Executive Function and Metacognition: Towards a Unifying Framework of Cognitive Self-Regulation

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Abstract Executive function and metacognition are higher-order cognitive processes that undergo steady improvements throughout childhood. They are highly relevant to daily functioning in various domains, including academic achievement. Both concepts have been intensively researched, but surprisingly little literature has sought to connect them theoretically and empirically. In the present review, I elaborate on the similarities between these concepts from a developmental perspective, including the definitions, developmental timetables, factors that lead to changes over time, and relations to academic achievement and intelligence. Simultaneously, the differences between these two domains of cognitive development are discussed. These include, in particular, the relative neglect of quantifying monitoring within research on executive functions and the disregard for the neuropsychological underpinnings of metacognition. Finally, this paper presents several avenues for future research and proposes a possible unifying framework of cognitive self-regulation that integrates executive function and metacognition and may lead to a better understanding of the emergence of cognitive selfregulation in development.

Keywords: executive function, metacognition, development, review

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Introduction One of the major milestones of a child`s cognitive development is the ability to intentionally regulate his or her own behavior and thinking. This includes the ability to stop performing an action when asked to do so (e.g., clapping one`s hands, talking, kicking the ball) and act in a goal-directed manner (e.g., getting out the right utensils for playing a certain game; remembering to do something at a certain time or place; selecting the best-suited strategy for solving a task). Further striking and far-reaching developments—for both the child and those in his/her environment (e.g., parents, teachers)—include the ability to stay focused despite distractions (e.g., going to fetch an object; finishing a task despite decreasing motivation) and to detect and correct errors. This literature review focuses on so-called “higher-order cognitive processes,” which play an important role in children’s development of self-regulating behavior and mental operations. Such processes include the monitoring, steering, controlling, and adapting of “lower- or first-level information processes,” such as encoding, storage, and retrieval of information. Two different bodies of the literature will be integrated: that focusing on “executive function” (EF) and that on “metacognition” (MC). In a previous brief report, some practically relevant similarities between EF and MC were outlined (Roebers & Feurer, 2016). The current paper aims to provide a more detailed review of the literature and a critical discussion of the avenues for future research. This review has been organized into two major sections: the first addresses the conceptual and theoretical issues related to EF and MC, while the second focuses on the developmental progression of these concepts, as well as their links to other variables and each other. The major aims of the present review are (a) to bring together two distinct bodies of cognitive and developmental literature related to the regulation of behavior and thinking, and (b) to elaborate on the many similarities and few differences between the concepts described therein. It is important to note that this review is not intended 4 to be exhaustive; rather, the content was selected based on its subjective relevance to developmental theory and practice. I. Conceptual and Theoretical Issues Historical Background In 1971, John Flavell introduced the concept of “metamemory,” and from the beginning linked it to developmental psychology. In discussing the potential factors that promote memory development in children, he referred to the concept of metamemory as “monitoring and knowledge of (memory) storage and retrieval operations” (p.277). The essential aspects of metamemorial knowledge, nowadays commonly referred to as declarative metamemory, were described in detail by Flavell and Wellman (1977), and include an individual's knowledge about various person, task, and strategy-related variables. Concerning the procedural aspects of MC, Hart (1967) might have been the first to directly relate monitoring to performance by introducing a calibration curve. Such a calibration approach (still used today in metacognitive research) allows researchers to estimate the degree to which monitoring is commensurate with actual performance; in other words, it enables researchers to assess the realism of on-task monitoring. Calibration curves are determined by plotting subjective estimates of correctness (i.e., monitoring judgments) against the objective proportion of correct responses, revealing either over- or under-confidence in individuals. Around the same time, Butterfield and colleagues (Butterfield, Wambold, & Belmont, 1973) suggested that memory improvements rely on two main factors: Namely, an individual's spontaneous and conscious access to memory monitoring and a task-unspecific executive control that allows for coordination of memory and memory monitoring. Together, these factors can improve memory performance—if applied in a sensible way during information processing. In a similar vein, Ann Brown (1975) explicitly added the concept of "knowing how to know" (i.e., "the ability to monitor and control," p. 146), which allowed a 5 child to deliberately learn and memorize information, as well as to use self-initiated, goaldirected strategies. Later, Flavell (1979) proposed the broader concept of "metacognition" as the constant interplay between metacognitive knowledge, metacognitive experiences (i.e., essentially momentary to longer-lasting monitoring experiences), and metacognitive actions (e.g., selecting the best mode for learning, executing the best-suited strategy). Conversely, researchers only became interested in EF in the late 1980s, with the emergence of various neuroanatomical, neurophysiological, and behavioral approaches to frontal lobe functioning in clinical neuropsychology (Welsh & Pennington, 1988). Initially, heterogeneous sets of behavioral deficits in adult patients with frontal lobe lesions were pooled under the term "executive function." This term captured patients' inability to inhibit a prepotent behavioral response, to mentally represent a plan, and to act in a goal-directed, selfdetermined, and flexible way in a variety of situations. Despite knowing of the rapid growth of the frontal lobes in primates' brain evolution (Fuster, 2008), researchers underestimated the impact of EF for typical development for a long time. The concept of executive function made a detour via developmental psychopathology before entering the field of developmental psychology: Pennington and colleagues (Pennington & Ozonoff, 1996; Welsh & Pennington 1988), in outlining the pronounced executive deficits in children with developmental disorders (especially those with attention deficit hyperactivity disorder [ADHD]), argued that EF is distinct from other information processing domains. Thus, as a "higher-order cognitive process," EF came to be seen as a primary driving force for typical development. Overall, despite being rooted in different research traditions, EF and MC are both factors now assumed to govern improvements in children's deliberate, goal-directed, and self-regulated information processing (Blair & Diamond, 2008; Kuhn, 1999). Contemporary Conceptualizations 6 Executive function. In the literature, "executive function" has been defined as a set of heterogeneous, higher-order cognitive processes involved in goal-directed, flexible, and adaptive behavior and the top-down regulation of cognition and behavior, that are particularly triggered in novel, challenging, and complex situations (Miyake et al., 2000). Zelazo (2015) noted that the situations in which top-down regulation through EF is necessary vary on a continuum from purely cognitive challenges (calling for "cool EFs") to motivationally significant situations (calling for "hot EFs"). Based on clinical observations of developmental disorders, the ability to inhibit automated responses and switch mental sets was also included in the concept of EF (Baddeley, 2000; Barkley, 1997). Although most researchers would agree that these different aspects of EF operate together and that a separation of the different processes is mostly impossible (Miyake & Friedman, 2012); separately measuring and investigating the various EF components can nevertheless shed light on differences in developmental timetables as well as the relative importance of the different EF components for various outcomes (Lee, Bull, & Ho, 2013). Note that there is some conceptual overlap between research on EF and Mischel's framework of "hot" and "cool" "self-control" (Metcalfe & Mischel, 1999) and also with temperament-based approaches to children's self-regulation (Rothbart & Bates, 1998). According to Mischel, there is a hot, emotional system that urges individuals to approach a desirable stimulus and a cool, cognitive system that executes top-down control over the hot system. Ideally, the cool system helps individuals resist temptations, postpone gratification, maintain pursuit of her/his initial goal, etc. Thus, it is the cool system that overlaps with EF. Furthermore, in Rothbart's conceptualization of temperament, individual differences in the dimension of "effortful control" can influence behavior in both affective and cognitive contexts (Rueda, Posner, & Rothbart, 2005). EF, in contrast, can primarily be delineated by its cognitive and volitional character and is used in situations to improve cognitive or behavioral 7 performance (Blair & Razza, 2007). Because this specific characteristic is a main similarity to MC, EF in more cognitive sense is the primary focus of the present review. Metacognition. Current conceptualizations of MC distinguish between declarative metacognitive knowledge (i.e., knowledge about cognition, learning processes, memory functioning, and factors influencing cognition, learning, and memory; Flavell, 1979), and procedural MC. Procedural MC comprises the processes of metacognitive monitoring (i.e., subjective assessments of ongoing cognitive activities: "how much effort do I have to put into learning this material?"; "did I sufficiently learn this material to remember the details later on?"; "how sure am I that this answer is correct?"), and metacognitive control (i.e., the regulation of current cognitive activities: selecting material for review while studying, differentially allocating study time to the learning material, withdrawing answers, or terminating memory search; Dunlosky & Metcalfe, 2009; Nelson & Narens, 1990). There is a constant flow of information between the different components of MC. In an iterative manner, metacognitive experiences made during learning and remembering (procedural metacognition) will lead back to changes in metacognitive knowledge (e.g., Dunlosky & Metcalfe, 2009; Efklides, 2011; Flavell, 1979). This brief review of the theoretical literature thus uncovers many similarities between EF and MC: both are conceptualized as higher-order cognitive processes enabling an individual to operate flexibly and adapt efficiently to new and challenging tasks. Furthermore, as opposed to automatized responses, EF and MC are generally considered to be controlled processes initiated by the individual (Norman & Shallice, 1980). In both literatures, these higher-order controlled processes embrace various sets of sub-processes (shifting, updating, and inhibition for EF; monitoring and control for MC). These sub-processes are theoretically distinct, and successful information processing relies on an efficient and goal-directed orchestration of individual elements. In other words, the sub-processes are operating together 8 and are constantly interacting with each other. Further, EF and MC similarly encompass dynamic and regulatory functions, which are utilized to optimize information processing of more elementary, first-order tasks. Internal Structure of EF and MC From a developmental perspective, the theoretically assumed subcomponents of EF and MC appear to manifest different changes over time. I describe these differing developmental timelines in the following paragraphs. Executive function. A battery of commonly used tasks has been found to yield three distinguishable yet interrelated latent factors of EF in adults (Miyake et al., 2000): updating (i.e., short-term storage and manipulation of a limited amount of information), inhibition (i.e., the ability to interrupt or inhibit automated or prepotent responses or behavior), and shifting (also called cognitive flexibility, and refers to the ability to flexibly shift attention between task demands and flexibly apply changing rules or mindsets). Today, these factors are recognized as the classical subcomponents of EF. Importantly, however, they seem to be relatively undifferentiated early in development

