage and resources (see, for instance, Kintsch, 1998).

However, this clear breakthrough in the knowledge of the workings of human mind is not free of weaknesses and restraints. A general weakness of cognitive neuroscience and psychology is the fragmentation of research field in diverse areas insufficiently connected, as well as the development of multiple mini-theories fitted to each of these parts and tasks (Newell, 1990). This propensity to

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fragment the study of the mind may have obvious benefits in an initial stage of the scientific endeavor. However, if we want to get ahead in our knowledge of cognitive processes, we need to develop unified theories and perspectives of their functioning. The need for unitary perspectives is especially relevant when our aim is to improve higher-level cognitive processes.

In this sense, a notorious feature of our knowledge of the mind is the imbalance between theoretical and applied knowledge. The considerable amount of empirical knowledge, acquired in recent decades, on the functioning of higher-level cognition in diverse contexts, mainly laboratory ones, is adequately explained by our thinking and reasoning theories. However, the effective way to improve people's deductive reasoning—a key psychological ability in a very large list of social activities, from declarative learning at school, to work in science and philosophy, as well as to the argumentation on social and political issues—remains unclear. This mismatch between theory and practice needs to be overcome and the recent advances in the field of cognitive training may help us to get it.

This kind of unitary perspective of higher-level cognition has been already applied in a close related field of thinking, reading comprehension (García-Madruga et al., 2016). According to this perspective, a basic strategy to enhance reading comprehension is training readers´ WM´s executive processes implied on the realization of a selected sample of reading tasks. This intervention program showed positive and relevant effects in two experiments carried out by García-Madruga and colleagues (García-Madruga et al., 2013) with Spanish students of third grade of primary school. Likewise, Carretti and colleagues (Carretti et al., 2017) replicated and extended the results confirming the positive effects of the intervention program in a sample of Italian students.

In a similar way, the aim of this paper is to connect and integrate knowledge from diverse cognitive areas to get a novel integrative proposal based on evidence of how to improve deductive reasoning. The application to a new thinking process, in addition to reading comprehension, would allow us to have new evidence about the fitness of our theoretical view. In the next section, we will present our proposal that try to clarify the relationship between higher-level thinking abilities, particularly, deductive reasoning, with WM and executive functions (EFs). The following section will be focused on how to improve deductive reasoning by training the involved WM's executive processes. The article ends with a general discussion of the work presented, its limitations and future perspectives.

Executive Functions, Working Memory, and Higher-Level Thinking Abilities

Pursuing intentions and reaching goals are central operations and principal activities of the human mind. EFs are usually considered as the set of cognitive skills necessary for controlling and self-regulating goal-oriented behavior. EFs are particularly required when goal-directed thoughts, intentions, and actions are complex and not automatized. EFs hence constitute a crucial concept in cognitive neuroscience and psychology. However, there is neither a consistent definition nor a common theoretical model of EFs. In fact, EF has frequently been considered as a difficult, elusive or even confusing concept (see Baggetta & Alexander, 2016; Jurado & Roselli, 2007; Klenberg et al., 2001).

The origin of this conceptual confusion is diverse. The first and most important is the twofold nature of EF, a neuropsychological concept centered mainly upon the activity of frontal cortices (see Cummings, 1993; Fuster, 1989; Lezak, 1982; Luria, 1966), and one that has also been adopted and widely used in experimental cognitive psychology (see García-Madruga et al., 2016). Apart from confirming the role of the frontal lobes in executive functioning, neuropsychological studies have shown that other cortical and non-cortical regions of the brain are also involved (see Alvarez & Emory, 2006). The development of diverse brain regions directly related with EFs is particularly relevant in infancy and early childhood, but it is also relevant in adolescence and continues till young adulthood (see Blakemore & Frith, 2005). Understanding brain bases and the developmental pattern of each EF is the main endeavor of the neuropsychological framework. From an experimental psychology perspective, a crucial task is to clarify the relationship between the EFs and two other basic psychological and cognitive concepts: WM and higher-level thinking abilities. This will help to eliminate, or at least diminish, any existing conceptual confusion.

According to Baddeley and Hitch (1974), WM is the cognitive system responsible for the temporary storage and manipulation of information. Thus, WM capacity refers to the number of items that can be recalled during a complex WM task. The multiple component model that has become the most influential proposal (Baddeley & Hitch, 1974; Baddeley, 2007, 2010) includes two domain-specific storage structures (the phonological loop and the visuospatial sketchpad), an episodic buffer that links the two prior components with long-term memory (LTM), and a central executive. The main component of the WM system is the central executive or executive control (EC): Apart from coordinating the other components, it is in charge of the attentional control of information. Cowan's embedded-processes model (Cowan, 1999) and Engle's general capacity model (Engle, 2001; Unsworth & Engle, 2007), while neglecting the existence of domain specific components in WM, share with Baddeley's model the idea of a domain general central executive whose main function is to control attention and organize the flux of information by updating representations and inhibiting any other representations and processes. As we can see, for these models, EF is carried out within WM by means of a kind of central executive.

An important related and very influential view by Miyake et al. (2000) maintains a unitary perspective regarding EF, and postulates three interrelated but diverse EFs. Within the WM framework, these authors claim that the three executive components of EF are:

1. Set shifting: The ability to flexibly switch back and forth between tasks or mental sets.
2. Updating WM representations: The ability to monitor incoming information for relevance to the task at hand and then appropriately update by replacing older with newer information.
3. Response inhibition: The ability to inhibit dominant, automatic, or prepotent responses.

Previous views share the idea that EFs are tightly related and, in fact, the diverse EFs can be considered a result of WM central executive actions. A different view is that proposed by Diamond (2013) from a developmental neurocognitive perspective. This author considers EFs as enabling the mental manipulation of ideas, managing novel information, inhibiting and resisting temptations, and staying focused during the execution of difficult tasks. A main feature of Diamond's conception is her proposal of two main types of EFs, core and higher order EFs. The core EFs are three: (a) WM, (b) inhibition or inhibitory control, and (c) cognitive flexibility. As we can see, these three core EFs agree in a broad sense with those proposed by Miyake et al. (2000): WM is related to the updating of WM representations, and cognitive flexibility is related to task shifting or switching. This proposal differs from previous ones regarding the relationship between WM and EF: WM now is a part or component of EFs.

According to Diamond, higher order EFs, such as problem-solving, planning, and reasoning, are built from the core EFs. The proposal of higher order EFs is an important contribution of Diamond's theory. We agree that searching for solutions to complex and difficult cognitive tasks such as inferring the logical conclusion of syllogisms, solving mathematical problems, or playing chess, may require, apart from the core EFs, other specific and more complicated EFs that we shall analyze further on. But Diamond's proposal confounds EFs with higher-level thinking: Problem-solving and reasoning are not exactly EFs.

