Running Head: METACOGNITION AND EXECUTIVE FUNCTION FOR AGENCY

Integrating metacognition and executive function to enhance young children's perception of and agency in their learning

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Abstract

Metacognition and executive function have evolved largely in parallel across disparate disciplines. Additionally, limited empirical evidence—particularly in early childhood—exists integrating the two constructs. However, theories of both implicate regulation of lower-order processes providing greater flexibility to cognition and behavior by increasing focus on perceptions and understanding of one's learning and self-regulatory agency over habitual reactions to the environment and automaticity. Furthermore, considerable research identifies both metacognition and executive function as important processes that predict positive outcomes including academic achievement and learning. In the current paper, we review extant associations between early metacognition and executive function and theorize about their integration with the purpose of informing young children's ability to be active agents of their own learning and development. In addition, we argue that metacognition and executive function interventions can provide pertinent and important evidence regarding the development of enhanced perceptions of one's learning and agency. Specifically, we propose that by integrating metacognition and executive function in developmental theory, research, instruction, and interventions, children's awareness and control, or agency, in relation to their own learning can be enhanced. To this end, ways to study and integrate these skills are suggested, with an emphasis on how researchers and practitioners can bring metacognition and executive function together—in early childhood—to enhance perceptions of learning and agency and contribute to theory and practice across disciplinary boundaries.

Keywords: Metacognition, Executive Function, Perceptions of Learning, Agency, Early Childhood Development

Highlights

- Metacognition and executive function (EF) are positively related to outcomes.
- Limited empirical evidence exits combining metacognition and EF in early childhood.
- Relations between and interventions involving early metacognition and EF reviewed.
- Integrating metacognition and EF may enhance perceptions of learning and agency.
- This integrated meta-model contributes to early childhood theory and practice.

Integrating metacognition and executive function to enhance young children's agency

An important aspect of most young children's lives is learning how to adapt to the world around them, whether complying with teachers' expectations about behavior in class, turn-taking on the playground, interacting with diverse individuals, or when unsupervised time presents freedom as well as temptation. As clinicians and researchers, how can we characterize the domain-general skills that cut across domains of life? As practitioners and parents, how can we support them? Here we focus on two sets of domain-general skills whose connection is often assumed, but not well-understood: metacognition and executive function (EF; Bryce, Whitebread, & Szücs, 2015; Fernandez-Duque, Baird, & Posner, 2000; Roebers, Cimeli, Röthlisberger, & Neuenschwander, 2012). Specifically, in the current paper we explore young children's ability to self-regulate or be active agents of their own learning and development.

Children as Agents of Their Learning

In what follows, we look for clues about the development of children's agency in, and perceptions of, their own learning by examining the mechanistic relation between metacognition and EF. Whereas the role of metacognition has often been discussed in domain-specific areas like reading and math, we focus on its role in the domain-general executive functions. In particular, we argue that the emergence of early metacognitive abilities enables young children to become increasingly aware —i.e., enhance their perceptions—of the information processing made possible by EF, to perceive and reflect upon their own EF, and thus to take increasing levels of control over their learning. This enables young children to move towards a more pro-active or agentic management of information and tasks they engage in.

Before delving into our thesis, we first conceptualize and elucidate metacognition and EF as important, interconnected, early-developing skills.

Conceptualizations

We focus on metacognition and EF due to their prominence and significance in early childhood and strong propensity to predict learning, developmental, and academic outcomes. They are explicitly linked together in the self-regulation literature (Lyons & Zelazo 2011; Roebers, 2017). We underscore metacognition as a pathway for facilitating children's understanding of *when* and *how* to apply EF by enhancing their understanding, learning, and agency.

We view metacognition as the knowledge, monitoring and control of one's cognition (Flavell, 1976; Nelson & Narens, 1994). For example, while building a puzzle, a child checks the front of the box (monitoring) and makes any needed adjustments to the construction (control). We view EF as a set of abilities—inhibitory control, working memory and shifting—which allow individuals to process information in a goal-directed, context-appropriate way, rather than based on habit or instinct (Diamond, 2013; Miyake et al., 2000). For example, a child remembers and follows multiple-step directions when visiting a museum (working memory); a child waits to be called on before answering a teacher's question (inhibitory control). We assert that across each of these components of EF, the transition from reactive to pro-active occurs as metacognitive processes enable increasing levels of self-regulation (i.e., agency).