(Diamond, 2013; Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al., 2011; Willoughby, Wirth, Blair, & Family Life Project Investigators, 2012). Over the course of development, EF components experience slow differentiation, with only two factors (inhibition and working memory) best representing the construct in preschool and early elementary school children (Brydges, Reid, Fox, & Anderson, 2012; Huizinga, Dolan, & van der Molen, 2006; Lee et al., 2012; van der Ven, Boom, Kroesbergen, & Leseman, 2012; Viterbori, Usai, Traverso, & De Franchis, 2015). Only in late childhood and adolescence (approx. 10–15 years of age) are the components of inhibition, working memory, and shifting empirically distinguishable (Lee et al., 2013; Lehto, Juujarvi, Kooistra, Pulkkinen, 2003; Monette, Bigras, & Lafrenière, 2015). 9 Metacognition. The theoretical assumptions and empirical evidence concerning the internal structure of MC point in a different direction. For procedural monitoring and control, the little empirical evidence available suggests relatively isolated and unconnected skills in elementary school children. The apparent fractionated nature of MC may be mainly methodological: studies on procedural MC typically include one measure each for monitoring and control, respectively. Additionally, there are almost no longitudinal studies on procedural metacognitive skills. Nevertheless, as one example, the ability to make accurate judgments of learning immediately after learning ("How sure am I that I will remember this information in the upcoming test tomorrow?") appears to be unrelated to adequate estimations of confidence given right after retrieving information ("How sure am I that I answered this question correctly?"; Destan, Hembacher, Ghetti, & Roebers, 2014; von der Linden & Roebers, 2006; von der Linden, Schneider, & Roebers, 2011). Through experience and feedback, these aspects of monitoring seem to merge into an overarching monitoring skill (van der Stel & Veenman, 2008). Empirical evidence in adults has also suggested only low correspondence of different monitoring indicators (Boduroglu, Tekcan, & Kapucu, 2014; Rhodes & Tauber, 2011). Little to nothing is known about whether and to what extent indicators of metacognitive control cohere with each other (e.g., differentially allocating study time to easy versus difficult learning material, making sensible re-study selections after a study period, selectively withdrawing previously given incorrect responses). In sum, although the developmental courses towards the adult-like internal structure of EF and MC appear to differ, the final and theoretically assumed factorial structures are very similar. Furthermore, for both concepts, there is a set of sub-processes or components that interact with each other. Although it has proven useful to investigate the respective subprocesses separately, in real-life situations, neither the components of EF (updating, switching, and inhibition) nor those of MC (monitoring and control) can be easily separated. 10 MC and EF in Frameworks of Self-Regulation From a broader perspective, MC and EF play a central role in models of selfregulation and self-regulated learning. These theoretical frameworks differ, however, with respect to the broadness of the contexts they are applicable to. Executive Function. When taking into account cognitive/learning, social-interactive, and personality viewpoints, self-regulation frameworks consider EF as a means of enabling self-regulation in various situations. In that sense, self-regulation is defined as goal-directed behavior for a broad variety of contexts, including academic contexts, health-related behavior, and social interactions. In their review of the empirical literature, Hofmann, Schmeichel, and Baddeley (2012) describe the many ways in which EF, as a narrow set of higher order information processes (see above), are linked to self-regulation. First, EF, as an outcome, can be impaired when an individual is confronted with strong self-regulatory demands, such as intense desires and needs (e.g., a child strongly desires to go out and play with other children but must finish homework first; crossing a dangerous road to reach a long-waited-for family member). Second, individual differences in EF can also enable or constrain self-regulatory outcomes in that good EF allows efficient self-regulation in other domains. For example, well-developed inhibitory skills may help to override impulses (i.e., maintain the required behavior until a task is completed), and good working memory capacity can help to keep the overarching goal in mind. EF may also moderate, mediate, or modify the influence of situational characteristics on self-regulated learning activities. These different links are integrated in Blair and Raver's (2015) model of children's developing self-regulation. According to their developmental perspective, self-regulation is a multi-level allostatic system of feed-forward and feedback processes operating at the biological, social-emotional (including temperamental), behavioral, and cognitive levels. The system is assumed to be triggered when prepotent responses are no longer adequate or the individual faces new task 11 demands. These multifaceted processes allow the child to adjust to the experiences and challenges in both informal social interactions and formal learning activities. Metacognition. Models of self-regulation concerning MC are often positioned in the context of educational research, such as investigations in classroom settings with ecologically valid study material. In such research, self-regulated learning is not only considered the main goal of primary and secondary education, but also expected to be a life-long learning process. Typically, these models comprise long-term academic goals, personal characteristics, and micro-processes operating during learning and remembering. However, the models differ with respect to the positioning of metacognitive monitoring and control: while metacognitive monitoring and control play a key role and are considered as main sources of the individual differences in all phases of the self-regulated learning process (for a review see Greene & Azevedo, 2007; Winne, 1996, 2001), the models of Boekaerts (1997) and Zimmerman (1990, 2008) situate MC at the micro- and task-levels. While the models of the of MC in self-regulated learning mentioned above do not explicitly include a developmental perspective, Efklides's model (2008, 2011) does. Her metacognitive and affective model of self-regulated learning (MASRL Model) proposes various mechanisms through which self-regulated learning improves over the course of development. With increasing metacognitive knowledge and through subjective metacognitive experiences within structured and unstructured learning situations (e.g., losing in a memory game because of distraction, not remembering the name of an age-mate, not being able to recall a poem), an individual becomes increasingly better at metacognitively monitoring and control. As long as feedback is intentionally provided (e.g., by the teacher) or occurs naturally (e.g., not finding a toy one has played with the previous day), the individual will, over time, improve his or her self-regulated information processing behavior. 12 Taken together, the above research suggests that the framing of EF is broader in comparison to that of MC. Self-regulated learning models tend to limit the relevance of MC to learning and remembering and to educational or academic contexts, whereas the scope for EF appears to be unlimited. In fact, empirical evidence for EF in children suggests that the construct is relevant to domains such as food intake (Riggs, Spruijt-Metz, Sakuma, Chou, & Pentz, 2010), less-structured leisure time activities (Barker et al., 2014), social relations (Nigg, Quamma, Greenberg, & Kusche, 1999), emotion regulation (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009), and social competence (Razza & Blair, 2009), along with academic achievement, and intelligence (see below). However, despite having a narrower theoretical scope, MC in children has been empirically linked to a large variety of contexts, as well. Apart from academic performance and intelligence (see below), these include autobiographical memory (Ghetti, Papini, & Angelini, 2006), perception (Balcomb & Gerken, 2008; Lyons & Ghetti, 2013), decision making (Coughlin, Hembacher, Lyons, & Ghetti, 2014), eyewitness memory and suggestibility (Roebers, 2002), and social-cognitive development (Lockl & Schneider, 2007). Moreover, creative research paradigms have shown that young children demonstrate better metacognitive skills in social interactive settings compared to when the child is alone (Bernard, Proust, & Clément, 2015; Goupil, RomandMonnier, & Kouider, 2016), suggesting that social interactions can facilitate the development of MC and play a noteworthy, but still often overlooked, role in many everyday life situations (see also Brinck & Liljenfors, 2013;