Higher-level thinking required to solve a problem or infer a logical conclusion demands the building of mental representations by integrating external and previously stored information and manipulating these in a cognitive space known as WM. According to the taxonomy of thinking formulated by Johnson-Laird (1988), problem-solving is the kind of thinking activity that, contrary to wandering mind's mere associative thinking, is goal-directed and has a purpose or objective. Reasoning is a type of problem-solving activity that has a clear and defined starting point, that is, the premises of the reasoning problem. From this definition, we can see that solving problems and reasoning certainly require EFs.

The thinking process in complex problem-solving and reasoning tasks involves various component sub-tasks that must be solved in a sequence and requires time to be done correctly. Individuals must keep their attention focused and the final goal of the task must be activated through the entire process. Other than the initial construction of representations and switching from one sub-task to the next, problem-solving and reasoning require individuals to update representations by activating LTM information and to inhibit and discard representations and responses. The fulfillment of these complex cognitive tasks demands that people activate all of their WM resources in a controlled and supervised way, that is, they require the activation of core EFs.

Besides core EFs, the complexity of computations and the extended-in-time character of resolution process often demands that individuals plan their behavior and as well as revise process and result. They often require the action of two higher order EFs: Planning and revision. Problem-solving activities may or may not require revising the final solution, but it usually requires elaborating a sequential plan of thinking activity. The Tower of Hanoi problem, for instance, a task used as a test of planning, does not require revision because the correct final solution is obvious. However, in mathematical problems, as Pólya (1945) has shown and every math teacher may corroborate, both planning and revision are crucial. On the other hand, in deductive reasoning, planning is not often required, but reflecting on the drawn conclusion and revising it are the final necessary steps of the reasoning process (see, e.g., Johnson-Laird & Byrne, 1991; Johnson-Laird et al., 1992).

The framework of EFs proposed by García-Madruga et al. (2016) is used in this paper to give account of these issues and to clarify the relationship between EF, WM, and higher-level thinking, particularly, reading comprehension (see Table 1) and deductive reasoning. As we can observe, this proposal includes, besides the three classic EFs proposed by Miyake et al. (2000) and Diamond (2013), a fourth core EF: Focusing and sustaining attention. This primary core EF is frequently forgotten in diverse theories, but as teachers and educational psychologists know, and Baddeley (2007) recognizes, the capacity to focus and direct attention is probably the most crucial WM's EF. These four core EFs agree with the

Table 1. *Main Types of Executive Functions according to García-Madruga et al. (2016)*

Executive Functions	General Characteristics
Focusing and sustaining attention	WM's on-line core EFs.
Switching attention	Every complex and novel cognitive task demands their use.
Activating and updating representations	
Inhibition	
Planning future cognitive behavior	Off-line higher order EFs
Revision of task execution	Complex thinking activities as problem solving and reasoning demand their use. They are carried out within WM and require applying core WM's EFs
Emotional control of behavior	Emotional processes
	They are involved in solving any kind of complex, novel and difficult task.

fourth component model proposed by Im-Bolter et al. (2006) that, other than WM's mental activation and mental inhibition capacity, also includes the EFs of shifting and updating.

Apart from the core and higher order cognitive EFs, there is another one clearly involved in an individual's action: The emotional control of behavior. The relevance of emotional or "hot" EFs has been pointed out by diverse authors, particularly by Zelazo et al. (1997; see also Zelazo et al., 2003). The ability to modulate and regulate emotional responses underlies all human behavior, including higher-level cognition.

We want to emphasize the tight relationships between EFs. These relationships change and develop with age and the consequent construction of a complex mind. As Miyake et al. (2000) highlighted, a main characteristic of the core EFs is that they are diverse but intimately related. The relationship between core and higher order EFs is also evident. Although planning and review have an early origin, EFs cannot develop adequately without the prior and substantial development of the core EFs. Higher order EFs require a prior ability to focus and maintain attention, to change attention between tasks, to update and connect with LTM, and to inhibit and resist automatic and intuitive responses and ideas (Diamond, 2013). Core EFs are in fact necessary preconditions of higher order EFs. The importance of inhibitory control is particularly clear in the executive functioning needed for complex thinking. Being able to devise a plan to solve a problem involves inhibiting unplanned but quicker responses; likewise, being willing to revise complex thinking activity implies the ability to inhibit closing the task too early.

In this section, we have presented our theoretical view on EF, its relationship with WM and the diverse kinds of EF involved in thinking, problem solving and deduction. Next section will address the enhancing of deductive reasoning from this theory, answering to three main questions: Why our training must be based on WM and EFs, how we have to carry out the intervention and what kind of deductive concepts and abilities we have to intervene on.

The Improving of Deductive Reasoning Abilities by Training the Involved WM's Executive Processes

This section encloses three diverse parts with different objectives. First part analyses the close relationship between deductive reasoning and WM and thus responds to first question above posed. In the second part, we carry out a critical analysis of recent work on cognitive training results and procedures answering to the question of how deduction can be improved. Finally, in the third part we will focus on the third question and present a basic intervention procedure that specifies the tasks to be trained.

Deductive Reasoning and WM's Executive Functions

Deductive reasoning is a kind of thinking activity that has a precise starting point, a set of premises, and a goal: Drawing a conclusion; therefore, many researchers have considered it as a type of problem solving. In deduction, the conclusions do not involve any increase in semantic information. Also, the process of connecting premises to the conclusion is ruled by logic, that is, the conclusions have to be necessary and consistent. Deductive reasoning, even the most elementary kind, is hence a complex phenomenon that requires individuals to follow a sequential process that includes various steps and tasks and the passage from one to another. A second source of complexity comes from the need to temporarily store and update the diverse representations needed to carry out a deductive sequence. A third aspect is meta-deductive and consists of the necessity to keep track of this sequential process by keeping in mind the restrictions that rule deduction.

There are diverse theories of deduction, the two classical being that of "mental rules" and "mental models." According to mental rules theories, people possess a set of rules, a sort of "natural logic" from which they reach a conclusion by following a sequence of steps. Reasoning proceeds thus in a derivation process in which people apply a series of rules and procedures that allows them to yield a conclusion (see Braine & O'Brien, 1998; Rips, 1994). Deduction is hence an effortful process that depends on the complexity of the deductive sequence and is therefore clearly affected by reasoners' WM capacity.