For the purposes of this paper we do not distinguish between different subcomponents of metacognition and EF because existing empirical evidence is sparse in the early years, even at

the broader level of the overarching constructs. Furthermore, there is mixed evidence that the subcomponents of EF can be reliably distinguished in young children (Hughes, Ensor, Wilson, & Graham, 2010; Roebers, 2017; Wiebe et al., 2011). Note that, for both metacognition and EF, these should not be taken as strict or static definitions. They are—in every sense—*working definitions* to be adjusted based on empirical evidence in what is currently a dynamic field of inquiry.

Based on these working definitions of metacognition and EF, we argue that these processes contribute to children's agency by making them active in the learning process, rather than just passively responding to external demands or routines. Thus, self-regulation through metacognition and EF, depends in part on children's perceptions of themselves as learners and their ability to adapt accordingly (see also Hacker, Dunlosky, & Graesser, 2009).

Behaviorally, metacognition and EF both show rapid growth in the early years. First, although continuing to mature for several years, many of the most radical changes observed in EF occur between four and six years of age (Carlson, 2005; Huizinga, Dolan, & van der Molen, 2006; Jurado & Rosselli, 2007). Similarly, rapid changes in metacognition are observed between three and seven years of age (Bryce et al., 2015; Roebers et al., 2012) with children beginning to use mental state terms around their second birthday (Bartsch & Wellman, 1995), reflecting emerging metacognition. Moreover, a 'lean version' of early metacognition—not requiring explicit awareness—has been shown as early as three-months (Sodian, Thoermer, Kristen, & Perst, 2012**;** see also Perner's 'MiniMeta', 2012). Across the lifespan, both metacognition and EF seem to share relations with other processes such as: theory of mind (Carlson & Moses, 2001; Frith, 2012; Sodian et al., 2012), self- and source-monitoring (Fernandez-Duque et al., 2000;

West, 1996), and goal neglect and planning (Fernandez-Duque et al., 2000). Souchay and Isingrini (2004) even propose that the decline in metacognitive control observed in older individuals may be explained by a decline in EF. Metacognition and EF thus share parallel developmental trajectories.

Theories of both metacognition and EF propose models reflecting modulation of lower-order processes (e.g., Nelson & Narens, 1990, 1994). In this way, meta / executive mechanisms add greater flexibility to cognition and behavior by enhancing perceptions of one's learning and agency, rather than relying on habitual reactions to the environment. Both involve monitoring and regulating input needed for goal-directed action. For example, asking for help can involve perceiving and being aware of one's abilities in relation to the current task (metacognition) and suppressing the impulse to repeat a failing strategy (EF).

Lastly and importantly, metacognition and EF share fundamental characteristics, in particular "controlled processing, relevance for self-regulated learning, neuropsychological correlates, developmental timetables, and mechanisms of change." (Roebers & Feurer, 2016, p. 40). Considerable research implicates both metacognition and EF as important processes for enhancing positive outcomes including academic achievement, learning, and well-being, though metacognition and EF have until now almost always been examined separately (Blair & Diamond, 2008; Roebers, 2017; Veenman & Spaans, 2005). Researchers have noted the importance of including both constructs in studies examining children's learning given their theoretical and empirical associations and hypothesized interacting relations over development (e.g., Bryce & Whitebread, 2012; Roebers et al., 2012; Whitebread, 1999).

By integrating metacognition and EF in developmental theory, research, instruction, and interventions, children's agency toward their own learning can be enhanced. We view this as a moment by moment iterative process. Children monitor their own mental processes like EF, and accumulate more metacognitive knowledge about them. In turn each aspect of information processing becomes more efficient, including children's ability to select from a repertoire of increasingly efficient strategies. As agency develops in early childhood, so does the ability to be pro-active and self-regulated in learning contexts.

Generalizing to New Situations

Elucidating metacognition and EF skills, their functions and interconnectedness in early childhood will make it easier for adults to support children's developing agency in their own learning. Several meta-analyses found that cognitive training in young children is most effective when meta-skills (e.g., metacognition and EF) are deliberately integrated (Dignath, Büttner, & Langfeldt, 2008; Dinsmore, Alexander & Loughlin, 2008; Hattie, Biggs, & Purdie, 1996; Rosenshine, Meister, & Chapman, 1996). We suggest that integrating metacognition and EF optimizes the chances of success due to an increase in children's perceptions of their own learning (e.g., Lyons & Zelazo, 2011). As noted by Lin (2001), this entails training a combination of specific skills and techniques (EF) along with knowledge about *how* and *when* to apply these in new circumstances (metacognition). In other words, supporting children's learning involves helping them develop agency over their own learning. This idea is similar to the Good Information Processor proposed by Borkowski, Chan, & Muthukrishna (2000), who "...understands *when*, *where* and *why* these strategies are important" (p. 4). We expand on this

concept and propose integrating metacognition and EF to specifically facilitate children's agency in their own learning.