Frith, 2012). Neuropsychological Underpinnings of EF and MC Executive Function. Besides the historical roots of EF concepts (see above) and the findings from varied disciplines already discussed, the neuropsychological underpinnings of EF are important and informative. Research has shown that the prefrontal cortex (PFC) is the brain region predominantly involved in EF. First, neuroimaging studies have consistently 13 shown that in children and adults, the PFC is strongly activated when EF tasks are performed (Wendelken, Munakata, Baym, Souza, & Bunge, 2012). Second, patients with PFC brain lesions have shown relatively circumscribed deficits in executive domains, such as attention, working memory, planning, inhibition, interference control, and decision-making (Fuster, 2008). Third, the PFC and behavioral correlates of EF both show a protracted development into adolescence and even adulthood (Diamond, 2000; Gogtay et al., 2004; Wendelken, Baym, Gazzaley, & Bunge, 2011). Fourth, children with ADHD or children with acquired brain damage (traumatic brain injury, stroke) typically show specific deficiencies in the domain of EF, as well as specific structural and functional abnormalities in their PFC (Anderson, Jacobs, & Anderson, 2008). Metacognition. Despite the intense research on MC in both cognitive and developmental psychology over recent decades, surprisingly few studies have addressed MC's neurophysiological and neuroanatomical basis. Moreover, the results of existing studies are difficult to interpret because of the confounds between first-order tasks (e.g., perception, memory, semantic knowledge) and second-order tasks (metacognitive task), thus making it difficult to attribute certain brain activation patterns solely to the metacognitive processes of interest (Metcalfe & Schwartz, 2016). In their review of studies on neurological patients (mainly patients with Alzheimer's disease and Korsakoff syndrome; see also Shimamura, 2000), Pannu and Kaszniak (2005) conclude that the PFC plays a central role in accurate monitoring and these processes can be distinguished from memory. This is in line with Bona and Silvanto's (2014) transcranial magnetic stimulation study, which showed that adults' confidence in memory, but not the memory itself, was specifically impaired. According to Metcalfe and Schwartz's (2016) review of the most recent neuroscientific evidence from healthy adults, complex neural circuits converging in the anterior cingulate cortex (ACC) and PFC contribute consistently to the processing of metacognitive information. In particular, the ventromedial PFC appears to be more closely linked to prospective judgments such as ease- 14 of-learning and feeling-of-knowing judgments. The anterior and dorsolateral PFC, by contrast, seem aligned to retrospective monitoring judgments, that is, to confidence judgments (Fleming & Dolan, 2012). Although performance monitoring has been more strongly emphasized in frameworks of MC rather than of EF (see above), there is a small yet often overlooked body of neuroscientific evidence on "error monitoring" that seems highly relevant for both concepts. Indeed, this may serve as a bridge between the two lines of research (Shimamura, 2000). In these experimental approaches, classic EF tasks, such as the Flanker task, go/no-go task, or the Dimensional Change Card Sorting task (DCCS; see above) are completed while subjects undergo electroencephalographic (EEG) recording. For analyzing these data, researchers focus on the neural signs of error detection. In other words, they examine whether there are neural correlates unambiguously attributable to the detection of a committed error (i.e., N2 amplitude in older children and adults or N4 amplitude in younger children; that is, a negative EEG response 200 or 400 ms post error; Fernandez-Duque, Baird, & Posner, 2000; for a recent review, see Wessel, 2012). Results show that an error may trigger negative eventrelated potentials (ERPs) shortly after it has been committed, the so-called "error-related negativity" (ERN). ERN (more in the dorsal regions) is functionally localized in the ACC (among other regions), which alerts the cognitive control system that adaptation is necessary (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Ridderinkhof, van den Wildenberg, Wery, Segalowitz, & Carter, 2004). In one such EEG study focusing on ERN, the brain activation of 7- to 18-year-old participants was assessed. Brain activation was measured 150 ms after an incorrect response in the Flanker task (Davies, Segalowitz, & Gavin, 2004a and b). Nicely matching the developmental literature regarding improvements in monitoring incorrect responses in the domain of MC (see below), the authors found pronounced age-related 15 increases in the amplitude of ERN. From around the age of 10, significant, negative post-error responses in the ACC were found, which were similar to the patterns observed in adults. Furthermore, using the DCCS task, EEG recording and even younger participants, Espinet, Anderson, and Zelazo (2012) found that conflict monitoring quantified through N2 amplitudes (more negative amplitudes 200 to 400 ms after conflict stimulus onset) reliably differed between "passers" and "failers" and correlated with performance in the DCCS (see also Waxer & Morton, 2011). Together, these findings suggest that decreases in N2 amplitude coincide with improvements in EF tasks, suggesting that error monitoring is explicitly involved in EF (Lamm, Zelazo, & Lewis, 2006). This may indicate that monitoring plays a more important role in EF development than often assumed in behavioral approaches. The Role of Monitoring in EF and MC In my view, when discussing theoretical differences between EF and MC, monitoring deserves extra attention. While monitoring has been explicitly conceptualized as an integral part of MC (Nelson & Narens, 1994), for EF, monitoring is only implicitly assumed to take place, but often not studied directly (although the data would be available, for example, in terms of post error slowing down). Monitoring is certainly a part of theories of EF. However, within literature on MC, the monitoring concept is explicitly invoked. Lyons and Zelazo (2011) have theoretically integrated the different literatures and characterized monitoring as a reflective process. If such processes can range from momentary, fluctuating experiences of uncertainty to fully conscious and verbally reported monitoring judgments (Flavell, 2000), then the difference between EF and MC in terms of monitoring is mainly theoretical—EF monitoring is more momentary and less explicit compared to MC monitoring. However, it is monitoring and the associated assumption of continuous bottom-up and top-down feedback loops during cognitive processing that critically distinguishes MC and EF on a theoretical level. Metacognitive monitoring offers explicit and theoretical explanations 16 and—even more importantly—enables empirical predictions of why, when, and under what circumstances executive processes are initiated, changed, or terminated. If monitoring is relatively accurate, knowing the reason for an individual's uncertainty about his or her learning progress allows him or her to specifically predict which pieces of information will be selected for re-study. Regarding the few existing EF studies that have addressed individuals' error monitoring (e.g., in EEG studies, as described below; Lyons & Zelazo, 2011) as well as post-error slow-down during EF tasks (Jones, Rothbart, & Posner, 2003), the nature of ongoing monitoring might in fact be very similar to monitoring captured in MC paradigms. At the same time and as Yeung and Summerfield (2012) point out, EF monitoring appears to be an all-or-none process (error detected or not), while MC monitoring is more graded and confidence can be reported on a continuum ranging from certainty to uncertainty. Unfortunately, in typical EF studies, researchers essentially focus on only the executive (control) processes (in terms of performance accuracy or reaction time to correct responses) but not the ongoing monitoring. Hence, further data, such as reaction time during and after incorrect trials (i.e., post-error slowing down), remain unexplored, despite being available. By hypothesis, directly addressing and quantifying monitoring processes within EF tasks would be an empirical means for bringing these fields closer together in future research. Furthermore, investigating the correspondence of brain activity patterns across a broader variety of EF and MC tasks, including classic MC contexts, would allow for integrating findings from different research domains into an overarching neuro-cognitive framework. Another fruitful neuroscientific direction for future research would be to use other psychophysiological methods in addition to EEG when investigating EF and MC. Two examples would be eye-tracking (Roderer & Roebers, 2010, 2014) and pupil dilatation (Johnson, Singley, Peckham, Johnson, & Bunge, 2014; Paulus, Proust, & Sodian, 2013). II. Developmental Progression and Essential Empirical Links 17 Developmental Progression in EF and MC Framed by the above discussion, in the following paragraphs I offer a summary of age-related improvements in EF and MC, with a specific focus on early developmental achievements. Table 1 captures some of this summary. There are a number of well-established measurement tools for EF. For MC, the summary will focus on examples of both very recent creative approaches and long-forgotten paradigms, with the aim of providing insights that could improve our developmental understanding of this concept (for a recent review see Roebers, 2014). I do not contend that the present review or Table 1 are exhaustive. Rather, I focus selectively on some clear and prototypical examples along with their main findings to illustrate parallels of EF and MC development in the age range of 2–6 years and to direct the reader to this literature. Because the information provided in the papers varies widely, an entirely consistent way of presenting the data is not possible. This is why the review outlines either the earliest point in development for these tasks to produce meaningful, reliable, and valid results or estimations of expected mean performance in typically developing children. --- insert Table 1 about here -- Executive function. Diamond (2006) argued that the ability to pass the A-Not-B task, which emerges at the end of children`s first year of life, indicates the emergence of EF components of inhibition and working memory. In an early study using this task, 16-montholds were found to be correct in 80% of the first conflict trials (not-A trial) when given a twochoice trial; by contrast, 2.5-year-olds were correct in about 90% of the trials when given a three-choice trial, which is a much more difficult (in terms of working memory demands) version of the task (Sophian & Wellman, 1983). This suggests that strong improvements in EF appear in this early age range. Continuous task improvements in inhibition can also be measured in children's second year of life, with either the "Baby Stroop" task (small objects belong to the baby, big objects to the mother; the rule is then reversed) or the "Shape Stroop" 18 task. Updating can also be quantified early on, such as with the so-called "Spin the pots task" (also the "Six Boxes" task where stickers are hidden in pots and the colors of the pots must be memorized). Such simple tasks reliably capture early individual differences in updating, differences that have been found to explain substantial variance in different social and cognitive outcomes (Carlson, 2005; Hughes & Ensor, 2007). By about the age of 3, children can also reliably complete a spatial conflict task (one object "goes" right, one "goes" left; the appearance of the object can then be congruent or incongruent) or the Day/Night task (i.e., saying "night" when a sun is presented, or "day" when a moon is presented). For these tasks, the number of errors or the reaction time reflects children's ability to engage in top-down control or inhibition. There are various updating or working memory tasks available (e.g., the Beads task or the self-ordered pointing task), and research employing such tasks has made it apparent that 3-year-olds' capacity is, on average, about 3 to 5 items, depending on the task (Hughes & Ensor, 2007; Hongwanishkul et al., 2005). Concerning shifting, the widely used DCCS task poses serious problems for 3-yearolds, while 60–80% of 4-year-old children pass the task (Zelazo, Müller, Frye, & Marcovitch, 2003); hence, a remarkable improvement in EF development appears to take place in children's third year of life, which is attributed to their growing ability to abstractly represent current and previous task rules. Similarly pronounced developmental achievements have been reported for inhibition tasks, such as "Simon says" (do not do what Simon says) or the "Bear and Dragon" (follow the nice bear's commands, but do not follow the bad dragon's commands). More precisely, children younger than 4 years of age have considerable difficulty in correctly responding to incongruent trials (Carlson & Moses, 2001; Jones, Rothbart, & Posner, 2003). However, a year later, these same children might have already reached the performance ceiling (this makes it further clear that such tasks might not be optimal for capturing a wider age range). 