The theory of mental models (the "model theory" for short) postulates that when individuals face deductive problems, they construct models or possibilities of the meaning of assertions consistent with what they describe (Johnson-Laird, 2008/2012). The main assumption of the model theory concerns the crucial role of WM in deduction: Representing and manipulating models in order to reach a conclusion entail cognitive work and effort (Barrouillet & Lecas, 1999). Therefore, reasoners are likely to base most of their inferences from the initial and incomplete representation or models of the premises. An inferential conclusion is necessarily valid if it holds in all the models of the premises. Finding a valid conclusion to complex problems requires that individuals build complete representations of premises and validate initial conclusions by searching for counterexamples that can make them false. In spite of their differences, rules and model theories agree that individuals' WM capacity affects deductive process and conclusions.

A more recent conception is probabilistic or suppositional theory on conditional reasoning (Evans & Over, 2004; Oaksford & Chater, 2003; Oberauer & Wilhem, 2003; for a recent review and proposal see Oaksford & Chater, 2020). This theory considers that the conditionals cannot be interpreted in truth-functional terms, that is to say their truth does not depend on the values of their component propositions as they are represented in the truth table, whether this is that of material implication or that of equivalence or biconditional. A conditional "If Antecedent then Consequent" is not understood as true or false but is understood as more or less credible or probable, and its probability is defined as the probability that the consequent is given, once the antecedent is given: P(Consequent/Antecedent). According to suppositional theories, conditional reasoning relies on a likelihood estimate process that consumes WM resources. But these WM demands are mainly based in connecting with information stored in LTM. There is not a high demanding process as the searching for counterexamples. Therefore, the reasoning process relying on suppositional theories does not require WM resources as heavily as does the reasoning process based on the construction of mental models and the search for counterexamples (Verschueren et al., 2005).

As we have seen, with nuances and peculiarities, the cognitive theories of deduction highlight the function that WM has in reasoning. Apart from these reasoning theories, there is a general theoretical approach on thinking and reasoning in which the role of WM and executive processes is crucial: Dual-process theories (see, Evans, 2008; Evans & Stanovich, 2013; Kahneman, 2011; Kahneman & Frederick, 2002; Sloman, 1996). These theories postulate the existence of two different types or processing systems of thinking: System 1 (intuitive) and System 2 (deliberative). System 1 is considered fast, unconscious, associative, and not dependent on WM. System 1 allows individuals to quickly access intuitive responses that can be valid, but it is also a source of pervasive mistakes. On the other hand, System 2 is slow, conscious, controlled, and strongly linked to reasoners' WM as well as their thinking dispositions or mental styles. WM is thus a defining feature of analytical System 2.

System 2 is required to solve complex reasoning problems, although this is not a sufficient condition for valid responses. Most dual-processing theories assume System 1 yields intuitive responses that subsequent System 2 deliberation may or may not modify. Stanovich et al. (2011) claim that deliberative reasoning requires override System 1 processing. Overriding System 1 and activating System 2 processing require an individual's executive control, as well as a propensity to think actively and resist the premature closing of problems. Executive control processes thus play a crucial role in analytical System 2 reasoning processes (see De Neys & Glumicic, 2008; Evans, 2009/2012; Thompson, 2009/2012). From a mental model perspective, García-Madruga et al. (2007) highlighted that the central executive was the crucial WM component in the explanation of propositional reasoning performance. In order to confirm the role of executive processes in deductive reasoning, these authors used two WM central executive measures: the classical Reading Span Test (RST) (Daneman & Carpenter, 1980), in which people have to remember the final word of a series of sentences; and a new test that loads more on the central executive since it demands that people solve and remember the word solutions to a series of verbal anaphora. These authors found that higher WM participants, as opposed to lower WM participants, gave reliably more correct System 2 responses and fewer intuitive (System 1) responses to the deductive problems, particularly on the new more complex anaphora measure. Likewise, studies with syllogistic reasoning problems have borne out the crucial role of WM, particularly the executive processes (see Capon et al., 2003), as well as its relationship with the two types of reasoning processes (see Gilhooly et al.,1999).

The role of executive processes, particularly inhibition, has been also pinpointed in the well-known Wason selection task. In this task four cards (A, P, 7, 2)

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with a letter on the one side and a number on the other side, people are asked to turn over the cards that falsifies the rule: "If there is a vowel on the one side, then there is an odd number on the other side." People usually choose A and 7. This bias is called the perceptual matching bias because people choose the mentioned items (Evans, 1989; Evans & Lynch, 1973); however, the correct answer is A and 2, that is, people need to inhibit their first answer and redirect attention to the alternative response. Houdé et al. (2000) ran an inhibition control training session to avoid the matching bias and found a shift of brain activation using a positron emission tomography (PET) scan from the posterior part of the brain on the pretest to a left prefrontal network on the posttest; that is, from perceptual-related areas to WM-related areas. According to Houdé and Borst (2015), learning to inhibit misleading heuristic responses from System 1 and activate the logical algorithms of System 2 is the critical course of action that allows a person to reason logically (see also Stanovich et al., 2011); however, this capacity is highly dependent on the maturation of the prefrontal cortex.

From the dual-process theory, metacognitive processes have been highlighted by Thompson and colleagues. According to Thompson et al. (2011), System 1 processes are accompanied by a metacognitive experience, called the feeling of rightness (FOR), that is, the confidence in one's intuitive responses which can signal when additional System 2 analysis is needed. They found a robust relationship between the low FOR and the activation of System 2. More recently, Bago et al. (2019) tried to activate System 2 thinking using a second guess (two-response) paradigm in the bat-and-ball problem:

> *"A bat and a ball together cost $1.10. The bat costs $1 more than the ball. How much does the ball cost?"*

This problem is included in the cognitive reflection test developed by Frederick (2005) that allows evaluating individuals' ability to override System 1 processes and be able to give a hard System 2 response. Bago et al. (2019) asked participants to give a first answer to this problem and rate the confidence in their own responses. The most probable response was the intuitive answer "10 cents". Participants were also less confident in their incorrect responses than the correct ones. In a second guess, in which participants were allowed to give a second response to the problem, they made fewer mistakes than in the first attempt. Also, they gave responses smaller than the intuitive "10 cents" getting closer to the correct answer "5 cents." According to the authors, although biased reasoners did not know the exact correct answer, they knew the right answer should be smaller than the intuitively biased response. As we can see, the low confidence in the intuitive responses is based on partial insight into the nature of one's error. These results confirm the role of the FOR and highlight the importance of metacognition in the searching for System 2 responses (Ackerman & Thompson, 2017).