Relation between Metacognition and EF in Development

Metacognition and EF are constantly taxed in children's everyday lives, in a variety of contexts (in class; on the playground; at home) and with a variety of things at stake (others' feelings; their own development, learning, academic achievement, and wellbeing; smooth functioning of a classroom; Baker, Gjersoe, Sibielska□Woch, Leslie, & Hood, 2011). For example, a child may say the first thing that comes to mind even if it could hurt a friend's feelings (EF failure) or while reading a book, a child is unaware of having skipped several pages (i.e., metacognition failure). Roebers (2017) recently proposed a unifying framework for metacognition and EF suggesting they are highly overlapping constructs. We build on this proposal specifically shining a light on how metacognition and EF operate together, supporting an ever-greater repertoire of adaptive behaviors for learning and development.

To our knowledge, there are three key review papers germane to this topic (Diamond, 2013; Dinsmore et al., 2008; Hofmann et al., 2012; note also Marcovitch, Jacques, Boseovski, & Zelazo [2008] who argue for a link between EF and self-reflection). Dinsmore et al.'s (2008) review encompasses metacognition and SR, but not EF. Hofmann et al. (2012) examined the research on EF and SR in adults without mentioning metacognition. The focus on adults means it does not address the question of how these abilities may be developmentally related and specifically implicated in children's perceptions of their own learning, which is central to the present paper. Diamond (2013) focused more on children, and proposed a model integrating EF and SR, but without metacognition. Recently, Roebers (2017) connected metacognition and EF

through a new unifying framework of cognitive self-regulation. In her review, she highlighted the broad overlap between EF and metacognition. We extend Roebers' (2017) analysis of relations between metacognition and EF to suggest that by integrating metacognition and EF in early years, we offer children the opportunity for greater agency in their own learning. We are not aware of any theoretical review paper examining the relations between metacognition and EF in early development, focused specifically on how they function together to enhance learning.

We approach our undertaking developmentally, focused on the childhood years, where rapid change can be observed in these abilities and underlying brain structures (e.g., Fernandez-Duque et al., 2000) yet empirical work regarding the relation between these skills is scarce. Our review is theoretical, focusing on how the integration of early metacognition and EF will enhance children's agency (including self-perceptions and self-regulated action). Taking a developmental focus complements investigations of the same abilities in adulthood (in particular see Hofmann, Schmeichel & Baddeley, 2012), and amounts to dismantling the engine of a car to better understand how it works. In the current paper, our contribution lies in elucidating 1) the agentic role of young children in their own learning focused on developing meta / executive skills 2) how children's perceptions of their own learning can be facilitated through early interventions focused on integrating EF and metacognition.

Examining the relation between metacognition and EF is rendered complicated by the lack of consensus over how to reliably operationalize each of these constructs. This includes fuzzy conceptualizations, with different researchers and practitioners using the same words to mean different things, or different words to mean the same thing, also known as the 'jingle-jangle' issue (e.g., Brown, 1987; Dinsmore et al., 2008; Lyons & Zelazo 2011; Morrison &

Grammer, 2016). In addition, metacognition and EF are often studied within different traditions and for different purposes. Often, EF research in early childhood takes a mechanistic focus prioritizing the elucidation of component parts and their interrelations whereas metacognition research in early childhood often tends to have a more practical focus on efficacy and improving learning.

Empirical evidence on associations between metacognition and EF is sparse (but see Roebers, 2017 for a recent review). As a result, we frame our paper as a forward-looking theoretical review in the absence of widely established and replicated findings on links between early metacognition and EF. Our own literature search found only a handful of papers that included explicit (and separate) measurement tools of both metacognition and EF in early childhood (ages two-eight). When we searched for either metacognition OR EF separately, we found thousands of empirical papers. However, when we searched for metacognition AND EF, we found 60 published papers. We then examined the abstracts for these 60 papers, evaluating study design; the conceptualization of metacognition and EF; and whether a "fatal flaw" was present. This resulted in a selection of 11 papers (see Table 1 for details).

