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Metacognitive processes and associations to executive function and motivation during a problem-solving task in 3–5 year olds

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Abstract

Metacognition—knowledge, monitoring, and regulation of cognition—is key to learning and academic achievement. This is robustly supported for K-12 and higher education learners while empirical evidence in early childhood is encouraging but limited. To address these gaps in the literature, our first goal was to investigate early metacognition across two developmentally appropriate measures. Our second goal was to examine associations to executive function and motivation. Participants were 77 preschoolers, aged 3–5. Metacognition was measured using a metacognitive knowledge interview (declarative metacognition) and a metacognitive skills observational scale (procedural), both in the context of a problem-solving puzzle task. Executive function was assessed with the Head Toes Knees Shoulder measure and motivation was operationalized as persistence (time on task) on the puzzle. All children exhibited evidence of metacognitive knowledge and skills. Declarative and procedural metacognition were significantly and positively related to one another and to executive function and motivation, though to varying degrees. Controlling for language and age, metacognition significantly and positively predicted executive function and motivation. Metacognitive *knowledge* predicted executive function and metacognitive *skills* predicted motivation. Results contribute to psychology and education by reinforcing recent findings that metacognition develops far younger than was originally thought, and explicating relations between and providing models for assessing early metacognition, executive function, and motivation. We propose that these skills are intentionally fostered in early childhood.

Keywords Metacognition · Executive function · Motivation · Early childhood · Early years

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The preschool years (in the United States typically ages 3–5) are a critical period for developing self-regulated learning (SRL) skills and strategies (Bronson 2000). Decades of work on SRL—beginning around Zimmerman 1990 with Zimmerman's highly influential paper (Zimmerman 1986)—have identified, conceptualized, and studied these SRL interrelated processes that are depicted by active (e.g., motivated, regulated, metacognitively aware and knowledgeable) learners. Many have suggested that the key SRL skills are metacognitive, executive function (EF), and motivational processes (e.g., Dignath et al. 2008). Metacognitive and EF skills are particularly influential on basic learning and developmental processes whereas motivation tends to have a greater positive effect on applied learning and academic achievement (e.g., Zimmerman 1990).

Metacognition and associations to executive function and motivation in early years

Within SRL factors, one—metacognition (Mc)—has consistently excelled in terms of predicting learning and academic achievement (e.g., Dignath et al. 2008; Wang et al. 1990). However, this has not been systematically examined in the early years (ages 5 and under), which are particularly fruitful for the optimizing learning and learning-to-learn (Bronson 2000). To this end, we focused on examining and elucidating metacognitive processes in 3–5-year-old children in the present study. Secondarily, because the SRL skills and strategies have all been found to be positively related to learning and one another, we examined early EF and motivation to better understand how these key SRL factors interact together in young children.

Metacognition

Metacognition includes knowledge, monitoring, and regulation of cognition. In its essence, it is "thinking about thinking" or "cognition about cognition" (i.e., Flavell 1976). While traditional conceptualizations of Mc have focused solely on monitoring *cognition* (e.g., Flavell 1979), more recent conceptualizations have incorporated monitoring of *behavior, emotions,* and *motivation* (e.g., Boekaerts 1999; Efklides 2011). Traditionally, Mc has been conceptualized as consisting of two main constructs: declarative metacognitive knowledge (of people, tasks, and strategies) and procedural metacognitive skills[1] (encompassing monitoring and control) (e.g., Brown 1978). Flavell's conception of Mc was that of a stage theory wherein, with experience, we learn to *monitor* our cognition by understanding what we need to monitor and *regulate* our thinking by setting goals and initiating strategies to achieve these goals and assess progress. Successful and efficient interactions between these metacognitive processes were proposed to predict and lead to enhanced learning and performance (Flavell 1976, 1979). Other prominent researchers have held similar beliefs, for example, underscoring Mc as a "hallmark of higher intelligence" (Brown 1987, p. 71) and conceptualizing it as highly

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[1] Throughout this paper, when referring to procedural Mc, we will use the term "skills" rather than "behaviors." Though skills are often referred to in relation to training whereas behaviors are referred to distinct from training or experience (e.g., Shamir et al. 2009), we use "skills" to indicate likely usefulness and to align with previous literature, procedural Mc is typically conceptualized as skills (Schneider and Lockl 2008; Veenman et al. 2006).

proficient information processing with executive (or meta) regulatory skills (Bewick et al. 1995; Brown 1978; Brown et al. 1983). Since that time, researchers have provided extensive empirical evidence—including several meta-analyses—that Mc is critical to academic success even after controlling for cognitive and other self-regulated learning—SRL—(e.g., motivation) factors (e.g., Dignath et al. 2008; Wang et al. 1990).

Early Years Metacognition

Because Mc has traditionally been believed to emerge around age 7–8 (e.g., Kreutzer et al. 1975; Veenman et al. 2006), the majority of what we know about early Mc is based on these middle-childhood years. However, the capacity to monitor one's cognitive operations appears to emerge during the preschool years between approximately ages 3–4 (Lyons and Ghetti 2013; Rohwer et al. 2012). During this time, children begin to be able to provide feeling-of-knowing judgments that predict later memory performance (Cultice et al. 1983) and to show awareness of comprehension failures (e.g., Revelle et al. 1985). Even so, Mc has rarely been examined in children prior to formalized schooling (for exceptions see Bryce and Whitebread 2012; Gourlay et al. 2020; Rohwer et al. 2012; Shamir et al. 2009; Whitebread 1999; Whitebread et al. 2007, 2009, 2010). This pioneering research has been critical for expanding our understanding of when and how Mc processes development as well as how to optimally characterize, facilitate, and assess these processes in young children. It is even rarer that researchers have included more than one measure of Mc in the same study or examined declarative metacognitive knowledge in depth such as by using an interview or set of metacognitive knowledge questions with children under the age of 7; this gap is particularly important to address because early years are essential to developing "best practices" of learning at basic as well as applied levels (e.g., Bronson 2000).

Executive function

Executive function (EF) is of particular interest to those who study preschool-aged (3–5-year-old) children because this period is a time of emergence and great growth in EF for most children (Diamond et al. 2005) and, in turn, has been studied widely in the early years (Diamond et al. 2005). EF is conceptually similar to Mc and is an important construct to consider while elucidating metacognitive processes (Marulis et al. 2020; Roebers 2017). Similar to Mc, EF involves a set of cognitive components working together to regulate behavior. The literature on EF implicates three central components: *working memory* (i.e., processing and manipulating stimuli), *inhibitory control* (self-control, inhibiting automatic reactions while initiating learnt yet adaptive or socially acceptable reactions) and *attentional shifting or cognitive flexibility* (resisting distraction and shifting tasks when necessary, mental set shifting) (Blair and Razza 2007; Diamond 2013; Miyake and Friedman 2012). In sum, EF involves neurocognitive processes important for goal- and future-directed actions (e.g., Follmer and Sperling 2016; Morrison et al. 2010) and typically emerges in the preschool years (Wiebe et al. 2011) making it important for gaining a more comprehensive understanding of early Mc through their associations, differences and similarities in e (Bewick et al. 1995).