19 Some EF tasks commonly used with adults have been adapted for use with children aged 5 years and older. Examples include the Stroop tasks, Backward Digit Recall, Simon task, and Flanker tasks (see Table 1). While for the age range of 2–4 years, qualitative changes (pass or fail; percent accurate responses) have been documented, speed-based dependent measures (reaction times) seem best for depicting individual differences in inhibition and shifting in 5-year-olds and older. Later on, that is, in elementary school children, a trade-off between accuracy and speed has repeatedly been documented (Best, Miller, & Jones, 2009), mirroring children's growing awareness that improvement in one aspect of performance (responding too quickly) might come at cost of another (errors). Updating, in contrast, is typically quantified in terms of the number of correct trials, with the length of the to-be-remembered sequence being continuously increased. While recalling 2 units of information is possible for most preschool children, recalling 3 or 4 units in reversed order poses difficulties, even to 6- to 7-year-olds (Pickering & Gathercole, 2001). Thus, in comparison to speed or interference measures of inhibition and shifting, for updating it appears that developmental progression is less continuous. Furthermore, developmental improvements in updating appear to slow down around the age of 12–13 years, suggesting that an individual might have reached its capacity limit around that age (Jarvis & Gathercole, 2003). Taken together, one major developmental milestone in EF development in terms of inhibition and shifting takes place between the ages of 3 and 4, which is attributed to improvements in ability to form abstract rule representations. A second major milestone can be observed between the ages of 6 and 8, when speed measures of EF performance are considered. In middle childhood and adolescence—while not the primary focus of this review— continuous developmental changes in EF can still be observed. In particular, in classic EF tasks, improvements in reaction times are observed over this age range (Best, Miller, & 20 Naglieri, 2011), along with substantial increases in the ability to manipulate multiple items simultaneously in mind, future planning, decision making, and relational reasoning (e.g., Blakemore & Mills, 2014; Dumontheil, Houlton, Christoff, & Blakemore, 2010; Paulus, Tsalas, Proust, & Sodian, 2014). Metacognition. Traditionally, it was assumed that the most pronounced developmental improvements in MC are observed once children enter formal schooling (Roebers, 2014; Schneider, 2015), mainly employing structured learning tasks. Recently, however, some innovative paradigms that include natural indicators of metacognitive control, such as help seeking (Coughlin et al., 2014), information seeking (e.g., Call & Carpenter, 2001), or optingout (Balcomb & Gerken, 2008; Bernard et al., 2015), have successfully explored metacognitive skills in younger children. As mentioned above, the focus in this section will especially concern recent studies, as well as some classic ones, that address early MC development. The aim is to draw a more differentiated picture of measurement of this concept, especially for emerging metacognitive monitoring and control skills. Table 1 provides some examples indicative of early, but still rudimentary metacognitive skills. The goal-directed behaviors of toddlers (24–26 months of age) in a hide-and-seek task are among the earliest indications of emerging metacognitive skills. More precisely, in an early study by DeLoache and colleagues (DeLoache et al., 1985) toddlers showed on average of 2–3 different behaviors indicating an awareness of forgetting and the prevention thereof, such as peeking, verbalizing, and pointing. Furthermore, within the context of a tower building task as well as in direct interaction with an experimenter giving ambiguous commands (e.g., "get the red one!"), monitoring (checking back and forth; asking for specification) and control (change of strategy, corrections) can be observed in the second year of life, and is even more pronounced in the third (Bullock & Lütkenhaus, 1988; Revelle et al., 1985). 21 However, these indicators of MC skills are typically only nominal data and thus are psychometrically sub-optimal. In the last years, Simona Ghetti's research group has successfully developed paradigms, mostly in the context of object perception and identification, suitable for detecting early MC. They found that, without an additional memory (cognitive) load, young children's emerging MC skills seem to be reliably quantifiable by using a 2-point scale ("unsure" – "very sure"; Lyons & Ghetti, 2013) or a 3-point scale ("unsure" – "neither sure nor unsure" – "very sure"; Coughlin et al., 2015; Hembacher & Ghetti, 2014). With these scales the majority of children of that age give more frequently low confidence judgments after providing incorrect responses compared to correct responses, indicating the emergence of the ability to metacognitively differentiate between correct and incorrect performance. However, from these studies it also appears that children`s concept of "certainty" is most likely dichotomous: that is, children at this young age are either "very sure" or "very unsure" about the accuracy of their answers (and they have a strong tendency to be very sure whenever partial knowledge or any sense of familiarity is present; Rohwer, Kloo, & Perner, 2012; see also Kim, Paulus, Sodian, & Proust, 2016). A relatively serious disadvantage of these studies (when aiming to integrate these MC components with EF) is the explicit nature of the monitoring and control measures used. To overcome this, Kim and colleagues (Kim et al., 2016) captured 3- and 4-year-old children's gestures of uncertainty, including the frequency of children's head tilting or shaking, shrugging, and looking away through video recording, in addition to their control decisions (verbally informing a third person or not, depending on their state of knowledge). While there were no age differences in the explicit indicators of MC (informing or not informing a third person), 4-year-olds showed significantly more non-verbal signs of uncertainty than did the 3- year-olds, with these uncertainty gestures becoming more frequent the less knowledge the children had. These findings might indicate a gradual developmental trajectory in early monitoring skills, one that may not be possible to capture using explicit measures. 22 By the age of 5, children begin showing increasingly differentiated monitoring judgments and more efficient control skills, according to studies charting MC development through memory recognition paradigms. Except for Balcomb and Gerken (2008) and Bernard et al. (2015) -- who documented first signs of monitoring-based control in 3.5- and 3-year-olds respectively-- the majority of studies have included 5-year-olds. Against the background of existing findings, one can expect kindergarteners to give reliably more positive monitoring judgments (judgments of learning: "how likely is it that you'll remember this name later on?", confidence judgments: "how confident are you that you got that answer correct?") to correct responses than to incorrect ones. Although their monitoring judgments are still strongly and positively biased (i.e., "overconfidence"; Lipowski, Merriman, & Dunlosky, 2013), children of that age are clearly beginning to build their control behavior and improve their selection of task strategies through monitoring (Coughlin et al., 2015; Destan et al., 2014; Destan & Roebers, 2015; Hembacher & Ghetti, 2014). Through daily experiences, including success and failure of their memory and learning efforts in school, children may slowly calibrate their monitoring skills (e.g., by becoming less overconfident, making more precise performance predictions, and being increasingly able to differentiate between correct and incorrect responses as well as between sufficient and insufficient learning). While monitoring skills are found to be relatively accurate by the age of 8, control skills (e.g., study time allocation, withdrawal of errors) are repeatedly found to lag behind, as children seem to have difficulties transferring their monitoring into adequate control actions. Indeed, the following actions still pose difficulties to older elementary school children: allocating study time in line with their judgments of learning (Lockl & Schneider, 2002), monitoring text comprehension and selecting text passages for re-reading (de Bruin, Thiede, Camp, & Redford, 2011), making performance predictions and selecting the most meaningful passages for re-studying (van Loon, de Bruin, van Gog, & van Merriënboer, 23 2013a), or withdrawing answers when unsure about their correctness (Krebs & Roebers, 2010). It is therefore not surprising that even in adolescence, metacognitive monitoring and control continue to improve. For example, in the context of decision-making tasks, individuals' relative confidence in different options and their strategy of seeking out additional information substantially improves between 11 and 18 years (Weil et al., 2013). In the context of reading comprehension, significant age differences have been documented in relation to monitoring discrepancies and correcting spelling errors in texts between the ages of 12 and 16 years (e.g., Hacker, 1997). Generally, as Roebers (2014) noted, metacognitive development in later childhood and adolescence can best be described as the fine-tuning of earlier developed monitoring and control skills, including the adaptive and increasingly flexible use of control actions and the efficient use of information stemming from progressively more accurate monitoring. In sum, the current literature provides considerable evidence for rudimentary EF and MC skills in children as young as 3 years of age. For both domains, children at around the age of 4 years start to increasingly differentiate between rules or mental sets (EF) as well as between different degrees of certainty (MC). A further parallel in terms of development takes place at around school entry. For EF, children show rather accurate performance in simple EF tasks, with the developmental progression concerning mostly the trade-off between speed and accuracy. For MC, the development involves fine-tuning monitoring in able to better act upon it during learning. Finally, there is evidence for a continuous and protracted development into adolescence within both domains, especially in the context of planning and problem solving (for overviews, see, for example, Blakemore & Mills, 2014; Schneider, 2015). Environmental Factors Influencing Developmental Progressions 24 The relatively similar developmental timetables in EF and MC just outlined lead to a question: "What are the underlying mechanisms of these developmental changes?" The literature on both concepts suggests that developmental progression is driven by a constant interaction with the child's environment (Bunge & Crone, 2009). For example, when solving a new task, a child faces numerous challenges, experiences troubles moving on, or detects errors. Consequently, the child may try different ways of mastering the task, either through trial-and-error or guidance by a more skilled individual. Strategies that turn out to be successful have a higher likelihood of being applied in later, similar situations than do unsuccessful strategies. Thus, I hypothesize that children continuously improve and fine-tune their EF and MC skills and adapt them according to the problem that needs solving. In the following paragraphs, I identify some prominent factors that I propose foster this developmental progression in EF and MC. Effects of Parenting on EF and MC. Research on factors that drive improvements in children's EF has consistently