Four of these papers discussed the connections between EF and metacognition theoretically, but did not include empirical measures of both constructs (Chevalier, Martis, Curran, & Munakata, 2015; Kovac-Cerovic, 1996; Watson & Westby, 2003; Whitebread et al., 2009) nor did they specifically touch on the idea of integrating metacognition and EF for enhanced agency in learning, one of the key contributions of the current paper. In their review paper, Watson and Westby (2003) examined the long-term effects of EF deficits of prenatal exposure to alcohol and other drugs and discussed implications for educational interventions.

Although their theoretical account of research and interventions implies a connection between supporting EF and metacognition, there is no empirical link between EF and metacognition in this paper and the implied relation between EF and metacognition is not examined in depth. In the empirical piece by Kovac-Cerovic (1996), parents interacted with their children on tasks within their children's zones of proximal development to foster their metacognitive development; however, there were no explicit EF tasks. In the introductory overview of the paper, the author alluded to—but did not explicitly examine—a connection between EF and metacognition. Chevalier et al. (2015) examined behavioral, eye-tracking, and electrophysiological measures of EF (termed executive control) and assessed the metacognitive processes inherent in children's responses to differential task conditions, but did not include separate measures of metacognition so that metacognition and EF could be analytically or statistically compared. In developing an observational instrument to measure early metacognition, Whitebread and colleagues (2009) wrote about the relation between EF and metacognition in their introduction, but did not dissociate the two constructs in the study's methods and results. Indeed, they included both metacognition (e.g., knowledge about tasks) and EF (e.g., control of behavior resulting in a change to the way something is done, i.e., switching) in a single instrument. So, it seems the relation between EF and metacognition is assumed to be established, though the precise nature of the association has not carefully been examined. Empirical work is necessary to shed light on this.

Beyond these four papers exploring theoretical links between EF and metacognition, only seven published papers empirically examined both EF and metacognition within the same study (Bryce et al., 2015; Chevalier & Blaye, 2016; Geurten, Catale, & Meulemans, 2016; Marulis, Palincsar, Berhenke, & Whitebread, 2016; Murray, Theakston, & Wells, 2016; Roebers et al.,

2012; Whitebread, 1999). There is further work with adults, for example Follmer & Sperling (2016) examined the mediating role of metacognition between EF and self-regulated learning. Further, Ciurli et al. (2010) and Souchay and Isingrini (2004) reported empirical work examining the association between EF and metacognition in clinical adult populations. However, our review focuses on the development of EF and metacognition specifically in relation to developing agency in one's learning.

In what follows we interpret the findings of the existing empirical evidence on the relations between EF and metacognition (see Table 1). However, as noted above, there are conceptual and methodological disparities across the studies, making some of these interpretations tentative.

Bryce et al. (2015) examined metacognition and EF skills in five- and seven-year-olds during a problem-solving task, and associations to educational achievement. They found moderate correlations between metacognition and EF in the five-year –olds, and weak correlations between metacognition and EF in the seven-year –olds. Metacognition was the strongest predictor of educational achievement in both age groups. Consequently, they suggested that mastering EF skills *alone* is insufficient for enhanced metacognition or educational achievement, consistent with our view that children need both metacognition and EF to become agents of their own learning. However, as this study used a correlational design, more work is needed to examine the causal links between metacognition and EF. For example, reporting partial correlations controlling for the child's age and verbal ability would contribute to the theoretical significance.

Chevalier and Blaye (2016) gave six- and ten-year-old children a self-paced EF (dimensional change card sort) task, and used response latencies (i.e., how long children took to prepare for a trial) and eye-tracking (where they were looking when the trial began) to deduce children's metacognition. Therefore, the metacognition measure was an indirect measure while the EF measure was a direct measure, meaning any comparison would be confounded by task demands. Nevertheless, the authors interpreted their findings as supporting the idea that developmental changes in EF may be driven, at least in part, by changes in metacognition. These findings suggest integrating metacognition and EF for the development of agency via perceptions of one's own learning. Overall, the authors found that gaze trajectories (metacognition) and performance on the task (EF) increased over time (i.e., older children were "more prepared" than younger children). Relatedly, older children were better at monitoring how they employed control, which the authors viewed as a reflection of the influence of metacognition on EF development.