Interrelations between Mc and EF in children under age 7 are often assumed but not well-understood theoretically or empirically (Marulis et al. 2020; Roebers 2017). However, though this work is focused predominantly on children above age 7, there are exceptions to this including empirical work by Bryce et al. (2015), Garner (2009), Roebers et al. (2012), Roebers and Feurer

(2016), Spiess et al. (2016), and Whitebread (1999) and theoretical work by Marulis et al. (2020), Fernandez-Duque et al. (2000), and Roebers (2017). For example, Roebers (2017) explained that though researchers have traditionally approached EF and Mc separately, there are many underlying similarities that warrant further investigation. Most recently, Marulis et al. (2020) emphasized the importance of examining and intervening on these skills in an integrative way in early childhood to best understand and affect development and learning.

Motivation

Like Mc and EF, motivation has been conceptualized and measured in many ways and has been identified as a key variable in children's cognitive, metacognitive, and SRL processes (e.g., Efklides 2011). Wolters and Pintrich (1998) conceptualized motivation as being akin to the starter of a car, such that it is prerequisite to participation; subsequent actions were attributed to self-regulation. In the current study, we conceptualized motivation within the framework of Bandura's social cognitive theory (Bandura 1989), as "goal-directed behavior" (Pintrich and Schunk 2002, p. 161) more broadly. Moreover, we operationalized motivation as persistence or time on task: the amount of time one chooses, or is able, to spend on a task that is moderately challenging (MacTurk and Morgan 1995; Berhenke et al. 2011). Persistence has been found to be associated with enhanced learning and academic achievement (Schunk 2008). By assessing young children's motivation in this way (i.e., observation of time spent on task), we intentionally limited the obstacles present in self-report of motivation that are of particular concern when examining skills and processes in young children (Berhenke et al. 2011). Throughout this paper, we have used the term motivation to represent persistence, or how much time is spent on task.

As with EF, theoretical and empirical links between metacognition (Mc) and motivation have not been thoroughly explored in early childhood nor is it clear how to disentangle these processes at the level of theory or of practice. There has been considerable theoretical and empirical literature regarding the interconnectedness between Mc and motivation in older children and adults (e.g., Dinsmore et al. 2008; Efklides 2011; Zimmerman and Moylan 2009). For example, Efklides (2011) described Mc as the ability to monitor and regulate one's cognition *under the influence of* motivation. Specifically, motivation was regarded as prerequisite to Mc (Efklides 2011). Similarly, many others have conceptualized Mc as a motivated process (e.g., Bandura 1989; Efklides 2011; Schunk 2008). Ever since the mid-1980s when researchers and educators began to discuss and study SRL, motivation and metacognition have been conceptualized as intertwined and to have reciprocal effects (Paris and Winograd 1990). Bandura (1989) suggested that metacognitive skills tend to be inconsequential if not applied with motivational factors such as perseverance and resilience. Relevant to applied contexts, Chatzipanteli et al. (2014) indicated that educational practitioners can best facilitate young children's Mc within an environment that is experienced as highly motivating and engaging (see also Whitebread et al. 2007, 2009 for additional work within early years education).

The current study

The focus of the current study was to elucidate metacognitive processes—centered on metacognitive knowledge and metacognitive skills—in 3–5 year-old children. We did this in the context of a problem-solving task based on literature indicating that individuals tend to display higher levels of metacognitive and executive processes while problem-solving (Antonietti et al.

2000; Aşık and Erktin 2019). We had two overarching aims: 1) to examine early years Mc and compare results across different measures, and 2) examine associations between Mc and EF as well as between Mc and motivation. Our specific aims and hypotheses are as follows.

First, we sought to examine the conceptualization and measurement of Mc in young children by assessing and comparing data revealed by two different measures of Mc. One measure focused on metacognitive knowledge while the other focused on metacognitive skills (monitoring and control). Based on recent research with preschool-aged children (e.g., Gourlay et al. 2020; Shamir et al. 2009; Whitebread et al. 2009), we hypothesized that our developmentally appropriate and sensitive measures (Marulis 2014; Marulis et al. 2016; see Appendices A-E)—would optimally elicit Mc in the early years (e.g., Bryce and Whitebread 2012) and that these two measures would be moderately correlated but that there would be meaningful variance left to explain, indicating that these are distinguishable components of metacognition. However, this remains largely an exploratory question as there are few studies that have examined metacognitive processes in this age range (see Marulis et al. 2016; Coughlin et al. 2015; Lyons and Ghetti 2013; Shamir et al. 2009; Whitebread et al. 2009 for exceptions).

Second, we sought to examine how these metacognitive processes were associated with EF and motivation to provide additional information regarding the conceptualization of Mc. To this end, we sought to examine correlations between variables (aim 2a) and assess the predictive power of Mc (knowledge and skills) for EF and motivation (aim 2b). Regarding aim 2a, we hypothesized that early Mc (both metacognitive knowledge and metacognitive skills) would be significantly and substantially associated with both EF and motivation (e.g., Whitebread 1999) and that metacognitive skills would have the stronger relation to EF compared to declarative metacognitive knowledge (e.g., Marulis et al. 2013; Roebers and Feurer 2016). Similarly, we hypothesized that metacognitive skills would relate more strongly to motivation (e.g., Bahri and Corebima 2015, however, see Zimmerman and Moylan (2009) for the possibility that relations between motivation and both components of Mc may be comparable). Finally, given the lack of early childhood literature contributions of Mc to EF and motivation, our last aim (2b) was exploratory. To our knowledge there are no studies which have a) focused on early years, b) included a full declarative interview along with systematic observation of procedural Mc in the same study, and c) examined associations to other key SRL processes such as EF and motivation.

Method

Participants

Participants were 77[2] 3-5-year-old children (*M*age = 4.22 years, *SD* = 0.78; *n*=30 3-year-olds; *n*=29 4-year-olds; *n*=18 5-year-olds; 61% female) who were recruited from six classrooms at a College Lab School in the Northeast region of the US. Participants came from predominantly English-speaking middle-class families; 64% were Caucasian, 24% Biracial, 4% Black/African American, 3% Latino, 1% Asian, and 4% did not report. Several children were unable

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[2] Originally, our sample included an additional 19 2-year-olds; however, 9 of these children were unable to complete any assessment and another three were only able to partially complete the assessments. Thus, we concluded that the tasks (never before used with children under 3) were not developmentally appropriate for 2-year-olds due to the verbal and time demands. We therefore excluded these participants.

to complete specific tasks because they were English language learners, diagnosed with a learning-related disability, didn't want to participate or continue with the assessments, or left the school prior to all assessments being completed; these children (*n*= 5) were excluded from the current analyses resulting in a sample of 72 children. On a few measures, we only obtained complete data for 71 children. This is explicated in the Results section.