suggested that the quality of parent–child interactions can only explain not only individual differences in EF performance but can also substantially predict EF growth over time (Blair, Raver, Berry & Family Life Project Investigators, 2014). Most of this research has focused on very young children (infants and toddlers), and involves having parents and their children solve a difficult task, such as jigsaw puzzle, together. The parental behavior during this task is observed and categorized. For this particular age range, individual differences in the mother's and father's "autonomy support" and "caregiver's sensitivity" (i.e., praising, encouraging pursuit of a task, elaborations, positive feedback), as well as the synchrony of parent and child behavior, are significantly associated with individual differences in EF performance and growth, potentially because these factors allow the child to develop a sense of mastery without too much control (Bernier, Carlson, & Whipple, 2010; Blair et al., 2014; Hughes & Ensor, 2009; Meuwissen & Carlson, 2015). Typically, these predictive links hold true even after controlling for socioeconomic status (family income or 25 parental education) and language development (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Meuwissen & Carlson, 2015). Furthermore, enduring environmental effects might have an even stronger impact on EF development (Matte-Gagné, Bernier, & Lalonde, 2014). Thus, parents' thoughtful and intentional efforts to support a child's goal-directed actions and problem-solving behaviors are a means of fostering the child's independence from external guidance or control; these, in turn, yield a positive impact on EF development (Carlson, 2009; Hughes, 2011). Concerning parental factors fostering early MC development, research has revealed similar findings regarding the importance of parents. Namely, parental language during social interactions might influence children`s metacognitive development. Specifically, parents' utterances relating to planning, self-monitoring, and control such as "what do you think we should do next?" "are you sure that this is right?" or "did you want it to go that way?" are considered important for MC development. In this context, an observational study showed that 39% of parents' task-related utterances were of metacognitive character; however, of those, only 8% were categorized as being related to monitoring (Thompson & Foster, 2013). Further evidence suggests that parents' metacognitive language is linked to their children's use of mental verbs (e.g., guess, think, know, forget, believe, remember, wonder), which in turn positively influences children's metacognitive knowledge (Lockl & Schneider, 2006). Additionally, parents differ in how they instruct children to use certain strategies, how they check or help children self-check their schoolwork, and how often they play certain games with their children (in particular games that require monitoring, control, or strategic thinking; Moore, Mullis, & Mullis, 1986). These differences among parents are substantially linked to children`s metacognitive development (Carr, Kurtz, Schneider, Turner, & Borkowski, 1989). Consequently, MC development—similar to EF development—is supported by parents' explicit and implicit input, which allows the child to have metacognitive experiences and 26 benefit from feedback and supervision. In the course of development, this seems to lead to improved MC skills. Effects of schooling on EF and MC. Schooling on its own, as well as direct instructions provided by teachers, are two further factors that influence EF and MC development, both in kindergarten and school-aged children alike. A cut-off design including children of similar age but who differ in terms of school enrolment (because they were born shortly before or shortly after the school's district cutoff date) helps address schooling effects. Concerning EF development, Burrage and colleagues' (Burrage et al., 2008) cut-off design study revealed a disproportionate EF improvement for the component of updating. Additionally, they reported a trend for an advantage in inhibition in children enrolled in kindergarten in comparison to age-mates who remained in pre-kindergarten. In a similar vein, when comparing children that either attended or could not attend school (because they live in countries where not all children can go to school), school-attending children typically outperform their non-attending age mates in terms of metacognitive skills (Rogoff, 1994). Going to school or kindergarten and thereby being confronted with the teachers` requests and assignments thus seems to foster a child's self-regulatory skills in both EF and MC. Despite the revealing findings of these studies, investigating the direct effects of instructions on EF and MC development would additionally illuminate the underlying mechanisms possibly responsible for progressive improvements. In an effort to link the memory-related quality of teachers' instructions to children`s development of strategic memory behavior (which is an aspect of MC), Coffman, Ornstein, McCall, and Curran (2008) conducted a classroom observation study. Similar to what was found for parents' influence (see above), only 5–9% of teachers' requests or explanations were categorized as being metacognitively oriented. Furthermore, considerable variance between different teachers was found. Those teachers who were classified as giving strategy suggestions and asking 27 metacognitive questions more often improved their first graders' metacognitive memory behavior in the long run. Specifically, first graders instructed by teachers with a strong mnemonic orientation underwent a stronger, more positive change in MC skills over the twoyear study period. These effects were later confirmed in an experimental approach (Grammer, Coffman, & Ornstein, 2013). Curriculum-based studies have also shown that the quality of teacher–

student interactions and types of classroom activities initiated and supervised by the teacher play a crucial role for EF development. For instance, Tools of the Mind (Bodrova & Leong, 1996), an educational approach based on Vytgotskian theory that strongly focuses on socio-dramatic play and teachers' scaffolding, yielded positive (albeit relatively small) effects on EF when implemented in kindergarten (e.g., Blair & Raver, 2014; Diamond, Barnett, Thomas, & Munro, 2007; but see Barnett et al., 2008). Similarly, Lillard and Else-Quest (2006) compared two different kinds of educational programs, with one being Montessori education. Montessori programs are characterized by age-mixed classes, provision of special materials, long time blocks of self-selected project work, no tests or grades, and mainly small group or individualized instructions. Five-year-old children randomly assigned to a Montessori educational kindergarten program were found to outperform children from a conventional kindergarten in terms of EF (Lillard & Else-Quest, 2006). Specifically, kindergarten children attending the Montessori education outperformed children in the "normal" kindergarten in terms of card sorting, a classical measure of task switching, while there were no differences in terms of vocabulary (known to be strongly influenced by family background characteristics). In this context, it is interesting to note that specific instructional effects on EF development tend to be stronger when children grow up in adverse environments (e.g., in poverty; Blair & Raver, 2014), which is of great practical importance. 28 Overall, the literature shows that, to a certain degree, EF and MC are higher-order cognitive processes that develop through children's continuous and active interaction with their natural environment. More sophisticated skills, however, develop only if an individual receives direct instructions, close supervision in critical situations or challenging tasks, and feedback from skilled partners. Such factors allow the child to experience the benefits and possible use of EF or MC. In other words, cognitive instructions and social learning mechanisms appear to be major developmental forces in the ontogeny of EF and MC. Relevance of EF and MC for Academic Performance Executive Function. Cross-sectional and longitudinal studies on EF have consistently revealed that EF is closely linked to different areas of school performance. Research does not evenly cover the different school subjects—it has generally focused more on mathematics than on literacy or science (Bull & Lee, 2014; Latzman, Elkovitch, Young, & Clark, 2010; Rhodes et al., 2016). In general, individual differences in EF typically explain 20–60% of the variance in children's school achievement. This holds true for young elementary school children through to high school students (Best et al., 2011; Roebers, Röthlisberger, Neuenschwander, Cimeli, Michel, & Jäger, 2014), and for early word reading and spelling to 10-year-olds' reading comprehension (Kieffer, Vukovic, & Berry, 2013). It also appears to apply to achievements in science and social studies (Latzman et al., 2010). As for mathematics, the impact of EF has been shown for different sub-domains, such as simple arithmetic or applied problems (Fuhs, Nesbitt, Farran, & Dong, 2014), and updating appears to have a larger impact compared to inhibition and shifting (Lee et al., 2012; Monette, Bigras, & Guay, 2011; Roebers, Röthlisberger, Cimeli, Michel, & Neuenschwander, 2011). Of course, this does not imply that the other EF components are negligible. In a meta-analysis in which only the effects of switching on school achievement were examined, reliable effects of 29 isolated measures of switching for mathematics and literacy performance were reported (Yeniad, Malda, Mesman, van Ijzendoorn, & Pieper, 2013). The impact of EF is long lasting: the predictive power of EF as a unified construct (latent variable) has appeared in a number of longitudinal studies. Typically, individual differences in EF for preschoolers and kindergarteners can explain between 5 and 36% of the variance in early academic attainment (e.g., Blair, Ursache, Greenberg, Vernon-Feagans, & Family Life Project Investigators, 2015; Clark, Sheffield, Wiebe, & Espy, 2013; Roebers, Röthlisberger, et al., 2014; Viterbori et al., 2015). As is the case in cross-sectional studies, longitudinal links between EF and academic achievement tend to be stronger for mathematics (explaining 25% of the variance) than for literacy (explaining 16% of the variance; Monette et al., 2011; see also Blair et al., 2015; Clark, Pritchard, & Woodward, 2009). Among the EF components, updating seems to be the most important predictor for later mathematical achievements and for a variety of mathematical skills (Viterbori et al., 2015). The effect of EF for school achievement is both direct (see above) and indirect. EF appears to facilitate learning-related behavior (β =.60, in Neuenschwander, Röthlisberger, Cimeli, & Roebers, 2012), and behavioral classroom adjustment, which in turn appears to positively influence later academic achievement (e.g., Clark et al., 2013; Fuhs, et al. 2014; Monette et al., 2011). Importantly, the effects of EF on academic achievement remain substantial when controlling for important predictors of academic achievement, such as socioeconomic background, home environment, and general cognitive abilities. Several studies have indicated the opposite—namely, that mathematics influence later EF performance (e.g., Blair et al., 2015; Clark et al., 2009, 2013). At the same time, note that these links are suggestive, because they cannot definitively test causal relations (Clements, Sarama, & Germeroth, 2016). 