Geurten et al. (2016) examined how metacognition (metamemory: knowledge of internal memory strategies, knowledge of external memory strategies and knowledge of general memory functioning) improves during childhood and the factors associated with this improvement. Four groups of children (age four, six, nine, and eleven) were assessed on a battery of EF tasks (working memory, inhibitory control, and planning) in addition to the metacognition tasks, as well as receptive vocabulary, verbal fluency, and intelligence measures. For the purposes of this paper examining early childhood, we focus on results for children aged four and six. Results included significant low to moderate associations between EF (working memory, planning, inhibitory control) and metacognition (both total score and the internal knowledge strategy) for six-year-olds (and up) but *not* four-year olds. Mediation analyses revealed that EF partially

mediated the impact of age on some aspects of metacognition, but not others, suggesting a nuanced relation between EF and metacognition.

Marulis and colleagues (2016) found associations between metacognition and EF in three- to five-year olds when children were given increasingly difficult puzzles. Metacognition was operationalized as metacognitive knowledge, based on a series of interview questions (e.g. "How well do you think you did on the puzzle?"). In another session, a combination of EF components was measured using the Head Toes Knees Shoulders task (HTKS; Ponitz, et al., 2008), where children responded to commands with a conflicting behavioral action (e.g., children must touch their toes when they hear "touch your head"). Lastly, as a covariate, expressive language was assessed using a standardized measure. Metacognition was more strongly related to academic achievement than EF, although EF and metacognition were interrelated.

Murray et al. (2016) aimed to improve young children's EF in the Marshmallow Test (delay of gratification; Mischel & Ebbesen, 1970) through the use of a metacognitive training technique known as the Attention Training Technique (ATT; Wells, 1990). The ATT involves metacognition because it develops children's strategic allocation of attention, to increase flexible choice via awareness of internal and external experiences. Five classes of five- and six-year olds were randomly assigned to either the ATT or a no-intervention (business as usual) condition and were tested pre- and post-intervention on delay of gratification, response inhibition (on a developmentally appropriate Stroop task), and measures of mood. Results indicated that children who received the ATT (metacognitive intervention) significantly increased on delay of gratification (EF) compared to the no-intervention condition. After controlling for age and months in school, the ATT and response inhibition task performance were significant

independent predictors of delay of gratification. This reflects the thesis of this paper regarding the integration of metacognition and EF for enhanced performance and outcomes.

Roebers et al. (2012) longitudinally assessed metacognition and EF in seven-year-olds and then followed up with them one year later. Metacognition was split into monitoring (indexed by confidence judgments in a writing task) and control (indexed by self-corrections in the writing task). EF was measured with multiple sub-tests, each designed to reflect a sub-component: inhibition, updating and fluency. Their findings suggest that EF was more closely associated with metacognitive control than with metacognitive monitoring. Note that the authors measured components of metacognition and EF with tasks requiring varying levels of explicit responses, and correlations were strongest between tasks with the most similar task requirements (e.g., less explicit tasks were inter-correlated more robustly; see also Middlebrooks & Sommer, 2012 for non-human animal work in this area). This highlights the importance of task demands when making comparisons between developmental mechanisms.

Lastly, Whitebread (1999) examined EF (working memory assessed via digit span, see Halford, 1980), and metacognition (metacognitive knowledge and awareness, confidence judgments, and monitoring and control via use of strategies) of six-, eight- and ten-year-olds related to problem-solving tasks. Children with limited metacognition tended to use inefficient strategies in the problem-solving task, placing a heavy load on EF (working memory). Children with more developed metacognitive abilities, however, tended to use efficient strategies, reducing the EF (working memory) load, so performance was less dependent on EF. This finding shows how the interplay between EF and metacognition may vary depending on the developmental level of the learner in question (see Table 1).