Measures and coding

Beyond the way Mc has been measured (e.g., decontextualized questions with high working memory load), some of the discrepancies regarding the onset and development of Mc are likely due to the developmental appropriateness of the type of measurement applied (e.g., verbal reports vs. observational studies) as well as the environment in which Mc was measured (e.g., lab vs. naturalistic settings such as preschool classrooms). In more recent studies of early Mc, researchers have employed naturalistic observational measures with the intention of limiting reliance on self-reports or assessments that require verbalizations in children under 7 years (e.g., Whitebread et al. 2007). Results revealed extensive evidence of metacognitive knowledge, strategies and regulation in 3-5 year-old school children (Gourlay et al. 2020; Jeong and Frye 2020; Shamir et al. 2009; Whitebread et al. 2007, 2009, 2010); evidence of Mc spanned across individual and group learning tasks and was predictive of cognitive ability and learning. These findings have laid a strong foundation for researchers to examine the predictive role of Mc in young children. Consistent with and expansive to this approach, we examined metacognitive knowledge and skills, motivation, and EF using developmentally appropriate tasks assessed within our college lab preschool, an ecologically valid setting that allowed for greater opportunities to elicit naturally occurring Mc (and related constructs: EF and motivation) than would a traditional research lab or artificial-learning setting.

The Wedgits© task

We developed the Wedgits© challenge-puzzle task (Appendix 1) based on guidelines set forth by mastery motivation researchers for tasks which provide just the right amount of challenge to keep young children engaged (e.g., Smiley and Dweck 1994) and our pilot analyses (Marulis et al. 2016; Berhenke et al. 2011) which indicated that it was appropriate and enjoyable for preschool-aged children and able to keep their engagement and optimize their emotional and behavioral processes. Furthermore, this task was designed to be challenging enough (not too easy and not too difficult), to identify the tip of each child's zone of proximal development (ZPDs; Vygotsky 1978) where scaffolding is needed for successful completion, to optimally elicit Mc (Prins et al. 2006). The Wedgits© task served as a contextualized activity designed to facilitate the elicitation of children's declarative metacognitive knowledge, procedural Mc, and motivation. The puzzle cards and allotted time (4 min) were chosen based on pilot work (Marulis et al. 2013, 2016; Berhenke 2013) to provide the appropriate level of challenge for the range of children of this age as well as to be engaging for the children to maintain their interest.

Specifically, children were instructed to build increasingly more challenging structures with Wedgits© puzzle pieces (D building blocks) that matched model cards. All children completed the first "warm-up" puzzle (model card 0; see Appendix 1). For this "warm-up" puzzle alone, the experimenter provided general scaffolding assistance if needed (i.e., no metacognitive, EF, or motivational suggestions). Next, all children attempted the second puzzle (model card 1) with no assistance. If they were able to complete this puzzle in under 4 minutes, they were given a third, and so on, up to five puzzles (model card 4). Children worked on one puzzle at a time and were only presented with a new, more challenging, model card if they successfully built the last one in 4 minutes or less unaided. The reason for this was that our main goal of this study was to precisely measure children's metacognitive knowledge and skills (monitoring and control) which are recruited predominantly during challenging tasks (e.g., Prins et al. 2006). To this end, we individualized this task so that Mc and motivation were assessed in connection with each child's most challenging puzzle; assessment scores were based on each child's "challenge puzzle" rather than using one specific puzzle for all children.

Metacognition

Metacognitive knowledge interview (McKI) Following the completion of the final (most challenging) Wedgits© block puzzle, children's declarative metacognitive knowledge was individually assessed using the Metacognitive Knowledge Interview (McKI; Marulis et al. 2016; see Appendix 2). The McKI was intentionally created to be a developmentally appropriate contextualized interview measure based on Flavell's (1976) original conceptualization of metacognitive knowledge of people, tasks, and strategies. All McKI assessments were conducted by the first author who is not only certified to teach PreK-6th grade and has an early childhood certification, but is also a researcher and college professor. Children were asked a series of 15 questions to assess their metacognitive knowledge regarding the Wedgits© task (see Appendices A & B; all questions with two choices were counterbalanced, e.g., #3: "Will the puzzle be harder/easier when you're older? Why?"). Questions 1, 4, 5, and 6 assessed knowledge of people, e.g.: "Do you think you did a good, okay, or not so god job on the puzzles? Why/Why not?"; "Would this puzzle be hard for another kid your age?". Questions 2, 3, 9, 10, and 11 assessed knowledge of tasks: "Would the puzzle be easier with bigger or smaller pieces? Why?"; "Would the puzzle be easier with more or less pieces? Why?". Questions 7, 8, 12, 13, 14, and 15 assessed knowledge of strategies: "Would talking to yourself during the puzzle be helpful? Why/Why not?"; "If I think about how the pieces would fit together before I try, will the puzzle be easier? Why/Why not?"

Responses were rated on a 0-2 scale as follows (Marulis et al. 2016): 0=not at all metacognitive, 1=partially metacognitive (e.g., they agreed that talking to oneself can be helpful in solving a task but their reason is not related to cognition or they did not know why), 2= appropriate metacognitive response (therefore the highest possible score was 30). This scoring system took into consideration both declarative and conditional metacognitive knowledge by analyzing children's "knowing that" and "knowing why" (Flavell and Wellman 1977). Two researchers independently coded 30% of the sample on the McKI (Intraclass Correlation [ICC]=.98).

Metacognitive skills in constructional play engagement (MetaSCoPE) coding scheme The Metacognitive Skills in Constructional Play Engagement (MetaSCoPE) is an observational tool (see Appendix 3) used to assesses procedural metacognitive skills during (quasi)naturalistic problem-solving tasks. It was designed to address both children's monitoring (i.e., ongoing assessment of problem-solving performance) and control (i.e., strategic responses to monitoring) of their performance (Nelson and Narens 1990) *and* their failure to do so or "lack of monitoring and control" (Bryce and Whitebread 2012). Each component of metacognitive skills included four specific skills. The coding scheme (Appendix 3) accounts for verbal and nonverbal behaviors and was found to be appropriate for preschoolers and was associated with their metacognitive and self-regulatory processes (Bryce et al. 2015;

Whitebread et al. 2009). To this end, we adapted this observational coding protocol for use with the Wedgits© task and named it MetaSCoPE (Appendix 1). Conceptually, the Wedgits© task is similar to Karmiloff-Smith's (1979) train-track problem-solving task used previously (Bryce and Whitebread 2012; Bryce et al. 2015). Two differences are 1) that the Wedgits© task was timed to provide motivational data (i.e., persistence / time on task) and 2) children were given progressively more challenging puzzles until unable to complete them within 4 minutes to elicit ZPD states in the children for optimal recruitment of Mc (Prins et al. 2006). The code categories (Bryce and Whitebread 2012; Bryce et al. 2015) aligned with the Wedgits© puzzle tasks overall Monitoring (e.g., "Checking Construction": The child checks their puzzle construction), Control (e.g., "Planning": Verbalizations that precede the action and indicate future actions such as "I am going to put the red piece on the bottom before this green one"), and Lack of Monitoring and Control (e.g., "Finishing Error": The child claims to be finished when there is a discrepancy between the puzzle they built and the model card). Our adaptations involved adjusting the language of the coding scheme to align explicitly with the Wedgits© problem-solving task and adding a Control category ("Change Construction"; see Appendix 3) to better categorize the various control actions that were observed. All analyses were conducted using the code categories rather than specific skills within (e.g., "planning" within metacognitive control).