A second important result of the two-response paradigm is the existence of intuitive logical responses (Bago & De Neys, 2017). These authors examined the time course of dual-process theory and used time pressure and/or cognitive load to make sure that the initial response was really intuitive. They asked participants in the initial stage of a two-response paradigm to respond as fast as possible with the first intuitive answer that comes to mind. In the second stage of response, participants were allowed to generate their response taking all the time they want. The authors confirmed that reasoners were frequently able to give correct, logical responses in the first stage. Moreover, these initial correct responses were fast and high confident, and were given in the face of conflicting heuristic responses. The obvious conclusion is that some participants facing difficult deductive problems may be able to give fast intuitive responses that are correct and logical.

The existence of intuitive logical responses has been confirmed using other experimental paradigms and has induced the proposal of a revised 2.0 dual process theory (see De Neys, 2018; De Neys & Pennycook, 2019). According to new proposal multiple types of intuitive responses will be cued simultaneously (De Neys, 2012; Pennycook et al., 2015), ones emerging from the traditional superficial and beliefs bias, and others from an acquired knowledge of some basic logical principles. The different available intuitions can vary in their strength or activation level. When two intuitive responses of similar strength are cued by System 1 processing, a conflict between them is likely detected, and the deliberate System 2 processing is called on (Pennycook et al., 2015). The deliberate processing can then be used to override the dominant intuitive response, but it also can be used only to verify or rationalize it (García-Madruga, 1983; Pennycook et al., 2015).

Logical intuitions are most likely the result of the automatization mechanism that underlies learning and characterize the transition from novel to expert knowledge and abilities in diverse fields (Shiffrin & Schneider, 1977). The deliberate-to-intuitive automatization process has long been recognized by dual-process theories. According to Kahneman and Frederick (2002, p. 3), "complex cognitive operations can migrate from System 2 to System 1 as proficiency and skill are acquired." These authors mention as typical example the capacity of chess masters to perceive the strength or weakness of chess positions instantly as a kind of automatized System 1 ability. Similarly, prolonged exposure to mathematical and deductive tasks at school would be in the origin of logical intuitions.

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But logical intuitions are not the most important acquisition of the deductive learning process included in the instructional procedure presented in this paper. Our main aim is the acquisition of the capacity to identify, inhibit and override biased intuitions, by means of the applying of an entire deliberating process.

Our proposal maintains that in order to teaching people how to deal with complex deductive tasks it is necessary to instruct and train them on how to apply during the searching of solution the main EFs involved: (a) To focus attention and activate all cognitive resources; (b) to switch attention from one cognitive task to another, that is, to pass from one step to the next in a deductive sequence; (c) to activate and use knowledge stored in LTM in order to update WM representations and access to connected logical knowledge; (d) to inhibit initial intuitive responses and discard irrelevant information; and (e) to revise intuitive responses in a controlled metacognitive way, overriding the biased ones and confirming the logical ones. Apart from these main EFs, but closely related with them, the unfamiliarity and difficulty of deductive tasks may lead reasoners to get stressed and run off from the task. Emotional control is hence a sixth EF that has also to be trained. For this reason, we propose to include all of these EFs in an integrative reasoning training procedure. Our training procedure will be focused on learning the main deductive and metadeductive principles which allow the correct understanding and revision of deductive statements and problems, as well as the emergence of logical intuitions. But before presenting our intervention procedure we need to analyze the recent advances in the field of cognitive training in which our intervention is based.

Cognitive Training and the Improvement of Higher-Level Cognitive Abilities

Initial work focused on reasoning trainability has evidenced that formal training and teaching can improve inferential abilities (e.g., Cheng et al., 1986; Nisbett et al., 1987). Over the last few decades, research on the potential of cognitive training in different areas of cognition, including reasoning (Ariës et al., 2014), has been growing (see, e.g., Strobach & Karbach, 2016). Previous studies focused on induced cognitive and neural plasticity have evidenced the impact of training on both the structure and functioning of neural networks (Barnes et al., 2016). Consistent with this view, the effectiveness of cognitive training interventions is hypothesized and discussed. There are different approaches to executive functioning training. Recent review by Diamond and Ling (2020), including computerized and non-computerized cognitive training, neurofeedback, school programs, physical activities, mindfulness practices, suggests that both noncomputerized cognitive training and school programs show better results than computerized training to improve EFs.

Most interventions aimed at improving WM and EF are based on the design and application of a process-based WM training regimen (i.e., training of specific cognitive processes without explicit strategy training) based on intensive and systematic practice of complex WM tasks (e.g., Cogmed Working Memory Training Program; Klingberg et al., 2005). The results of different systematic reviews on the effectiveness of this type of intensive and systematic cognitive WM training programs indicate that they improve the performance on the trained tasks and other untrained WM tasks that share features close to those of the trained tasks (see Klingberg, 2010; Melby-Lervåg et al., 2016; Soveri et al., 2017). Positive effects were found in school-aged children, and adolescents with typical development (for review, Karbach & Unger, 2014; Melby-Lervåg & Hulme, 2013), but also up to adulthood (Karbach & Verhaeghen, 2014). Positive effects were also found with students with cognitive deficits (Dunning et al., 2013) or learning difficulties (Titz & Karbach, 2014). However, recent reviews (Sala & Gobet, 2017, 2020) suggest that the transfer effect of WM training to other cognitive abilities (fluid intelligence, academic skills, reading, or mathematics) is zero or, when observed, is minimal in typically developing school-children aged between 3 and 16 years.

Hence, the core question to be elucidated is what conditions give rise to the possible transfer following WM and EF training. In that respect, two main proposals both restraining widely the capacity of transfer are posed. One hypothesis is that WM training enhances the specific processes within WM that are engaged by particular tasks: a process-specific transfer view. Consequently, transfer should only be expected when trained and untrained tasks both place demands on the same processes (see, von Bastian & Oberauer, 2014). A second more restrictive perspective proposed by Gathercole et al. (2019) maintains that transfer from WM training is a consequence of the development of new routines that must be implemented to accomplish a mental activity and are applied to new tasks. In other words, transfer only occurs when individuals have learned a new complex cognitive skill in the course of training and when that skill can be applied to a novel task with similar structure. The new "routine" is needed to execute the precise sequence of cognitive processes when a task has complex and unfamiliar cognitive requirements.

On a more particular note with respect to a domain-specific training, some additional evidence comes from studies analyzing increased reasoning scores following different forms of WM training, particularly the

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specific impact of strategy-based WM training on reasoning. Ariës et al. (2017) reviewed literature and concluded that there is no convincing evidence that content-based WM training alone (e.g., n-back training) improves adolescents' reasoning skills in education. However, training that combines both content-based WM-capacity and reasoning-strategy could serve as an effective instrument to enhance school-based reasoning achievements.