In short, while still needing to be replicated and extended, there are a small number of findings in early childhood that support a developmental association between metacognition and EF. We argue that metacognition facilitates children's perception of their own information processing in general, and EF in particular, allowing children to reflect and be pro-active in their own learning. Specifically, in this paper, we claim that the way metacognition can help children to build agency over their own learning is by making it clear *when*, *how* and *why* to use EF. In other words, having EF skills does not guarantee they will be used. It is more likely they will be used if the learning is made visible, i.e. through the explicit integration of metacognition and EF, enabling children to instrumentalize the tools they have. This is not a new suggestion regarding domain-specific learning. Indeed, metacognitive skills have been shown to predict achievement across domains (e.g., inductive reasoning: Prins, Veenman, & Elshout, 2006; mathematics: Lucangeli & Cornoldi, 1997; science: White & Frederiksen, 1998; writing: Harris, Graham, Brindle, & Sandmel, 2009; and reading comprehension: Palincsar & Brown, 1984). Such findings have been widely disseminated to teachers and practitioners, in reading comprehension (Cross & Paris, 1988; Paris, Wixson, & Palincsar, 1986; Pressley, 2002) and mathematics education (Desoete, Roeyers, & Buysse, 2001; Garofalo & Lester, 1985; Schneider & Artelt, 2010). The distinct contribution of the current theoretical review regarding children's perception of their learning and agency is twofold. First, we propose that metacognition be specifically integrated with EF, particularly in instruction and interventions. In other words, not only does metacognition facilitate achievement in specific domains, but also in domain-general skills such as EF. Secondly, we focus on early childhood, where there is still limited theory and evidence regarding the role of metacognition in relation to other skills.

Evidence from Metacognition and EF Intervention Studies

In what follows we adopt a more practical orientation, taking stock of the lessons learned from early metacognition and EF interventions regarding the impact on learning and achievement. Specifically, we will see that EF interventions tend to support specific skills relevant for specific tasks. By contrast metacognition interventions are more likely to be broad and integrative, promoting the generalization of learned skills by contextualizing new strategies. We also propose reasons metacognition and EF interventions may differ in their nature and scope of effectiveness. Namely, we submit that where interventions support children in integrating metacognition and EF for learning (the "when, where and why"), children develop greater agency in their learning, leading to more sustained, generalizable outcomes.

EF Interventions

Evidence from EF interventions is mixed. Whereas targeted skills may be improved, generalized transfer of specific EF training is not normally observed. In cases where EF training has a wider impact on learning and development than the specific skills that were trained, it is because the approach to training was more holistic.

Jacob and Parkinson (2015) conducted a meta-analysis to examine the effectiveness of EF preschool interventions. In the majority of interventions reviewed, participants were given a "dose" of EF training and then tested on whether this transferred to learning and academic achievement in a systematic and controlled way. Although some interventions showed narrow training effects of particular skills, these gains did not tend to have wider impacts on other areas of learning and development. Surprisingly, they found that, overall, there were negligible effects on cognition and problem-solving (e.g., Diamond, 2006). Pandey and colleagues (2018) recently reported more consistent, though not large, effects of EF interventions in their systematic review

and meta-analysis. In reviewing interventions across preschool and adolescence, these authors found that positive effects of interventions on self-regulatory skills, including EF, have been observed in a range of outcomes including academic achievement, but also other life outcomes like healthy behaviors and employment status. A brief overview of the nature of the interventions may help shed some light on why effects generalize or replicate in some cases, but not in others.

Whole curriculum: Tools of the Mind (*Tools*) targets EF in preschool-aged children (Bodrova & Leong, 2007). One key component of the program is that teachers scaffold children in writing explicit plans for their dramatic play, so that play becomes more complex and planful and is more likely to exercise EF. Moreover, teachers facilitate children's representation skills by encouraging them to record their plans using drawing or writing in a variety of areas such as mathematics. EF can be enhanced via the *Tools* curriculum, relative to business as usual, in low-income preschool-aged children (e.g., Diamond, Barnett, Thomas, & Munro, 2007). However, note that Farran, Wilson, Lipsey, & Turner, (2013) did not replicate this effect (see also Barnett et al., 2008). Furthermore, preschool teachers who were trained to use the *Tools* curriculum were rated as having better classroom management than those who were not *Tools* trained. However, EF may have been enhanced by *Tools*, but this did not lead to significant gains in a broader sense (Diamond & Ling, 2016; Jacob & Parkinson, 2015). Another whole curriculum supporting the development of EF that did lead to measurable wider outcomes was the Chicago School Readiness Project (Raver et al. 2011). This curriculum arguably supports more than just EF, given the emphasis on both emotion control on the children's part, and stress reduction on the teachers' part. The notion of offering children and teachers a wide range of strategies for a wide range of situations is consistent with the idea of intentionally integrating metacognition and EF for applying more basic skills. Another example was provided by Benzing and colleagues

(2018) who conducted an intervention later in primary school with 10-12-year-olds. Following an eight-week intervention, with a passive control group, specific improvements were detected in EF, but no other outcomes were tested so the generalizability cannot be evaluated.