The MetaSCoPE coding scheme was applied to the last (challenge) puzzle (the puzzle that the child was unable to successfully complete unaided in 4 minutes or less). Children received 1 point per instance of metacognitive (i.e., monitoring and control) skill displayed and deducted 1 point for each behavior that was not metacognitive or missed opportunity. For example, if a child checked over their construction 4 times during the Wedgits© task, they would receive 4 points, but if they also used brute force twice to try to make pieces fit (not indicative of monitoring), they would receive -2 for a MetaSCoPE c score of 2 points (Appendix 3). Two researchers independently coded 30% of the sample (ICC=.97).

Motivation

Persistence / time-on-task Persistence, or time on task, was quantified as the number of seconds (out of 240 seconds / 4 minutes) when a child's visual, physical, or verbal attention was on task in an intentional way (e.g., the child may have been holding the puzzle pieces but looking at something in the distance, which would be off-task because the physical attention was not intentional). As with the MetaSCoPE and McKI assessments, persistence was only calculated on the last puzzle (i.e., the challenge-puzzle that the child could not successfully complete unaided in 4 minutes or less). Two researchers independently coded 30% of the sample (ICC=.99). See Appendix 4 for full coding description.

Executive function

Head-toes-knees-shoulders (HTKS) The HTKS assessment task (Ponitz et al. 2008; Ponitz et al. 2009) is an established and validated behavioral self-regulation (SR) instrument that is administered to individual children to measure applied EF skills, which include processing and manipulating stimuli (working memory), resisting distraction and shifting tasks and mental sets when necessary (attentional control; cognitive flexibility), and inhibiting automatic reactions to stimuli while initiating learnt yet adaptive or socially acceptable reactions (inhibitory control or response inhibition) (Blair and Razza 2007). These skills are typically used for goal-directed action (Follmer and Sperling 2016) and have been found to be related to emerging Mc (e.g., Marulis et al. 2013, 2016).

Importantly for this study, components of EF identified as distinct in older children and adults (working memory, inhibition, cognitive flexibility; Diamond 2013; Miyake and Friedman 2012) tend to be intertwined early in development and difficult to parse apart (Marulis et al. 2020; Roebers 2017). Importantly, there is empirical evidence that EF operates as a unitary, domain-general construct in early childhood and only becomes differentiated later in childhood around age 6 (Wiebe et al. 2008) or 10 (Roebers 2017). Thus, an integrated, broad, measure of EF incorporating working memory, inhibition, and cognitive flexibility was used in this study (i.e., the HTKS task). Furthermore, this approach aligns with the unitary way EF functions in young children (Roebers 2017; Wiebe et al. 2008, 2011).

During the HTKS activity, the experimenter asked children to remember rules (e.g., “touch your toes”) and respond with an action that is in conflict with these rules (e.g., children must touch their head when they hear the command “touch your toes”). In this way, children needed to recruit their working memory and response inhibition in order to inhibit their dominant response to follow the commands. Furthermore, as the task got increasingly difficult, children needed to flexibly shift their attention. Specifically, in the last part of the HTKS, the rules change so that when asked to “touch your toes,” children must touch their shoulders (instead of their head). Responses were rated on a 0-2 scale as follows (Ponitz et al. 2008): 0= incorrect response; 1=any action toward the incorrect response, but self-corrected to end with correct response; 2 = correct response.

Expressive language

Lastly, the children’s expressive language was assessed with the Brigance Early Childhood Inventory to serve as a covariate due to its importance related to the assessed skills particularly articulated metacognitive knowledge or declarative Mc (Whitebread et al. 2010).

Procedure

All children were individually assessed in two 15-25-minute sessions separated by 3-5 days. The first author conducted all of the Wedgits© puzzle and metacognitive knowledge interview (McKI) assessments in one session while the second author conducted the large majority of the (other) sessions targeting EF. During both sessions, children completed tasks with one experimenter present and all (counterbalanced) sessions were video recorded. We intentionally video recorded all sessions for inter-rater assessments, confirming the accuracy of children’s responses to the metacognitive knowledge interview (which were written as dictated by the first author), and so on. In addition, video-recording the children during the Wedgits© task was done to allow us to carefully analyze children’s metacognitive skills (monitoring and control) using the MetaSCoPE observational tool after they completed the task. Video-recorded observational assessments have previously been used, and found to be valid, when assessing metacognitive, EF, and motivational processes (e.g., Gourlay et al. 2020; Robson 2010; Whitebread et al. 2009).

The first (conceptual not ordinal) session focused on metacognitive processes and motivation. After establishing rapport, including a developmentally appropriate explanation of the "games they would be playing today," the experimenter administered the Wedgits© task following the steps outlined previously. Procedural metacognitive skills and motivation were coded directly from video-recordings of the Wedgits© task. Directly after the task, the experimenter administered the Metacognitive Knowledge Interview to assess children's declarative metacognitive knowledge. The other session focused on EF, which we assessed using the Head-Toes-Knees-Shoulders (HTKS) task described previously. Some children received the Wedgits© task first and then the HTKS task; others received the HTKS task first and then the Wedgits© task. Lastly, children's language skills were obtained from a standardized test administered by the teachers at the lab school. This covariate was used specifically to distinguish Mc from language skills.

Analytic plan

Our first aim was to examine evidence of early Mc by comparing data revealed by two different measures of Mc. To do this, we observed levels of Mc using a developmentally appropriate metacognitive interview (McKI) and observational tool (MetaSCoPE). The McKI targeted declarative metacognitive knowledge and the MetaSCoPE assessed procedural metacognitive skills. Our second aim was twofold: first, we sought to examine associations between Mc (knowledge and skills) with EF and motivation (aim 2a). To achieve this, partial Pearson correlations (controlling for expressive language and age) were conducted. Second, we sought to understand the predictive abilities of metacognitive knowledge and skills for EF and motivation (aim 2b). Backwards stepwise regression was conducted to indicate whether, and to what extent, metacognitive knowledge or skills predicted (each other), EF and motivation controlling for language and age. Because these analyses remove the least significant contributor at each step, unique contributors can be established. Specifically, we examined declarative (i.e., McKI) and procedural Mc (i.e., MetaSCoPE) as predictors of one another and our two main dependent variables, EF and motivation. When conducting analyses, we used pairwise deletion to account for missing data as several children completed one or several but not all assessments. We did not find an order of assessment measure or session effect.