30 Metacognition. Reviewing the literature on the relevance of MC for academic performance is a challenge. This is because, for one, developmental psychologists have focused on the developmental progression of various aspects of MC by conducting experiments with different age groups and often neglecting individual differences within age groups. Furthermore, procedural MC is always assessed within the context of certain tasks, which are often school-related ones themselves. Nonetheless, existing studies suggest a substantial and direct link between MC and performance in adults and children (e.g., Dunlosky & Rawson, 2012; Geurten, Catale, & Meulemans, 2015; for overviews see Dunlosky & Metcalfe, 2009; Schneider, 2015). In Krebs and Roebers's (2010) study, 9- to 12- year-old children achieved between 25% and 50% gains in test performance (i.e., accuracy) through adequate metacognitive control. Similarly, students who severely overestimate their performance (i.e., poor monitoring or poor calibration), either before or after completing a task, typically perform the poorest (e.g., Dunlosky & Metcalfe, 2009; Dunning, Johnson, Ehrlinger, & Kruger, 2003; Kruger & Dunnig, 1999). In a short-term longitudinal study, fifth graders were asked to predict their test results in every test taken throughout of the school year (Roderer & Roebers, 2014). The weak students overestimated their test result as much as 20%, while the high-performing students were mostly accurate in predicting their achievement (only 5% overestimation); this pattern held true over the entire school year. This "unskilled but unaware" effect is even more pronounced in younger compared to older children or adults (Destan & Roebers, 2015; Lipko, Dunlosky, & Merriman, 2009; Lipowski, Merriman, & Dunlosky, 2013). Overall, MC seems critical for students' effective regulation of learning and remembering, with the effects of procedural MC on achievement being direct and long-lasting (Vo, Li, Kornell, Pouget, & Cantlon, 2014). The substantial impact of procedural MC on academic achievement holds true for reading (meta-comprehension skills; De Bruin et al., 2011; Markman, 1979; Pressley & Afflerbach, 1995), writing (Hacker, Keener, & Kircher, 2009), mathematics (Desoete, 31 Roeyers, & De Clercq, 2003; Dunlosky & Metcalfe, 2009), science (Roderer & Roebers, 2014; van Loon, de Bruin, van Gog, van Merriënboer, & Dunlosky, 2014), and general knowledge tests (Roebers, Krebs, & Roderer, 2014). When comparing the patterns of results across different age groups, it appears all children require a certain degree of monitoring and control skills; otherwise, no significant and positive effect on performance is observed. In younger elementary school children, high confidence is typically linked with better performance (explaining up to 50% of the variance in performance; Roebers, Krebs, et al., 2014; note that this effect has been attributed partly to motivation and persistence, see Shin, Bjorklund, & Beck, 2007). In older elementary school children, however, metacognitive monitoring is substantially linked to efficient MC control behavior (β = .30) that, in turn, positively influences academic performance (β = .28; Roebers, Krebs, et al., 2014; see also Schneider et al., 1987). In their longitudinal study, Rinne and Mazzocco (2014) did not only test whether metacognitive monitoring skills were cross-sectionally related to mathematical achievement in students in grades 5–8, but also whether accurate monitoring contributes to improvements in mathematics over time. Their regression models revealed that good monitoring skills predicted increases in arithmetic (β = .27). The authors interpreted their findings as an indication that good monitoring skills directly enable a student to more effectively control mathematical information processing (e.g., more flexible problem solving strategies, more sensible error detection). This, in turn, leads to a more efficient allocation of effort, more attention on harder compared to easier problems, a better use of feedback, and, overall, to benefits in mathematical achievement. For younger children, the link between MC and academic performance might be in the opposite direction: More precisely, increasing skills in first-order tasks might support the development of metacognitive skills. A recent study with second graders showed that spelling 32 skills in the beginning of the school year predict spelling skills at the end of the second grade; at the same time, positive longitudinal links from earlier spelling to later metacognitive monitoring (discriminating between correctly and incorrectly spelled words: β = .33) and later control (correction of errors: β = .40; Roebers & Spiess, 2017) have been documented, suggesting that academic performance might also facilitate accurate MC. Together, the evidence has indicated bi-directional links between MC and achievement, with these relations possibly undergoing changes over time as competencies in both the first order tasks and MC improve. Relative Importance of EF and MC for Academic Performance. Undoubtedly, both EF and MC are directly related to children's academic achievement, both cross-sectionally and longitudinally. Thus, the question arises which, if either, of these two constructs is more important? Obviously, this issue can only be tackled when measurements of both are included in one study. One investigation did so by simultaneously estimating the predictive power of EF and MC for 8-year-olds' academic achievement in mathematics and literacy (Roebers, Cimeli, Röthlisberger, & Neuenschwander, 2012). While EF was assessed with the classic tasks of the EF components, MC was quantified only in the context of a spelling task. Both EF and MC were strongly linked to curriculum-valid, independent tests of school performance. While the impact of EF was valid for both mathematics and literacy (β = .66 and .48, respectively), the effects of MC were only marginally significant for mathematics but very strong for literacy (β = .24 and .56, respectively). These findings, together with those of Rinne and Mazzocco (2014; who showed that monitoring accuracy contributes to improvements in mathematics), suggest that the predictive power of EF for academic attainment is more general, whereas the effect of MC is more circumscribed but possibly even stronger, because it is also task-bound (see also Bryce, Whitebread, & Szucs, 2014, for a cross-sectional study on this topic including younger children). 33 At the same time, when explaining academic performance with EF or MC, we might in fact be looking at and addressing the same underlying mechanisms. An individual's awareness that one has not yet achieved the desired goal (e.g., working too slow, using an inappropriate strategy), or that one has to only pay attention to certain task features, in combination with the general ability to act on this introspection, might be a common (monitoring) ground for EF and MC. This is especially true when predicting academic performance. Even if labeled and studied differently, the exchange of bottom-up, first-order task performance information (error/performance monitoring) with top-down regulation of ongoing cognitive processes (executive control) constitutes, at least in my view, an important shared feature of EF and MC. Similar to what has been termed "psychological distancing" in addressing commonalities between EF and theory of mind (e.g., Carlson, Claxton, & Moses, 2015; Carlson, Davis, & Leach, 2005; Devine & Hughes, 2014), an individual's ability to take a meta-view on one's ongoing information processing and to act on this meta-view might be shared between EF and MC. In other words, the ability "to step back" from ongoing processing (triggered through some fast and early monitoring processes and made possible through inhibition) and to observe oneself as an agent with the intention to improve one's performance is a central aspect to both EF and MC, which calls for an integration into one framework. Relations of EF and MC to Intelligence As just noted, EF and MC are strongly related to school achievement. Examining intelligence should also be helpful, because traditionally that has been considered the prototypic predictor of academic attainment. All three constructs—MC, EF, IQ-- are higherorder cognitive processes, triggered and utilized in complex tasks and problem-solving contexts. According to Sternberg`s theoretical perspective on intelligence, EF and MC may be considered integral parts of intelligence and show massive overlap between each other 34 (Sternberg, 1985; 1999). Consequently, once intelligence is controlled for, one would assume that no further variance in school achievement would be explained through EF or MC, respectively. Executive Function. Empirical studies addressing overlap between intelligence, EF, and MC have not found evidence for strong overlap. When linking EF and intelligence at the task level, moderate associations in the range of r = .25 to .40 have been reported (Cornoldi, Orsini, Cianci, Giofrè, & Pezzuti, 2013; Friedman et al., 2006; Lee, Pe, Ang, & Stankov, 2009), and this pattern generalizes across a wide age range, from 7-year-olds to adolescents, and for both fluid and crystallized intelligence (Brydges et al., 2012; Friedman et al., 2006; Lee et al., 2009). Studies considering the different EF subcomponents have suggested that shifting and updating each make a unique contribution to intelligence (Lee et al., 2009; Yeniad et al., 2013). Together, the overlap between EF and intelligence is substantial, but not total; significant amounts of variance in intelligence remain unexplained, leaving room for other information processes. Metacognition. There are only a few studies directly linking MC to intelligence. However, learning-disabled children are consistently found to have poor declarative and procedural metacognitive skills (e.g., Desoete, Roeyers, & Huylebroeck, 2006; Job & Klassen, 2012). Likewise, gifted compared to non-gifted children typically have a more elaborate metacognitive knowledge base, are able to more accurately monitor their learning progress, and can more efficiently control their learning and academic performance (Alexander & Schwanenflugel, 1996; Krebs & Roebers, 2012; Snyder, Nietfeld, & Linnenbrink-Garcia, 2011). Using the term "metacognitive skillfulness," which covers declarative metacognitive knowledge and qualitative as well as quantitative data from "thinking aloud" protocols, Veenman and colleagues have documented parallel developmental improvements and substantial overlaps between MC and intelligence, with the 35 correlations between them ranging from r = .16 to .39 (Panaoura & Philippou, 2007; van der Stel & Veenman, 2008, 2010, 2014; van der Stel, Veenman, Deelen, & Haenen, 2010). Obviously, both EF and MC share a significant amount of variance with concurrent measures of intelligence, although the overlap seems to be larger for EF than for MC. An interesting follow-up question then concerns the predictive power of EF and MC versus intelligence for academic achievement. Given the lack of studies that have simultaneously included EF, MC, and intelligence in predicting academic achievement, the current review focuses separately on the predictive powers of EF or MC versus intelligence. Rather few studies have simultaneously compared the longitudinal links of EF or intelligence with academic outcome measures. Those that exist suggest that intelligence is more closely related to objective measures of school performance than is EF (for a meta-analysis, see Yeniad et al., 2013), whereas EF has greater potential to contribute to the prediction of school performance over and above intelligence. In other words, even after controlling for individual differences in intelligence, EF has been reported to explain a further 6–10% of the variance in school performance). Interestingly, this pattern holds true for young (preschool) children when predicting early academic outcomes (Clark et al., 2009) as well as for older (middle to high school) students, and generalizes to different