For our purposes, we will focus on those cognitive training programs integrated into the school curriculum itself, so that the training is carried out in the social setting of classroom and in the context of learning tasks in which EFs are required (see Barnes et al., 2016; Meltzer et al., 2007). As mentioned above, previous findings indicate that school cognitive training programs showed mildly better results than computerized approaches at improving EFs measures (see Blair & Raver, 2014; Diamond & Ling, 2020). Although there are still scarce studies that try to improve EF in the context of learning activities that can be part of the curriculum, the results promise to enhance academic skills in the domain of mathematics problem-solving (Swanson, 2015), reading comprehension (García-Madruga et al., 2013), and reasoning (Ariës et al., 2014).

Our theoretical view maintains that an effective way to improve higher-level cognitive abilities by WM training would be through the design and implementation of instructional programs that explicitly emphasize the activation of the WM's online core EFs—the general domain component of EC—in the context of new and complex cognitive tasks that involve executive functioning in a specific domain (e.g., arithmetic, Sánchez-Pérez et al., 2018; reading comprehension, García-Madruga et al., 2013; reasoning, Ariës et al., 2014; see also Gobet & Sala, 2022). We share the idea that there is a general mechanism underlying the transfer from complex WM tasks to higher-level cognitive abilities such as reasoning, but we claim that there is also a specific mechanism bounded to the use of concrete tasks in the diverse fields. Thus, the activation of the specific mechanism involves both analyzing the role of EFs in the selected higher-level thinking ability and selecting a set of relevant tasks to train in the higher-level thinking field. Hence, our approach could also be aligned with the cognitive training as skill acquisition hypothesis (Gathercole et al., 2019) given that we attempt to improve higher-level thinking abilities (e.g., deductive reasoning) through WM and EF training during the carrying out of new and complex reasoning tasks. This aspect is an essential difference with respect to training programs particularly focused on intensive and systematic practice of complex WM tasks. The second main feature is that our training perspective is close to an ecological vision of cognitive training applied to education (Moreau & Conway, 2014). According to this view, the training proposal integrates complexity, novelty, and diversity to maximize ecological validity. This means that students will be engaged in complex and novel activities that combine diverse cognitive demands, as noted, and have real-world applications; meanwhile the program is designed to be implemented in educative natural classroom settings.

Overall, the findings suggest a promising line to design training programs for improving WM and EFs. Executive functioning training appears to transfer in some conditions, even though transfer appears to be narrow and some important questions remain. As Diamond (2013; Diamond & Ling, 2016, 2020) pointed out, a few principles seem to hold for effective training: (a) WM and EFs can be improved at any age through cognitive training and practice; (b) EF gains seem to depend on the amount of repeated practice; (c) EFs need to be continually challenged by training programs that keep incrementing task difficulty progressively as a person's skill improves; and (d) often those with the poorest EFs consistently gain the most from any program that improves EFs. Our view justifies the promotion of controlled processes using a metacognitive approach. In this way the participants would receive guidance in order to recognize the existence of control processes in the training program activities, as well as to think about and be aware of their importance.

In this vein, in the next section of this paper, we propose a training program with specific activities that have a relevant content for secondary students, for instance, fallacies in ordinary context, false beliefs of individuals, and fake news.

This part has allowed us to substantiate four main basic questions concerning to how to intervene. According to our review, our intervention program will not be a typical program of training WM and EF tasks to improve reasoning abilities, as it will be based on the improvement of WM and EF *during* and *within* the process of solving deductive and metadeductive tasks. Nevertheless, direct training of WM and EF has also an important role in our training method: Following Gathercole's (2019) view, the training of WM complex tasks implies to develop and practice diverse mental subroutines that are also involved in deductive and metadeductive tasks. As a matter of fact, complex WM and deductive reasoning share the need to activate the same core executive processes to solve tasks that demand reasoners to build and integrate multiple representations to draw inferences and remember the final result of a sequential thinking process. Our intervention program will apply the above effective training principles highlighted by Diamond and, likewise, it will be integrated in the context of learning activities at classroom.

A Metacognitive Training Procedure to Improve Deductive Reasoning

The development of reasoning seems to be closely related to the development of WM and executive processes (see, e.g., Camos & Barrouillet, 2018). With age, children are increasingly able to understand and infer valid conclusions from propositional assertions. According to the model theory, the developmental pattern is related to the number of true possibilities contained within each assertion: children first interpret conjunctions, and then disjunctions and conditionals. First defended by the model theory, this pattern of acquisition is directly related to an increase in WM capacity during childhood and adolescence (see Johnson-Laird, 1990; Johnson-Laird et al., 1992; see also Barrouillet & Lecas, 1999; Santamaría et al., 2013).

Due to its special relevance, researchers have paid particular attention to the development of conditionals. Children's interpretation of conditionals, such as "If it rains then Eliza uses an umbrella," seems to be based mainly on the construction of only one true possibility, the initial one that affirms both clauses: the antecedent and the consequent (it rains and Eliza uses umbrella); conditionals are thus interpreted as conjunctions. Older children and preadolescents are also able to construct and use a second possibility in which the antecedent and the consequent are negated (it does not rain and Eliza does not use umbrella); that is, at this age, most individuals make a biconditional interpretation of "if" assertions. Finally, only late adolescents and adults are able to build the third true conditional possibility which negates the antecedent and affirms the consequent (it does not rain and Eliza use umbrella). A complete interpretation of conditionals is thus a late developmental acquisition, particularly with abstract premises (see, e.g., Barrouillet et al., 2000; Markovits, 2000; Markovits & Barrouillet, 2002; Rojas-Barahona et al., 2010).

A similar developmental pattern was found in the interpretation and reasoning from syllogistic premises with abstract content by García-Madruga (1982). In this study, students of four academic levels (seventh graders, ninth graders, eleventh graders, and first year university students) were asked to interpret the four syllogistic premises by means of Euler diagrams. They were also asked to solve a set of syllogistic problems of various difficulties. The percentage of mistaken interpretations of the four types of syllogistic premises decreased with age, from seventh graders (12 years old) to university students (18.9 years old), although the percentage of incomplete representations (i.e., correct but not complete responses) was very high in both adolescents and adults. For instance, only a half of adolescents (eleventh graders, 16.5 years) and young adults (university students,) were able to correctly interpret universal affirmative assertions, such as "All A are B." The percentage of correct responses in the syllogistic reasoning task also increased with age, although the most difficult problems (i.e., those that demands exhaustivity and require searching for counterexamples) were also very difficult for older students.