Results

Descriptive and correlational analyses

The first aim of this study was to explore the conceptualization and measurement of early Mc through the comparison of the data revealed by two different measures of Mc, namely a declarative measure and a procedural measure. On average, children received 13.77 ($n = 71$, $SD = 6.06$, range 0–28) out of 30 possible points on the McKI measure of declarative metacognitive knowledge. Additionally, children displayed 33.81 ($n = 72$, $SD = 21.15$, range -20 to 93) instances of metacognitive skills as measured by the MetaSCoPE observational measure of procedural Mc. There is neither a floor nor ceiling for the MetaSCoPE scores; we coded the number of discrete instances of metacognitive skills in 4 min (240 s) during the child's last (i.e., most challenging) Wedgits© puzzle. Because there comparative data is not available, one way to interpret this result is that, on average, children displayed a

Table 1 Partial Pearson correlations between metacognitive processes (knowledge and skills) and executive function, motivation in preschool-aged children controlling for language and age

	McKI[a] (71)	MetaSCoPE[b] (72)	HTKS[c] (71)	ToT[d] (72)
McKI	–	.545**	.410**	.409**
MetaSCoPE		–	.607**	.295*
HTKS			–	.271*
ToT				–

Note: $n = 71$–72 (specific *n*s shown in parentheses after measure) $^*p \leq .05$, $^{**}p < .001$

[a] McKI: Metacognitive Knowledge Interview measure of declarative metacognitive knowledge[b] MetaSCoPE: Metacognitive Skills in Constructional Play Engagement measure of observed procedural metacognitive skills[c] HTKS: Head-Toes-Knees-Shoulder measure of executive function

[d] ToT: Time on Task measure of observed persistence (motivation)

metacognitive skill every 7 s while they were working on their most challenging puzzle (i.e., the puzzle they could not complete in 4 min or less). Children's average score on the HTKS measure of EF was 14.49 ($n = 71$, $SD = 16.00$, range 0–53) out of 60 possible points and they were on task for 212.32 ($n = 72$, $SD = 40.03$, range 39–240) out of 240 possible seconds.

Aim 2a was to examine how these metacognitive processes are associated with EF and motivation skills during problem-solving. Significant associations (see Table 1)[3] were found between all variables ranging from small-moderate to large magnitude ($r = .27$–$.61$; Cohen 1988). Importantly, and supportive of the hypothesis for our first aim, there was a moderate, positive relation between McKI (declarative metacognitive knowledge) and MetaSCoPE (procedural metacognitive skills), $r = .55$, $p < .001$; Mc did not function unitarily. Broadly, these results support our hypothesis (2a) that Mc would be positively and significantly correlated with both EF and motivation. However, our specific prediction that *procedural* metacognitive skills—as opposed to *declarative* metacognitive knowledge—would be more strongly related to both EF and motivation was not entirely supported. The magnitude of the correlation between procedural Mc and motivation and between procedural Mc and EF was the same ($r = .41$, $p < .001$). However, for EF, declarative Mc had a stronger correlation ($r = .61$, $p < .001$) meaning that *declarative* and not *procedural* Mc was more strongly associated with EF. The opposite was true for declarative Mc and motivation ($r = .26$, $p < .05$).

Metacognitive processes as predictors of executive function and motivation

To examine whether and how declarative metacognitive knowledge and skills predicted children's EF and motivation, we used backwards stepwise regression (Aim 2b). Specifically, we were interested in whether Mc would uniquely contribute to these processes. In Table 2, we present data from the regression models that addressed this aim. Metacognitive *knowledge* (the McKI; $\beta = .63$, $p < .001$) was uniquely contributed to the prediction of EF (i.e., the HTKS) predicting EF *above and beyond age* and accounting for 40% of the variance, $F(1, 66) = 44.33$, $R^2 = .40$. In contrast, 26% of the variance in motivation (time-on-task / persistence) was predicted by metacognitive *skills* (the MetaSCoPE; $\beta = .34$, $p = .01$) and, age (at a borderline-conventional level of significance, $\beta = .25$, $p = .05$), $F(2, 65) = 11.24$, $R^2 = .26$ (Table 2).

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[3] We collapsed the data across ages as associations were similar in children aged 3, 4, and 5.

Table 2 Contributions of metacognitive processes (knowledge and skills) to executive function and motivation (final models) controlling for language and age

HTKS[a]	$R^2 = .40$	$F(1, 66) = 44.33$***
	β	*p*
Step 1		
ToT[b]	.09	.44
Language	.01	.79
Age	.07	.39
McKI[c]	.50	<.001
MetaSCoPE[d]	.09	.46
Step 2		
ToT	.10	.37
Age	.06	.47
McKI	.54	<.001
MetaSCoPE	.10	.42
Step 3		
ToT	.13	.21
McKI	.60	<.001
MetaSCoPE	.11	.44
Step 4		
ToT	.12	.33
McKI	.61	<.001
Step 5 (final model)		
McKI	.63	<.001
ToT[b]	$R^2 = .26$	$F(2, 65) = 11.24$***
	β	*p*
Step 1		
Age	.24	.11
Language	−.07	.78
McKI[c]	−.06	.75
MetaSCoPE[d]	.33	.02
HTKS	.11	.44
Step 2		
Age	.22	.11
McKI	.06	.72
MetaSCoPE	.31	.02
HTKS	.09	.48
Step 3		
Age	.22	.10
MetaSCoPE	.31	.20
HTKS	.09	.48
Step 4 (final model		
Age	.25	.05
MetaSCoPE	.34	.01

Note: *** $p < .001$

Though age significantly predicted motivation, it was entered as a control variable

[a] HTKS: Head-Toes-Knees-Shoulder measure of executive function

[b] ToT: Time on Task measure of observed persistence (motivation)

[c] McKI: Metacognitive Knowledge Interview measure of declarative metacognitive knowledge

[d] MetaSCoPE: Metacognitive Skills in Constructional Play Engagement measure of observed procedural metacognitive skills

Discussion

Our overarching goal for the current study was to investigate 3-5-year-old's Mc—specifically their metacognitive knowledge (of people, tasks, and strategies) and metacognitive skills (monitoring and control)—and associations to EF and motivation during a problem-solving task. Exploring early Mc and these associated constructs will clarify the theoretical frameworks of each construct, how they function together across development, as well as have important practical implications for fields such as education and clinical psychology.

Research aim 1

Our hypothesis was largely supported. Not only did our measures reveal extensive[4] evidence of Mc (e.g., Whitebread 1999) even in children as young as 3-years, with substantial variance, but importantly, each measure facilitated the elicitation and depiction of different components of early Mc; 3-5-year-olds' declarative metacognitive knowledge (McKI) was moderately related to their procedural metacognitive skills (MetaSCoPE). This suggests that although the two constructs are related—as one would expect when considering Mc as a broad interrelated construct—these measures largely tapped into unique components (knowledge and skills) of Mc.