school domains (literacy, mathematics, social studies, science; Latzman et al., 2010). In comparing the impacts of MC and intelligence on children's academic performance, a similar picture emerges as for EF. Individual differences in MC have an additional and direct effect on students' learning outcomes, after controlling for the influence of intelligence (for example, 26% additional unique metacognitive variance explains history achievement, over and above intelligence; van der Stel & Veenman, 2014). Further, it appears that in younger students (late elementary school children), the impact of MC on academic attainment over and above that of intelligence is smaller compared to in older students, for whom MC 36 has been reported to be more important than intelligence in the domains of mathematics and history (van der Stel & Veenman, 2010; van der Stel et al., 2010). Empirical links between EF and MC In this last section, direct links between the two constructs of EF and MC will be considered. Against the background of similarities reviewed so far, one would expect strong evidence for a close link between these two higher-order information processes. Surprisingly, very few studies have directly addressed the shared processes and variances. Moreover, the results do not confirm the assumption of closely linked domains. With respect to declarative MC, one recent study documented substantial links between verbal fluency (an often-used index of switching), and working memory and an overall measure of declarative metamemory in 6- and 9-year-olds (Geurten, Catale, & Meulemans, 2016). This pattern, however, was found neither for 4- nor for 11-year-olds. Furthermore, it did not generalize to inhibition. Regarding procedural MC, researchers have mostly used individual EF subcomponents to explain variance in MC (and not vice versa), particularly updating. This is because it is commonly assumed that the iterative flow of information in both a bottom-up (monitoring) and top-down (control) direction requires sufficient cognitive capacity, which is best captured with updating measures. Studies by Dunlosky and Thiede (2004, Experiment 3) and Rhodes and Kelley (2005) have documented this link for adults. Rather few studies have also addressed the link in elementary school children—that is, in children aged 5–10 years. Interestingly, these studies have consistently found a significant, albeit small, association between working memory (or updating) and MC, explaining between 5 and 10% of the variance (with correlations consistently being in the $r = .20–.35$ range). The included MC measures range from strategic behavior in a memory task (DeMarie & Ferron, 2003) to metacognitive control in the context of a school achievement test (Spiess, Meier, & Roebers, 2015, 2016). When both monitoring and control measures are available, the results point to a 37 closer link between updating and control than between updating and monitoring (Bryce et al., 2014; Roebers et al., 2012). It thus seems safe to conclude that individual differences in updating are related to metacognitive skills, both in children and adults. In the context of children's flexible strategy use, Kuhn and Pease (2010) have reported that inhibition might be a necessary but insufficient prerequisite of effective use of metacognition. Successful problem solving or efficient memory operations might rely on the production of a new strategy as well as the inhibition of a previously used strategy. When using more classical indicators of inhibition (Stroop tasks) and MC, Bryce and colleagues (2014) reported a correlation of $r = .35$ between inhibition and monitoring (i.e., looking back and checking in a train-track building task) among 5- and 7-year-olds. However, in Roebers et al.'s (2012) study, monitoring discrimination was not found to be associated with inhibitory skills, whereas 8-year-olds' metacognitive control in a spelling task was (with $rs = .25–.29$; see also Spiess et al., 2016, for similar findings). Finally, one would theoretically expect that shifting one's attention back and forth between the task at hand (an EF component) and ongoing metacognitive processes (MC) could be a crucial link between the two. However, results from the few existing studies (embodying a variety of approaches) have mainly reported insubstantial links between switching (or shifting, or cognitive flexibility) and metacognitive monitoring and control in elementary school children

(Roebers et al., 2012; Spiess et al., 2016). Moreover, it is important to note here that in some other studies trying to link EF components with MC, only non-significant links between MC and EF in children were found (e.g., Destan & Roebers, 2015; Geurten, Catale, et al., 2015), suggesting that the links reported above are far from firmly established. Although these approaches are interesting, they have some serious methodological disadvantages. For one, EF tasks, and even more so MC tasks, trigger non-executive or non- 38 metacognitive processes, such as domain-specific knowledge, momentary motivation, and familiarity with the task. For another, no single EF component or MC aspect can be quantified in isolation, because the different sub-processes within one concept are strongly intertwined and mutually dependent. Miyake and Friedman (2012) labeled this issue as the "taskimpurity" problem in the context of EF, but it also seems to apply to MC. For instance, working memory strongly relies on an individual's ability to inhibit interference and shift between the storage and processing of to-be-remembered information. Or, a learner's re-study selections might be based on her or his—more or less accurate—monitoring of learning progress (monitoring-based control). As a result, the true amounts of shared variances between "pure" EF and MC are likely underestimated (Roebers & Feurer, 2016). Structural equation modeling techniques (SEM) offer a unique solution to these methodological concerns. With such an approach, the individual EF or MC tasks can be loaded onto a latent EF or MC factor, respectively, which then captures only the shared variances of the individual indicators. These variances can then be used on the construct-level to estimate the relations between EF and MC. To date, only two studies have addressed direct links between EF and MC at the latent-variable level, using SEM techniques. One of them, a cross-sectional approach including second graders, reported a link as high as $\beta = .51$ between metacognitive control and EF (with indicators of inhibition, updating, and shifting (verbal fluency) being used to load onto the latent EF variable; Roebers et al., 2012). The link between metacognitive monitoring and EF, however, was not significant. Since monitoring and control were found to be strongly related ($\beta = .46$), it seems that there is no direct effect of monitoring on EF. In a follow-up study targeting direct links between EF and metacognitive control only, Spiess and colleagues (2016) confirmed a concurrent relation between the two constructs. Individual differences in second graders' EF and MC were substantially related at the beginning of the 39 school year, accounting for as much as 34% of the shared variance. Apart from this link and because of the very high stability of both constructs in that short-term longitudinal study, earlier EF or MC did not predict subsequent EF or MC (i.e., at the end of the second school year). These findings suggest that the developmental progression in the two constructs are not entirely dependent on each other, but rather follow distinct pathways, at least in this age. One possible reason that the empirical links between EF and MC are lower than one might expect is children's ability to form meta-representations—that is, some kind of selfawareness of one's performance is necessary to switch from automated to controlled processes or to change a selected strategy. Consequently, age-related and individual differences in the ability to hold a representation of one's performance should be related to both EF and MC. In this context, one cross-sectional and one longitudinal study reported substantial links between kindergarteners' and second graders' self-perceptions of competence (i.e., self-concept) and EF or MC (Hughes & Ensor, 2010; Roebers et al., 2012). Following this argument, a child's ability to hold in mind two divergent representations (actual and desired performance) might even constitute a link between EF and MC, at least in young children. In the domain of theory-of-mind development, understanding that one entity can be represented in two different ways (for example, by two different individuals, as is investigated in so-called false-belief tasks) is an important achievement in cognitive and social-emotional development. From this perspective, theory-of-mind skills might moderate the link between EF and MC. This assumption has been supported by a handful of studies revealing empirical associations of EF and MC with theory-of-mind skills. Specifically, while Carlson and colleagues found significant links between preschoolers' EF and their theory-of-mind skills (Carlson et al., 2015; Carlson, White, & Davis-Unger, 2014), other researchers report links between theory-of-mind skills and either declarative (Lecce, 40 Caputi, & Pagnin, 2015; Lecce, Demichelli, Zocchi, & Palladino, 2015; Lockl & Schneider, 2006, 2007) or procedural monitoring skills (Feurer, Sassu, Cimeli, & Roebers, 2015). Besides these theoretical accounts, there are also methodological reasons for the empirically poor links between EF and MC. For one, EF is typically quantified in a decontextualized manner using electronic devices that present simple stimuli. MC, in contrast, is almost always measured in a circumscribed, explicit, and task-specific context, such as by reading a text, learning paired associates, or solving a certain problem. Consequently, it is quite likely that MC measurements include greater variance attributable to domain- or taskspecific knowledge or familiarity than do EF tasks (e.g., responding to the stimuli's orientation). For another, the focus of the measurements entails a further methodological difference between the two domains. For EF tasks, the focus is either on accuracy (e.g., DCCS task or updating tasks), speed of information processing (e.g., the Simon task or Flanker task), or both (which is because most tasks have a speed-accuracy trade-off: if you respond too fast, you are risking errors). Primary measures of MC, in contrast, focus on the timing of processes (MC during encoding, storage, or retrieval) and the qualitative nature of measurement. If one would use, for example, reaction-time-based measures of MC (see, for example, Koriat & Ackerman, 2010; van Loon, de Bruin, van Gog, & van Merriënboer, 2013b) and relate them to reaction-time-based measures of EF (e.g., Flanker performance in terms of reaction times), the obtained correspondence might be more substantial. The same might be true for more qualitative measures of EF (e.g., complex versions of the DCCS task) in relation to classical MC measures (e.g., flexible strategy use). Future research should broaden the methodological approaches for quantifying EF and MC, and thereby provide a more comprehensive picture of the assumed links. One might assume that the direct empirical links between EF and MC documented so far are due to their overlapping effects with intelligence. In other words, it is possible that the 41 relation between EF and MC is best explained with individual differences in intelligence. Unfortunately, no study has yet included intelligence when linking EF and MC. This constitutes an important issue for future studies. Drawing on the literature linking EF to theory-of-mind skills, I expect that the link between metacognitive control (but not necessarily monitoring) and EF still holds