WM's capacity is not, however, the only variable that explains the development of reasoning abilities throughout childhood and adolescence. As Inhelder and Piaget (1955) claimed, there are some specific changes in reasoning abilities during preadolescence and early adolescence, between 12 and 15 years: The acquisition of formal thought would be the result of a complete and prolonged in time period of school learning. Formal operations were explicitly characterized by Inhelder and Piaget (1955) as deductive reasoning abilities. Thinking does not require concrete or real situation but works in an abstract way, in the possible world, by means of propositional statements and hypotheses that can be exhaustively checked. As we can observe, the acquisition of formal thinking would imply the emergence of logical intuitions.

The connection between formal operational thought and logical intuitions may be explained from the concept of metalogical or metadeductive knowledge and abilities and its development. According to Moshman (1990; 2011), the new deductive abilities acquired in the stage of formal operations by adolescents must be interpreted as metalogical or metadeductive. They involve an individual's capacity to reflect on one's own logical activity itself and to distinguish between logical validity and reality. Metadeductive abilities include the implicit understanding of the logical system and its basic concepts of necessity and validity, as well as the explicit use of this knowledge by applying metalogical strategies, such as searching for counterexamples. There is a gradual acquisition of metalogical awareness during preadolescent and adolescent years: from 11 to 12 years, preadolescents begin to understand the concepts of necessity, consistency, and the validity of logical conclusions (Markovits et al., 2014; Santamaría et al., 2013). However, preadolescents and adolescents cannot think about the logical system as a whole and take it as an object of knowledge. Explicit metalogic capacity only becomes possible in late adolescence and adulthood when individuals are already able to apply metadeductive strategies in solving deductive problems. This late acquisition is unsurprising since these strategies involve applying the metadeductive concepts of necessity and consistency. This application is mostly difficult and demands the activation of the EFs. Searching for counterexamples is a deliberation process that implies both

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metadeductive concepts trying to falsify an initial conclusion. Exhaustivity also demands to apply both concepts in a task requiring high motivation and the avoiding of a premature close. The correct applying of these interrelated concepts and strategies will allow reasoners to solve any type of deductive problems.

Velasco and García-Madruga (1997) investigated the development of metalogical understanding and logical reasoning using abstract syllogistic premises during preadolescence and adolescence (between seventh and twelfth graders). They confirmed that a third of seventh graders (12.5 years old) were still unable to understand the logical concepts of necessity and validity correctly. Likewise, these authors found that only a half of twelfth graders (17.8 years old) used the strategy of searching for counterexamples spontaneously.

Given the developmental pattern we have briefly described, we may conclude that an instructional program on WM executive processes to achieve a global improvement of deductive reasoning and generate a general understanding of basic deductive and metadeductive concepts and abilities cannot be applied before adolescence. A successful earlier intervention on deduction is possible but limited to specific inferential rules and schemes and focused solely on the metacognitive acquisition and use of basic logical concepts, as Christoforides et al. (2016) have demonstrated through the implementation of a training program on conditional inferences for children between the ages of 8 and 11 years.

Our theoretical explanation on the relationship between EFs and thinking allows us to design a procedure for training deductive reasoning with adolescents. A first step in deduction is to reach the correct interpretation of premises, that is, to build a correct representation of premise meaning. The comprehension of premises is not specific to reasoning, but the goal-oriented sequential task of manipulating representations in order to arrive at a necessary conclusion is. This sequential task is performed in WM and can be defined as a specific kind of updating process. It is not driven by the input, as in the case of ordinary reading comprehension, but instead is a top-down updating process driven by reasoners' meta-deductive concepts and abilities. This meta-deductive knowledge includes the following tenants that: (a) Premises and conclusions must be consistent; (b) a valid conclusion must be necessary; (c) a useful strategy to reach a valid conclusion is one of searching for counterexamples; and (d) when looking for a necessary conclusion, reasoners should never quit before evaluating all the possibilities (i.e., their work must be exhaustive). In order to reach a valid conclusion in complex reasoning problems, individuals have to carry out a sequential top-down updating process that includes the following stages (see Johnson-Laird & Byrne, 1991; see also Fangmeier et al., 2006):

1. Comprehension of premises. Reasoners have to understand deductive premises in depth. They should search for and be aware of the different possibilities of the meaning of sentences. These possibilities must be consistent.

2. Integration of premises and formulation of an initial conclusion. This initial intuitive conclusion is likely not necessary; it is based only on a partial set of possibilities. Reasoners have to recognize that this initial response is likely invalid and therefore they should inhibit it. Some individuals can have a logical correct intuition which is likely correct, but it has also to be validated.

3. Validation. This revision phase is particularly important, and it takes time and can be very demanding from a cognitive and motivational perspective.

3 a. Applying a strategy of searching for counterexamples involves activating LTM knowledge, using diverse possibilities of the meaning of sentences, and combining these possibilities in order to falsify the initial conclusion.

3 b. Validation may be completed in two cases only: (a) A new conclusion without counterexamples has been found; and (b) An exhaustive analysis of the meaning of sentences does not find a necessary conclusion.

The four main objectives of the training program are to improve reasoners: (a) Comprehension of deductive assertions and premises; (b) metadeductive knowledge and revision strategies; (c) inhibitory control to avoid intuitive responses and a premature closure of the task; and (d) metacognitive control and monitoring of the updating process by means of explicit instruction and repeated practice to automatize the applying of metadeductive concepts and strategies. This fourth objective also includes the emotional control of the training tasks during the applying of program. The program is designed to be applied to 15–16 years old adolescents (tenth grade level) and consists of 12 sessions of 50 min, and eight different tasks (see Table 2). The first session focuses on explicitly laying out the theoretical basis of the instructional program, that is, the role of executive and metacognitive processes in reasoning. The presentation of the trained EFs is illustrated with a specific icon for each executive process (see Table 3). In this first session, we explain the sequence of deduction, the role of diverse executive processes including emotional control of the task, the difference between deduction and metadeduction, and the importance of metacognitive awareness of deduction.