Recent researchers (e.g., Louca-Papaleontiou et al. 2012; Robson 2010; Shamir et al. 2009; Whitebread et al. 2007, 2009, 2010) have provided evidence of Mc that is beyond what had been indicated by researchers framed within a traditional Piagetian stage-like view of development (closely linked with age) or production-deficit model prior to age 7 (e.g., Flavell 1976; Kreutzer et al. 1975; Veenman et al. 2006). Importantly, these studies did not employ measures that were similar to those in the current study contextually (linked intentionally and directly to engaging classroom-based tasks such as puzzles) or developmentally appropriately (conducted immediately after a cognitive task, about which Mc is examined, such as our construction puzzle). Consistent with these results, we found extensive evidence of declarative metacognitive knowledge (children earning nearly half of the points possible on the McKI or 15/30) and procedural metacognitive skills (34 instances in 4 minutes) in relation to a problem-solving construction talk in 3-5-year-olds. Due to limited research which provides a comprehensive characterization of metacognitive processes in this age, we do not yet know have calibration information regarding the efficacy of metacognitive knowledge and skills, and, conversely, whether children can be "too metacognitive" during problem-solving tasks in a way that hinders performance.

Research aims 2a and 2b

Regarding our second aim, we found varying associations between Mc and EF and between Mc and motivation (Table 1). Associations differed by metacognitive measure—though not entirely as hypothesized—ranging from low to high providing evidence on how these SRL skills are related in young children during a challenge problem-solving task. Additionally, metacognitive knowledge (McKI) and metacognitive skills (MetaSCoPE) uniquely and

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[4] Because research that examines metacognition in children this young is limited, we do not have more specific benchmarks for categorization of or comparison to our findings. However, previous studies (Robson 2010; Whitebread 1999) have used the term "extensive" to refer to "frequently occurring" indicators of metacognitive behaviors such as found in this study thus, we have adopted that term.

differentially predicted the dependent variables (Table 2). We discuss these results in detail below.

Executive function and metacognition

Our hypothesis (2a) that EF would be more strongly related to procedural than declarative Mc was *not* supported. While young children's EF skills were moderately to highly associated with their Mc overall, they were more strongly associated to declarative metacognitive *knowledge* as opposed to procedural metacognitive *skills*. Our hypothesis (2a) was made based on previous literature (e.g., Roebers and Feurer 2016) and the conceptual similarity between responding to stimuli at a procedural level (i.e., on both the HTKS and MetaSCoPE). However, it may be that, at this age, it is more difficult to respond to a metacognitive knowledge interview—even one that is contextualized and developmentally appropriate—and EF is key to success on this task.

Our related aim (2b) about the predictive power of Mc for EF was entirely exploratory. Aligning with results from aim 2a above, metacognitive knowledge provided the most unique and strongest contributions to predicting EF, *above and beyond age* which is of particularly interest and importance during this period of rapid development and malleability (i.e., ages 3-5). This indicates that expressing one's knowledge about people (self and others), tasks, and strategies (i.e., declarative metacognitive knowledge) may be of distinct importance for EF skills such as working memory, inhibition, cognitive flexibility.

Motivation and metacognition

In contrast, our hypothesis (2a) that motivation would be associated more strongly with procedural than declarative Mc *was* supported. Motivation was more strongly related to metacognitive *skills* compared to metacognitive *knowledge*. We made this hypothesis (2a) based on the similarity between task demands and, in this instance, the empirical evidence aligned with the conceptual proximity.

Related to our exploratory aim (2b) of examining the predictive power of Mc for motivation, metacognitive skills—but not metacognitive knowledge—was indicated as a unique predictor by the regression model. This is in alignment with results from 2a in the preceding paragraph. Unlike the skills underlying EF, it may be that children's ability to persist on a task is not requisite to their ability to express knowledge.

Limitations and future research

Though our results are informative for early development and learning, it is important to emphasize that they stem from cross-sectional design. We intend to examine early Mc longitudinally, including through an examination of an early years Mc intervention. This will facilitate causal inferences at the basic level, and more comprehensive and beneficial applications to early years development, learning, and education. Another limitation was the measure of children's early language development, the Brigance Early Childhood Inventory III which was administered by the college lab preschool teachers as part of their regular yearly assessment. In future studies, we will use specific standardized measures intended to assess change over time such. Lastly, and in alignment with the multitrait-multimethod (MTMM) approach (Campbell and Fiske 1959) and more recently with other researchers focused on SRL who call for the inclusion of diverse measurement tools for greater contribution to research on Mc (e.g., Whitebread et al. 2010), we intend to add additional measure of EF and motivation.

Future research is planned to address these limitations and further examine early metacognitive processes, how (and when) they overlap with EF and motivation, and whether (and when) they are (pre)requisite, bidirectional, or subsuming. We also plan to examine how additional factors such as family, school, and individual differences may be related to Mc. Results of this study are part of a programmatic agenda of research (*Metacognitive Processes in Development [MinD*]). The main impetus for the *MinD* project is to fill gaps in the current literature by developing a comprehensive understanding of early years Mc its developmental trajectory and associations to other SRL—as well as cognitive and academic—processes. An additional goal is the application of this information to early years educational practices. The current study the first step in this endeavor. Specifically, the aim is to expand current understanding by proposing that Mc a) develops earlier than previously believed, b) is already (i.e., without explicit instruction or intervention) extensive and predictive of development and learning even in early years, c) is multifaceted, d) is associated with but unique from EF and motivation, and e) interacts dynamically with these related skills beginning in early childhood. This conceptualization can further both theory and application (e.g., that this dynamic intersection is what is needed for effective intervention).

Recently, Roebers (2017) integrated Mc and EF through her unifying framework of cognitive self-regulation and highlights the importance of focusing on the conceptual, theoretical, empirical, and predictive similarities rather than the distinctions between these constructs. Roebers (2017) does not, however, explicitly suggest that this critical interaction (between Mc and EF) begins in the very early years of life, as we do (also see Marulis et al. 2020). Nor does she include motivation in her framework which we believe is an important contributor to cognitive self-regulation and learning more generally. There is much more to be explored regarding how these skills and their interactions relate to development and learning in early childhood (e.g., see Follmer and Sperling 2016 for a similar framework and findings with an adult population).

Contributions and recommendations

Nonetheless, results from this study indicate that metacognitive processes in early childhood may be similar to those in individuals aged 7 and above in terms of relations to and unique and robust contributions to learning and academic achievement (Dignath et al. 2008; Wang et al. 1990). This contribution has strong and important implications for researchers and practitioners seeking to understand and improve young children's meta-skills. An important limitation of previous methods for measuring Mc in young children has been *either* the use of decontextualized, abstract, or retrospective interviews *or* using observational approaches only. Ideally, future assessment approaches strike a balance between these by measuring early Mc in ways similar to the current study or other integrative measurement approaches. The integration of the McKI (declarative metacognitive knowledge) and MetaSCoPE (procedural metacognitive skills) contributes to the understanding not only of metacognitive processes, but also of measurement approaches and what type of data is revealed.

As recently proposed (e.g., Aşık and Erktin 2019; Whitebread et al. 2010), research focused on Mc in young children should be conducted within a facilitative context that is engaging, familiar, developmentally appropriate to more precisely conceptualize and assess metacognitive processes at the basic level, and better understand associations between Mc and learning, cognitive processes, and academic achievement for application to early years education. To answer this call, we conducted our study at a college lab school and integrated the recently developed Wedgits© and McKI measures (Marulis et al. 2016) with an observational approach previously found to be developmentally appropriate and effective (e.g., Whitebread et al. 2009), and, importantly, provided evidence in support of this view.