Targeted bolt-ons. In addition to the well-known whole school programs, there have been several attempts to improve specific subcomponents of EF (e.g., working memory; inhibitory control; shifting) through targeted training programs for individual children (e.g., Nutley et al., 2011; Rueda, Checa & Combita, 2012). Targeted EF interventions, inspired by the experimental psychology tradition, tend to observe limited success for wider transfer, beyond the specific tasks where training took place (Cardoso et al., 2018; Dunning, Holmes, & Gathercole, 2013; Moreau & Conway, 2014). It seems that children are more likely to use new cognitive skills, such as EF strategies, when they are also given support to contextualize those skills, with help in knowing *how* and *when* to apply them.

Metacognition Interventions

To examine what underlies successful interventions on metacognition, we again look to a meta-analysis (Dignath & Büttner, 2008) and a meta-review (Dignath et al., 2008) targeting primary school children. Both of these meta-studies highlight the importance of context in supporting the development of metacognitive skills, such as training teachers or parents, or giving children strategic tools to facilitate transfer from a specific training situation to application of the newly learned metacognitive skills in other situations.

Metacognition interventions tend to be designed with a holistic educational perspective, supporting learners across a range of areas such as cognition, self-regulated learning, motivation

and affect. Theoretically, educational perspectives are more likely to be influenced by sociocultural theory (Vygotsky, 1978), which suggests that children learn optimally through social interactions with others. This is reflected in the fact that metacognition interventions frequently include a teacher-training and peer component, with children being prompted to explain their thinking and reasoning to others (e.g., Perels, Merget-Kullmann, Wende, Schmitz, & Buchbinder, 2009;). Lin (2001) underscores the recent shift in metacognition research from training strategies to creating social environments that support metacognition. Moreover, metacognition training programs now tend to focus both on domain-specific knowledge (e.g., reading or mathematics) and knowledge about and perception of the learning process itself. To our knowledge, this perspective shift has not widely manifested within EF interventions.

Though there are considerably fewer early childhood metacognition than EF interventions, we know of three that specifically target metacognitive skills in young children (Gonida, Kiosseoglou, & Papakyriakidou, 2015; Rueda, Pozuelos, Paz-Alonso, Combita-Merchan, & Abundis, 2011; Whitebread, Pino-Pasternak, & Coltman, 2015), which all found significant, and substantial, positive effects. The Perels et al. (2009) intervention cited above, though inherently metacognitive, did not target metacognition directly. Instead, it focused on the self-regulation cycle of pre-action, action, and post-action phases. Furthermore, this intervention targeted preschool teachers rather than children (though effects were seen for both teachers and children). Of the other three, only one—Children Articulating Thinking (ChAT) a dialogic and problem-solving based intervention (Whitebread et al., 2015)—is similar in scope to *Tools* in that it was integrated into a school curriculum and conducted over the course of a year by classroom teachers who were trained by experimenters. This intervention was designed to facilitate five- and six-year-olds' metacognition via collaborative problem-solving and dialogue

(i.e., talk activities; Mercer & Littleton, 2007) within science and art domains and problem-solving tasks. Significant metacognitive benefits were found for the experimental (and not comparison) group. Encouragingly, unlike the targeted EF training programmes mentioned above, some transfer to non-trained tasks was found. Therefore, we recommend that future metacognition interventions examine transfer effects to skills, tasks, or contexts, not specifically trained in the intervention.

In sum, evidence (though limited) suggests that interventions are more likely to produce significant, far transfer effects when they explicitly incorporate metacognition: *how, why,* and *when* to apply the EF to new situations. These are tools that educators can easily incorporate into their everyday practices with children of a range of abilities to facilitate the development and application of metacognition and EF.

Moreover, different EFs may be relevant in different contexts, and the ability to strategically apply them may rely on the learner's perception of the learning task. For example, it could be helpful for a child to understand (metacognition) that recruiting working memory skills (EF) is important for multiple-step problems, while being aware that (metacognition) using cognitive flexibility (EF) is important for solving open-ended problems. Likewise, knowing (metacognition) that one needs to put forth or recruit extra effort to inhibit distracting temptations and follow through on plans (EF) may be crucial for finishing pragmatic tasks like putting away art supplies. These examples begin to offer a picture of how these distinct yet interacting processes may feed into one another in the service of young children's agency in their own learning.