We also present the FOR perspective in the activation of System 2 and the identification of fallacies: When the FOR is low, System 2 tends to activate. As being a result of automatization, logical intuitions would have a high FOR, and System 2 processes would not likely need to

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Table 2. *Description of Sessions and Training Tasks in the Deductive Reasoning Program*

Sessions	Tasks
Session 1	Introduction. Executive Processes in Reasoning. The sequence of deduction. Deduction and metadeduction. The development of metacognitive awareness of deduction. Fallacies and logical intuitions. The "feeling of rightness". What are we going to do? From lazy thinking to active thinking. The six executive processes we are going to train.
Sessions 2 and 3	Reasoning Task 1. Consistency. WM Task 1. Analogies. Reasoning short Task 5. Fallacies and Games.
Sessions 4 and 5	Reasoning Task 2. Necessity. WM Task 2. Anaphora. Reasoning short Task 5. Fallacies and Games.
Sessions 6 and 7	Reasoning Tasks 1 and 2. Consistency and necessity. WM Task 3. Operation. Reasoning short Task 5. Fallacies and Games.
Sessions 8 and 9	Reasoning Task 3. Searching for counterexamples. Reasoning Task 4. Exhaustivity. Reasoning short Task 5. Fallacies and Games.
Sessions 10 and 11	Reasoning Task 3. Searching for counterexamples. Reasoning Task 4. Exhaustivity. Reasoning short Task 5. Fallacies and Games.
Session 12	Recapitulation. Applicability and usefulness. Deduction and education: Automatization of deductive principles. Rationality and fallacies in ordinary life.

activate. This perspective has an interesting instructional corollary: To improve the activation of System 2 training must include instructional experiences that diminish people's FOR when facing fallacies. Likewise, we present the concept of logical intuitions and how to automatize metadeductive principles to get them. The following is an example of the specific reasoning contents:

Pablo is not very good in Maths. Isabel, his teacher, has told him: "if you work harder then you will pass the exam." In summertime, after the end of exams, we met Pablo and asked him whether he passed the mathematics exam or not. He told us: "The teacher is a liar, I did not work harder but I passed" What do you think? Is the teacher a liar? Why?

To solve this example participants will have to identify the "negation of antecedent" fallacy in a conditional "If A then B". Pablo committed this fallacy when considers that Isabel is a liar. According to this fallacy, when the antecedent is negated "I did not work harder," the only true possibility is the negation of the consequent "I did not pass the exam," therefore "I did not work harder and I passed the exam" is considered false, however this is wrong. Participants in our training program faced to this example will probably have a low FOR in this fallacy. Training work will have as objective to identifying and overriding the "negation of antecedent" fallacy, that is, to acquire a logical intuition against this fallacy.

The final session of the program is that of recapitulation: The main aspects of training as well as its utility for diverse situations and intellectual contexts are described and discussed with participants. Among a few of these contexts, practical examples are presented on daily situations, politics, argumentation, and academic subjects in the social and natural sciences, and that of mathematics.

The training tasks used in the program are three WM tasks and five reasoning tasks. At the end of these tasks a brief assessment of possible emotional troubles is carried out. All the training sessions, except the first and last ones, end with a short reasoning task that presents to secondary students some basic fallacies to be identified, as well as various activities relevant to their interests, such as Sudoku, detective games, and detecting fake news.

The instructional techniques are the same as those used in the reading comprehension program designed by García-Madruga et al. (2013): Direct instruction, modeling, and guided and independent practice. The three WM tasks are the analogy, anaphora, and operation tasks. In these tasks, participants must solve a series of verbal analogies, anaphora, or simple arithmetic problems and remember the solution to each of them. These tasks are complex dual tasks that involve the repeated operation of solving an inferential problem, as well as storing and maintaining activated in WM its solution. Therefore, WM tasks require the activation of the four core executive processes: Participants must focus and switch attention, update and connect to LTM to infer the solution to be remembered, and to inhibit wrong responses to the inference task. Most importantly, these WM tasks possess a very similar structure to reasoning tasks. Although a more precise analysis would be necessary, we think that these tasks probably involve some of the cognitive routines

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Table 3. *The Executive Processes Trained, Their Icons, and Reasoning Phases (in Italics) and Tasks*

Executive Function	Icons	Reasoning phases and tasks tapping into each executive function
Focusing		*Comprehension of premises, Integration of premises*, Anaphora, Analogies, Operation, Necessity, Consistency, Fallacies and Games.
Switching		*Comprehension of premises, Integration of premises*, Anaphora, Analogies, Operation, Necessity, Consistency, Fallacies and Games.
Connection with knowledge		*Comprehension of premises, Integration of premises*, Anaphora, Analogies, Operation, Necessity, Consistency, Fallacies and Games.
Semantic updating in WM		*Comprehension of premises, Integration of premises*, Anaphora, Analogies, Operation, Necessity, Consistency, Fallacies and Games.
Inhibition		*Comprehension of premises, Integration of premises*, *Validation*, Anaphora, Analogies, Operation, Necessity, Consistency, Searching for counterexamples, Exhaustivity, Fallacies and Games.
Revision		*Comprehension of premises, Integration of premises Validation*, Searching for counterexamples, Exhaustivity, Fallacies and Games.
Emotional control		All reasoning phases and instruction tasks.

also included in deductive reasoning tasks (see Gathercole et al., 2019).

In reasoning tasks, we use an adaptive learning procedure, that is, in each task, problems are presented in an increasing order of difficulty. This adaptive procedure is certainly important because promotes motivation and reduce the emergence of emotional control troubles. Participant's behavior throughout each task is recorded. The four core executive processes are involved in each of the training tasks and problems. Moreover, the sequential task of drawing valid deductive inferences requires the active monitoring of the reasoning process, inhibiting a premature closing of the task and revising any conclusions reached. In Table 3, the involvement of diverse EFs in each stage and task of reasoning can be observed. As mentioned above, the five reasoning tasks, particularly Task 5, include activities that address issues, contexts and contents of specific interest for secondary students, such as fallacies, Sudoku, fake news, etc. An example of task to work the main reasoning tasks (consistency, necessity, exhaustivity and searching for counterexamples) would be:

Premise 1: If it rains, then Eliza uses umbrella.
Premise 2: It rains.
Conclusion: She uses umbrella.

Is this conclusion (a) possible; (b) impossible; (c) necessary true?

In this task, people are asked to select the correct response. To resolve this problem properly, they need to search counterexamples that falsify this conclusion. As there is not an alternative conclusion, then the conclusion is necessarily true.

A second example would be:

Premise1: If it rains, then Eliza uses umbrella.
Premise 2: It does not rain.
Conclusion: She does not use umbrella.

In this case, the conclusion is not necessary, just possible, because there is another alternative conclusion, e.g., "it does not rain, and she uses umbrella." In the next example, the conclusion is impossible because it is not consistent with premises, that is, it does not follow from them. For example:

Premise1: If it rains, then Eliza uses umbrella.
Premise 2: It rains.
Conclusion: She does not use umbrella.