For researchers, we recommend precisely investigating Mc at the component level not only to comprehensively understand it conceptually but also to distinguish which components are most important for specific domains or areas of development or whether—and how—the components of Mc interact together for optimum development and learning. This includes declarative and procedural Mc—targeted in the current study—as well as other identified components such as metacognitive experiences (Efklides 2011).

This is also important for addressing the jingle jangle fallacy (Gonzalez et al. 2020). *Jingle* (Thorndike 1904) refers to using the *same* terms for *different* constructs such as using SRL to represent both EF and Mc. Conversely, *jangle* (Kelley 1927) refers to using *different* terms for the *same* constructs such as EF and Mc being used interchangeably to represent the same underlying construct of regulating one's behavior, emotions, and cognition. This phenomenon is particularly pervasive in self-regulated learning and Mc literature (Dinsmore et al. 2008; Morrison and Grammer 2016). Gaining a deeper understanding of mediating and moderating factors may provide more prescriptive information both for designing research that includes these factors and for designing learning environments, tasks, and policies.

For practitioners working with preschool-aged children, we suggest integrating Mc, EF, and motivation within their learning environments (see Marulis et al. 2020). Furthermore, we propose that researchers and practitioners are mindful of the multifaceted nature of Mc regarding components such as knowledge or skills (and convergence / divergence within). For example, a young child may be highly metacognitively knowledgeable while having low or moderate metacognitive skills, or vice versa. Accordingly, it is likely most beneficial to children's development and learning that these processes are understood, valued, facilitated, scaffolded, and / or explicitly taught. However, as mentioned earlier, this research is in its infancy, therefore, caution is warranted until a deeper understanding of the parameters around the development and effectiveness of metacognitive processes for learning and academic performance is reached.

Ideally, research on Mc in the early years would parallel that of EF regarding basic and applied dimensions including the comprehensive conceptualization and examination of components, associations to other developmental processes, limitations, and early years intervention and instruction efficacy.

Findings from this study contribute to the fields of education and psychology in two significant ways. First, a clearer and more comprehensive conceptualization of Mc was revealed through the analysis of data across different measurements and examining associations to important and conceptually similar skills in 3-5-year-olds (EF and motivation). Integrating and examining SRL skills longitudinally in multiple contexts (type of schools, homes, or research labs) is central to moving forward in understanding these concepts and how they impact one another in early development more deeply, as well as elucidating their importance to development, learning and academic success (e.g., Roebers 2017). Second, results provide information beneficial to the design and enactment of effective early intervention focused on Mc, EF, and motivation to enhance developmental and learning outcomes.

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The authors declare that they do not have any potential conflicts of interests either financial or relationships. All procedures performed in this study that involved human participants were in accordance with the ethical standards of the Connecticut College Institutional Review Board. Lastly, informed consent was obtained from the children's parents or guardians and child assent was obtained from all individual participants who were included in this study.

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Appendix 1: Wedgits© problem-solving task

Contextual task to elicit metacognition (knowledge and skills) and motivation (persistence)

Researcher instructions:

1. Make sure the camera is pointed at the child and recording; make sure that you will not block the camera when you sit down.
2. Show the child the blocks and the design on the first card. Say, **"First, I want you to make the blocks look exactly like the blocks in this picture. Can you make the blocks look like this picture?"**
3. Let the child work until finished. Help child as needed or if asked on this practice puzzle only (model 0).
4. Say, **"You did a great job with that!** Show the child the design on the second card (model 1). **Now, I want you to make the blocks look exactly like this picture."**
5. Let the child work without helping. Stop the child at 4:00 if still working.
6. If child takes less than 4 min to finish puzzle 2 (most children), **SKIP TO STEP 7.** Otherwise, say, **"We are out of time. If we had more time, would you want to work**

more on this one *(hold up first picture)* **or this one** *(hold up second picture)***?" "Why?"** Record child responses.

7. Now show the child the design on the third card (model 2). Say, **"You did a great job with that one, too! Let's do another one. Make the blocks look exactly like this picture."**
8. Let the child work without helping. Stop the child at 4:00 if he/she is still working.
9. Tell the child, **"We are out of time. If you had more time to work, would you like to keep trying this one** (hold up the picture of the last completed puzzle) **or build this other one again** (hold up the last picture)**?** Record child response. **"Why?"** Record child response.
10. Continue in this way until child is unable to complete successfully complete the puzzle (i.e., it looks exactly like the model picture) in 4 min or less.

Appendix 2: Metacognitive Knowledge Interview (McKI)

Assessment tool to measure metacognitive knowledge

Once the Wedgits© puzzle task is complete, tell child: **"Thank you for working on the puzzles! I would like to talk to you about the puzzles you just did and about your thinking. My job is to learn about how kids learn and think and I have a few questions for you, Okay?"** Once child assents, say**: "Thank you. Remember, there are no right or wrong answers; I only want to know what you think. Just give** ***your*** **best answer."** (If they don't agree, try to prod them by saying that 'I really need your help and want to learn about how kids think'.)

1. **"Do you think you did a good job, an okay job or not so good of a job on the puzzles?"** Circle child's response. If they say they did a good job, ask "What did you do to help you do a good job?" If they answer okay or not so good, ask "What do you think would have helped you do an even better job?
2. **"Did you think anything was hard?" If no, ask: "Why not?" If yes, ask "Why?**
3. **"Will the puzzle be harder/easier when you're older? Why?"**
4. **"Would these puzzles be hard for another kid your age? Why/why not?"**
5. **"How did you know if you were getting the puzzles right?"**

Show child the 'alien' finger puppet and say: "**I have a friend to show you. This puppet's name is Gogi and she or he** (use same gender as the child) **is from another land. (She or he) does not go to a school like yours or have a teacher like yours and doesn't know anything about** puzzles like the ones you just did. Will you help Gogi learn about these kind of puzzles?" Wait for child to assent and say: **"Thank you."** (If they don't agree, prompt once by indicating that Gogi would really like to learn about these puzzles.)

6. **"Would these puzzles be easier for Gogi or you? Why?"**
7. **"What should Gogi do if (she or he) is having trouble with the puzzle?"**
8. **"Would it be helpful for Gogi to talk to (herself or himself) about the puzzle while doing the puzzle? Why would/wouldn't that be a helpful thing to do?**

"Gogi has some questions for you about puzzles like this one. Okay?" Have Gogi 'speak' directly to the child and ask the following:

9. **"Would the puzzle be easier with bigger or smaller pieces? Why?"**

10. **"Would the puzzle be easier with more or less pieces? Why?"**

11. **"If all of the puzzle pieces were the same color, like in this picture** (show the Wedgits© booklet of all-purple Wedgits©) **would the puzzle be easier?** If yes, ask: **"Why?"** If no, ask, **"Why not?"**

12. **"If I think about how the pieces would fit together before I try, would the puzzle be easier?** If yes, ask: **"Why?"** If no, ask, **"Why not?"**

13. **"If I gather (demonstrate) the pieces I need first and then build the puzzle, would it be easier? Why/Why not?"**

14. **"What if you were watching TV while you were building it, would it be easier? Why? /Why not?"**

15. **"If I close my eyes while I do the puzzle, will it be easier?** If yes, ask: "Why?" If no, ask, **"Why not?"**

"Thank you for sharing all of your ideas and how you think with Gogi!