Lines for Future Research

In what follows, we propose ways to extend our understanding of how to use integrated metacognition and EF to promote agency in children's learning.

First, it seems vital to understand how the associations between metacognition and EF may vary across different knowledge domains and types of activities. Steps could be taken in this direction by focusing efforts on longitudinal and intervention studies in the early years of life. The success of such an endeavor will depend on the careful design of research studies, and the use of sensitive measures of metacognition and EF, and examining non-verbal as well as verbal approaches (Perner, 2012). Such research would reveal the degree to which these factors facilitate metacognition and EF, and could potentially uncover alternative representational tools (e.g., mental imagery as opposed to self-talk) that may be taught in clinical or educational settings to support metacognition and EF (Kuvalja, Basilio, Verma, & Whitebread, 2013). Furthermore, future studies should account for other factors that may affect the success of integrated metacognition and EF for learning, such as motivation and IQ.

Second, a promising area for future research surrounds the portfolio of measurement tools in research designs. When Dinsmore et al. (2008) analyzed the alignment between authors' construct definitions of metacognition and the types of measures they used, they found substantial variance. They concluded with a plea for researchers and educators to be 'vigilant' in their operationalization of constructs. A similar issue arises in the EF literature, with studies often measuring EF in variable ways. It is also common to witness a range of tasks, with widely differing task demands, within a single study. Theoretical interpretations are constrained by substantial differences in task requirements, rendering it challenging to compare across studies. To avoid the jingle-jangle problem and elucidate the developmental relations between

metacognition and EF, we need precise conceptualizations and aligned assessments. How are the metacognition and EF subcomponents distinct from one another? How are they related? What is the relation between metacognition and EF, and their subcomponents? This precision would then allow for consistency across studies, and accuracy in assessing the influence of each construct on children's agency in their own learning.

In addition to rigorous research tools, transdisciplinary collaborations are essential. We see optimal value in adopting a combination of theoretical and practical approaches in examining ways to enhance children's agency: metacognition, reflecting the ecologically relevant context where learning occurs, is just as important as the individual psychological mechanisms that support reasoning and action via EF. On the one hand, educators have experience in thinking about ecologically valid scenarios that can be used to develop scalable solutions. On the other hand, researchers have experience in devising rigorous measures and interpreting findings along theoretical lines. Together, they could contribute to building our knowledge about the fundamental psychological processes involved in metacognition and EF, and the environmental factors that affect them to support children in gaining deeper agency.

Finally, varied research designs are also critical. Multiple sources of data, including observations/quasi-experiments, experiments, and parent or teacher reports of the same abilities can provide converging evidence, a more nuanced picture of the developmental relations between metacognition and EF, and indications of how combining these constructs in interactions, instruction, and intervention may enhance children's perception of their own learning and agency. Furthermore, neuroscientific methods present a promising avenue to explore implicit processes relating to both metacognition and EF, without requiring a conscious

or verbalizable component to the task (Gilbert & Burgess, 2008; Hajcak, Moser, Yeung & Simons, 2005; Torpey, Hajcak, Kim, Kujawa, & Klein, 2012).

Conclusions and implications

Our theoretical review aimed to demonstrate how the integration of metacognition and EF can support children's perception of, and agency over, their own learning. This involves making learning visible (via integrating metacognition with EF skills) so children can appreciate their strengths and limitations, evaluate their own performance, and make appropriate adjustments. This also involves children's ability to be strategic and engaged in achieving their learning goals, knowing *how*, *when* and *why* to use specific EF processes. Making learning visible by integrating metacognition and EF can also support transfer to a range of new situations beyond which the original learning took place. Together this suggests that children's metacognition and EF work most effectively in consort to support their agency.

There are also clear areas where practitioners can take steps to support children's metacognition and EF. Practitioners and researchers together should carefully consider using rich approaches to assessing what children know about their own learning, and what they can do, when, and how. Furthermore, it is clear, given the substantial individual differences observed between and within children, that children need help recruiting metacognition and EF in the right way at the right time. Therefore, we conclude with a call for a multi-tiered approach involving lab- and classroom-based research and integrated transdisciplinary metacognition and EF training for both educators and children.

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