This type of tasks allows us to work on the main concepts that are important to think rationally and not fall into intuitive answers. People learn to exhaustively represent the possibilities, not just the first possibility that comes to mind, as well as to look for counterexamples and infer whether the conclusion is consistent or inconsistent with the premises, and therefore determine whether the conclusions are necessary, possible or impossible. As Johnson-Laird (2015) has highlighted, the key for improving thinking is to represent the highest number of possibilities. As the model theory has showed, one of the most persistent phenomena in deductive reasoning is the presence of illusions (see Khemlani & Johnson-Laird, 2017). According to this theory, these errors are made because people tend to represent just the initial models. Our prediction is that the present intervention program should be efficient to reduce these illusions by helping people to bear in mind as many alternatives as possible, not only the initial models, and also to search for counterexamples.

Discussion

Improving people's thinking and reasoning abilities is not a simple and easy task. To develop intervention procedures and training methods to improve thinking, we need to overcome the fragmentation of our knowledge and run through the limits between diverse areas and fields of neurocognitive science and psychology, particularly, the study of thinking, WM and executive processes, cognitive training and school education. We need hence trespass subject matters boundaries and become us in trespassers, as Albert Hirschman used to say speaking for social sciences.

Our theoretical view on executive processes allows us to develop specific procedures to improve thinking abilities. Following this theoretical background, we designed and evaluated empirically a procedure to improve reading comprehension in primary school students (Carretti et al., 2017; García-Madruga et al., 2013; García-Madruga et al., 2016). We think that, like in reading comprehension, a synergic confluence of the EFs and cognitive training with the theoretical analysis of deductive reasoning is possible. In the present paper, we present a proposal about the main EFs that are involved in higher-level cognition and, particularly, in deductive reasoning. According to our view, the EFs involved in deductive reasoning are: (a) To focus attention; (b) to switch attention from one cognitive task to another; (c) to update WM representations connecting with LTM knowledge; (d) to inhibit initial intuitive responses and discard irrelevant information; (e) to revise intuitive responses in a controlled metacognitive way; and (f) to control the emotional stress likely yielded by solving new tasks.

Our program to enhance deductive reasoning does not only comprise deductive contents and tasks but also includes the direct training of the complex WM tasks, although it is based on the training of the executive processes involved in deduction. As a matter of fact, complex WM and deductive reasoning share the need to activate the same core executive processes in an endeavor that demands people to manipulate and integrate multiple representations to draw inferences and remember the final result of a sequential thinking process.

The metacognitive procedure to improve deductive reasoning presented aims to integrate our claims regarding executive processes and the feasibility of its training, with an explanatory framework of deductive reasoning based mainly on mental models, dual processing and metadeductive approaches. The model theory and dual processing perspective allows us to analyze the diverse kind of deductive problems, as well as predict System 1 biases and the difficulty of the System 2 cognitive work. To avoid erroneous intuitive biased responses and achieve valid deductive conclusions, our proposal includes the training of the four metadeductive concepts and strategies that underlie deductive ability: Consistency, necessity, search of counterexamples and exhaustivity. Students' instructive work begins promoting a deep comprehension of deductive sentences and focuses on the applying of the six EFs to the explicit phases of the deductive process. Three particularly important features of the intervention program are to enhance the metacognitive monitoring of the updating process by means of explicit instruction and repeated practice, the inhibitory control, and the revision of intuitive responses. The logical intuitions that will emerge as a result of the intervention program may also need to be revised. This revision of logical intuitions will not probably cost either a lot of time or many cognitive resources since they have been recently acquired and will be almost obvious for participants. Our theoretical view on cognitive training holds that training complex WM tasks is also necessary since if they are adequately selected and used a transfer is possible. In line with Gathercole et al. (2019), we seek that training generates transfer using WM tasks that demand remembering elements that have been inferred. This kind of WM tasks involves the development of the same required routines necessary to adequately solve deductive problems, that is, the close interplay between WM and inference.

In the proposed cognitive training, individuals must learn new complex cognitive skills, as well as deductive and metadeductive principles that can be applied in different reasoning tasks required at school. As a matter of fact, these skills and concepts constitute the core learning abilities in complex declarative learning. Furthermore, metacognitive training promotes subject's conscious awareness of the relevance of the WM's executive control of deductive reasoning process and, by extension, of the higher-level cognitive process required at school.

Our proposal is based on the main theories and evidence on the research areas briefly examined and reviewed. The novelty of our intervention procedure emerges from the explicit integration of the diverse knowledge sources with a common applied aim: the improvement of deduction by means of an intervention program. As a matter of fact, the integrated view proposed in this paper is partially reached in other training and intervention proposals, though in less clear and explicit ways. In other words, some of the features of our proposal on the improvement of higher-level cognition are already present in the research atmosphere of the field. But some other features are new, for instance, the relationship between the development of metadeductive knowledge and logical intuitions. The main contribution of our proposal is that it is consistent, precise and testable.

Testability is both a positive characteristic of our intervention procedure and a main limitation of our work: The intervention program is only rationally based and is hence needed of empirical verification. Therefore, the empirical testing of our intervention procedure is the necessary next research step. This indispensable experimental testing work is not simple; it requires, at least, the following tasks:

1. To verify the predicted increase of deductive reasoning abilities. This involves the use of at least an active control group and to check not only the final result of the program but also some testing of the intervention process, as well as of the diverse tasks included.

2. Our program is based in the training of six basic EFs so an increase of students' ability in these EFs is predicted and must be checked in diverse tasks. Among them should be specific tasks on each EF and a fluid intelligence task.

3. Program also includes instruction to detect and prevent some basic fallacies in social ordinary contexts and acquire logical intuitions from the acquisition of metadeductive concepts and strategies. These new abilities of detecting and avoiding these fallacies as well as to use new logical intuitions should be also checked.

4. Finally, we predict an improvement in students learning abilities that should be shown in academic performance. It is expected to find not only a near transfer effect of training to measures of EFs and deduction, but also some evidence of moderate transfer effects that should be measured as improvements in learning abilities that tap or place demands on deduction and cognitively active and controlled performance from the learner in school subjects, particularly in mathematics-science subgroup of school subjects (e.g., Duque de Blas et al., 2021; García-Madruga et al., 2016; Gómez-Chacón et al., 2014; Gómez-Veiga et al., 2018). The checking of this predicted increase in academic performance is also a task to be carried out. There might be different cognitive (Deary et al., 2007), motivational (Gottfried, 2019) and environmental (Sirin, 2005) factors that have an influence and can explain the variation in academic achievement, so they should be considered when assessing the effectiveness of the proposed training program.

In this paper we have tried to present a sound and coherent synthesis of state-of-the-art of our understanding and information on how to improve thinking abilities in secondary school students. This proposal deserves to be known and discussed and obviously empirically tested.

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