Appendix 3

Table 3 MetaSCoPE (Metacognitive Skills in Constructional Play Engagement) Coding Scheme Assessment tool to measure metacognitive skills, adapted^a for Wedgits© problem-solving task

	Description	Example (Verbal)	Example (Non-Verbal)
MONITORING	**Awareness:** Child verbalizes previous or current knowledge and understanding related to constructing the puzzle.	"I need to try another piece""This one is hard to make!""My sister says that you should always start with the biggest pieces for puzzles"	This skill is evidenced through **verbalizations.**
	Checking Construction: Child pauses / glances at the construction **with our without verbalizing.**	This skill might be accompanied by verbalizations such as "Let me see…"	Child pauses and glances directly at the puzzle made so far.
	Checking Card: Child checks (looks) at the model card before continuing building the puzzle **with our without verbalizing.**	This skill might be accompanied by verbalizations such as "Let me see…"	Child pauses and glances directly at the model card.
	Evaluation: Child indicates judgment / appraisal related to constructing the puzzle.	"I did it! Perfect!" "I'll never figure this out!" "Hmmm, this doesn't look right""Ta Da!"	Child looks at the finished puzzle and forms a huge smile. Child looks at the puzzle, furrows their brows and frowns.
CONTROL	**Change Construction:** Child makes a distinct change in their construction based on monitoring it **with our without verbalizing.**	This skill is evidenced through **actions.**	Child looks at card, then at puzzle and says: "That's not right, I need a red square block."Child places a piece on top, which topples, then wiggles the piece around until it clicks in place.

Table 3 (continued)

	Description	Example (Verbal)	Example (Non-Verbal)
	Planning: Child makes a **verbalization preceding an action.**	"I'm going to do the small (or top) pieces first."	This skill is evidenced through children's **verbalizations.**
	Seeking: Child intentionally attempts to find something related to constructing the puzzle **with our without verbalizing**.	To check for intentionality, this skill is evidenced through **actions.**	Child scans the pieces, selects one and places it straight away.Child singsongs: "Yellow piece, yellow piece …" while looking through the blocks.
	Sorting: Child attempts to organize (sort, group, arrange) something related to constructing the puzzle **with our without verbalizing.**	This skill is evidenced through **actions.**	Child compares shape of pieces and groups shapes together.Child moves card before saying: "Now I can see it better!"
LACK of MONITORING and CONTROL	**Brute Force:** Child tries to force a piece when it is not fitting into place **with our without verbalizing**.	This skill is evidenced through **actions.**	Child stands and strains to push a piece down with both hands while saying: "Go in!"Child forcefully tries to click 2 pieces together
	Finishing Error: Child claims to be finished though there is a major discrepancy between the puzzle they built and the model card.	"I'm all done.""Finished!"	To check for intentionality, this skill is primarily evidenced through **verbalizations.** (Exception: nods in response to the question: "Are you finished?" *This is rare.*)
	Goal Neglect: Child deliberately builds something that doesn't match the card.	Child says: "I like making this big pile instead!" while stacking blocks. Child says: "I love red!" as they build with only the red blocks and push others aside.	To check for intentionality, this skill is primarily evidenced through **verbalizations.** (Exception: builds **more than** 2 pieces without looking at card or construction. *This is rare.*)
	Repetition: Child deliberately makes an incorrect placement twice or more (each repetition is counted separately).	This skill is evidenced through **actions**.	Child put a big piece on top, it does not click into place, removes it, then immediately selects the same block and places it in the same exact place.

(MetaSCoPE coding scheme was adapted from observational coding in Bryce and Whitebread 2012*;* Bryce et al. 2015*)*

Appendix 4: Wedgits© Time on Task

Assessment tool to measure motivation (time-on-task / persistence)

Instructions: Watch the video to determine which puzzle is to be coded (Coders should code the last puzzle; in other words, the puzzle that the child works on for 4 min without finishing)

1. Record the starting time as right after saying "Can you make the blocks look like the blocks in this picture?". The ending time *should* be 4 min later. However, record the ending time as when you hear the beeping of the phone timer alarm on the video.
2. Time on Task is coded using the computer timer (on the video software). When the child goes off-task, pause the video and record the amount of time in the "Time intervals off task" column until they return back to being on-task (for example, if they go off-task at 6:05, and then back on task at 6:15, record "6:05–6:15" in the "Time intervals off task" column).
3. Next, calculate total amount of seconds (out of a possible 240) and record in column 1.
4. Then do the same again and record in column 2.
5. Last, average your two scores and record in column 3.

On task is coded when visual, physical, **and / or** verbal attention is on the task (for example, the child may be holding the puzzle pieces / blocks but looking at something in the distance, which would be off-task because the physical attention is not intentional). **On-task** indicators include looking for where a piece goes, thinking about the task (either a verbalization such as "I wonder how I can do this"; or non-verbally such as resting their hand on their face with a concentrated look or a distinct pause with an intent stare [could be at the puzzle or in the air, etc.] and a look of being perplexed or trying to figure something out with an absence of other actions / off task indicators), or asking the experimenter for help (e.g., "Does this go here?"). Overall, **"on task"** refers to behavior that is indicative of cognitive engagement with the task.

Off task is coded when the child's visual, physical, **and / or** verbal attention is off the task. **Off task** indicators include looking around the room at toys, touching other objects in the room, using the task objects in a way other than related to building the puzzle (e.g., pretend play, for example, using the model card as a "credit card", or **explicitly** (i.e., articulated) building something other than the intended picture (for example, they say "I don't want to build that one, I'm going to build a pyramid instead" or "I'm not going to build that one"). The deviation from building the goal puzzle is indicated by either a present statement (e.g., "I am making a house!") or a retrospective statement (e.g., "Look what I made!"). A behavior that is **off task** would also be a child putting the puzzle pieces around on their head, distracted by others in the room or talking to the experimenter about anything other than the task or a strategy related to the task (for example: "My Dad told me to organize the pieces first when I work on a puzzle") **for 3 s or more.** In addition, if a child drops blocks or falls out of their chair, this is not considered off task unless it is NOT in the "service of performing the task". In other words, if they are retrieving a piece in order to continue building the puzzle, it is **on task.** If they see something on the ground that distracts their attention to something that is not in the service of the goal of building the puzzle, then, they are **off task.** Similarly, if they fall out of their chair, that is on task unless they become distracted by the incident for **more than 3 s** and do not get back to the task at hand (unless they are having trouble getting back up, etc. This is for distracted attention-physical, verbal, or visual).

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