true after controlling for intelligence. Several studies have shown that the EF–theory-of-mind link remains substantial even after controlling for language abilities (Carlson & Moses, 2001; Devine & Hughes, 2014; Lockl & Schneider, 2007), which points to unique shared processes. Thus, even though intelligence, EF, and MC are higher-order cognitive processes (see above), I assume that an EF–MC link remains significant even when controlling for psychometric intelligence. This is because EF and MC involve information processes that are more proximal and similar to each other than to intelligence. In particular, the control aspect of EF and MC, which is triggered to improve current task performance, is not made explicit in intelligence. Towards a Unifying Framework of Cognitive Self-Regulation Because EF and MC have different research traditions and are embedded in different theoretical frameworks, the connection between the two has not received sufficient attention. In the present review, key aspects relevant to cognitive functioning in general as well as for self-regulatory skills in particular have been discussed separately for EF and MC, with a focus on the similarities between these two domains. With respect to controlled (versus automated) processing, neuropsychological correlates, relevance to self-regulated behavior (especially learning, intelligence, and academic performance), developmental timetables, and the driving forces for developmental progression, it appears that there are more commonalities than differences between the two constructs. Against this theoretical and empirical background, and with the aim of theoretically integrating EF and MC, I propose that a core feature for an overarching framework of these 42 two concepts concerns an individual's ability to form and use meta-representations of cognitive and learning processes. This includes the ability to look at one's actions at a remove, ideally objectively, and to act on the information that stems from this metaperspective. [Although not the primary focus here, from this perspective, theory of mind skills may also be incorporated as meta-representations of one's own and others' thoughts, motivations, and goals, or, more generally, cognitive processing (Frith, 2012; Kuhn, 2000; Perner, Lang, & Kloo, 2002)]. According to such a view, the integration of these two concepts would provide a domain-general, second-order cognitive processing account, with EF and MC being expressions of the same underlying system of self-regulative processing (Best & Miller, 2010; Kuhn, 2000). Within this integrative view, monitoring processes would be another shared, and central feature. The neuroscientific evidence suggests that one can assume a network of brain areas, predominantly located in the PFC and ACC, which alerts the system if ongoing information processing should be slowed down or adjusted. The activity of such a monitoring system would be a prerequisite for both EF and metacognitive control (see Espinet, Anderson, & Zelazo, 2013, for a training approach). Although not studied simultaneously, monitoring appears to be very similar in its neuro-anatomical and neuro-physiological function and structure in both the EF and MC contexts, differentially recruiting interacting neural circuits. As such, EF and MC monitoring can range from very fast monitoring that alerts the system of a potential error in an all-or-none reaction (detectable as N2 and N4 in EEG studies or as posterror slowing at the behavioral level) to the more explicit and verbalized forms of fine-grained monitoring (Dumontheil et al., 2010; Fleming & Dolan, 2012; Metcalfe & Schwartz, 2016; Weil et al., 2013; Wessel, 2012; Yeung & Summerfield, 2012). Such a wider range of monitoring processes might constitute an avenue for better understanding the development of cognitive self-regulation: momentary all-or-none error detections may also serve as a developmental precursor for more fine-grained monitoring skills. 43 Concerning how EF and MC are related under the umbrella concept of cognitive selfregulation, empirical data have predominantly pointed to an "expression account" (Carlson et al., 2015; Devine & Hughes, 2014), by which EF facilitates or is necessary for MC. In other words, EF deficits would be responsible for MC failures (e.g., experiencing comprehension problems while reading, but nevertheless continuing reading; mixing up the names of playmates, but not asking for clarification; realizing that one is using an inefficient strategy, but still sticking to that strategy). From this perspective, EF are necessary for metacognitive control at the basic level of any self-regulated cognitive task. For example, inhibition enables hesitation and interruption (Bryce et al., 2014); working memory is involved in the exchange of information between first- and second-order processing (the task at hand and the corresponding metacognitive monitoring and control processes; Dunlosky & Thiede, 2004; Spiess et al., 2015); and shifting is triggered whenever information from monitoring must be translated into control actions. Thus, one may consider EF and EF error monitoring as rapid micro-processes that operate at the very basic level of information processing and can integrate with the slower metacognitive control processes. Consequently, EF would be necessary, but still not sufficient, for efficient metacognitive control. Within this integrated framework, metacognitive monitoring and control processes are thought to be slower, longer-lasting, more fine-tuned, and therefore possibly farther-reaching. One reason for this assumption is that MC is always very closely connected to, and even dependent on, the first-order task. In other words, metacognitive processes loop (or make a "detour" and are thereby slowed down) via the domain-specific knowledge or prior experiences an individual has for the task at hand (e.g., the better a child gets in spelling, the better she or he can monitor her or his spelling and act on this). There is a bulk of evidence showing that domain-specific knowledge is strongly related to efficient MC. Furthermore, longitudinal data also suggest that domain-specific knowledge for the task to which MC is applied predicts developmental improvements in MC (Roebers & Spiess, 2017), which links 44 MC more strongly to the domain-specific knowledge or task experiences than EF. This is not, of course, to say that EF is not influenced by a person's domain-specific knowledge (see, for example, working memory performance for chess positions recalled by chess experts and novices; Chi, 1978). However, the prior knowledge effect is likely to be substantially stronger in MC than in EF. At the same time, I posit that EF and MC have a dynamic relation in the course of development. In other words, the relationship between EF and MC within a broader conceptualization of cognitive self-regulation is likely to change over time, as EF and MC undergo substantial improvements in childhood and this is likely to affect their interplay. In very young children, EF and MC may be mutually dependent on the ability to form, experience, and use meta-perspectives on behaviors, outcomes, actions, and cognition. Once this ability is established, which occurs around the age of 4–6 years, EF may be a prerequisite of MC (Roebers et al., 2012). More specifically, EF skills might then be needed to master metacognitive demands in a task (self-initiated stopping and double checking: error monitoring and inhibition; shifting strategies: switching; using monitoring for control: updating). By the time an individual has acquired basic MC skills (typically in the early elementary school years), further improvements in MC might then be facilitated by, but no longer fully depend on, EF because domain-specific knowledge increasingly comes into play (Roebers & Spiess, 2017). Based on these assumptions, one would consider EF to have a causally primary role in the development of MC, but only early on. Later in development, EF and MC may follow distinguishable (although similar) developmental timetables. This would explain why some individuals may be good in EF but may nevertheless perform poorly in MC (or vice versa). Going forward, I have not only suggested encouraging avenues for a theoretical integration of EF and MC but also better empirical approaches for examining these two 45 concepts. To improve our understanding of the commonalities and differences of EF and MC, and of the development of cognitive self-regulation in the course of development, multilevel, multi-methodological lines of research are needed. Behaviorally and neuro-scientifically investigating the early and perhaps common ontogenetic roots of EF and MC within a cognitive developmental framework (e.g., integrating EF error monitoring with MC monitoring) may be a promising way to achieve a conceptual integration and a developmental framework for the ontogeny of cognitive self-regulation. 46

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Table 1 Examples of Early Developmental Achievements in Executive Function and Metacognition (2 to 6 years) Executive Functions Metacognition 2 years • A-Not-B task (inhibition; Sophian & Wellman, 1983): 2 year olds reach out correctly on the first conflict trial (3 hiding locations) in 75-92%; 2 ½ yr olds perform already at ceiling; • Spin the pots task/Six Boxes (updating; Hughes & Ensor, 2007; Wiebe, Espy, & Charak, 2008): on average about 75% correct trials; • Baby Stroop/ Shape Stroop (inhibition; Carlson, 2005; Hughes & Ensor, 2007): on average about 60-70% accuracy. • Hide and Seek game (DeLoache, Cassidy & Brown, 1985): children show on average 2 - 3 different and specific behaviors indicating preventing forgetting (e.g., peeking, pointing, approaching, verbalizing etc.); • Tower Building task (Bullock & Lütkenhaus, 1988): with 26-32 months of age, 85- 100% of the children compare own construction with targeted state (=monitoring); 48-58% of the 26-32 months olds made corrections during building (=control). 3 years • Spatial conflict task (modified Simon task/inhibition; GeradiCaulton, 2000): about 90% accuracy on spatially incompatible trials; • Day/night task (Go/NoGo inhibition task; Carlson & Moses, 2001; Gerstadt, Hong, & Diamond, 1994): about 60% accuracy; • Beads task (updating; Hughes & Ensor, 2007): about 50% of the trials correct; • Self-ordered pointing (updating; Hongwanishkul, Happaney, Lee, & Zelazo, 2005): on average 4-5 items correctly remembered. • Interaction with experimenter (Revelle, Wellman, & Karabenick, 1985): when asked to bring an ambiguously described item, 3 yr olds asked in about 50% of the requests for specification (=monitoring); • Perceptual Identification task (Coughlin, Hembacher, Lyons, & Ghetti, 2015): on average “40% confident” (3-point scale) for incorrect and “50% confident” for correct responses (=monitoring); selective help-seeking when less than on average “40% sure” (=control) leading to higher accuracy; • Picture naming task with opting out (Bernard, Proust, & Clément, 2015): of all items 3 yr olds opted out, only 7% were later accurately solved indicating good uncertainty monitoring; • Paired-associate learning task (Balcomb & Gerken, 2008): after 3 yr olds have declined a recognition trial (=monitoring), accuracy of their later response on that trial is systematically poorer (approx. 50%) compared to the accepted trials (approx. 80% accuracy). • Dimensional Change Card Sorting task (shifting; Zelazo, Müller, Frye, & Marcovitch, 2003): 50-80% of 4-yr olds pass; • Informing or not informing a third person about the content of a box (Kim et al., 2016): 4 yr olds produce gestures indicative of uncertainty in 35-45% of the trials when they are ignorant; 66 4 years • Simon Says/Bear-Dragon task (Inhibition tasks; Carlson & Moses, 2011; Jones, Rothbart, & Posner, 2003): approx. 80-90% accuracy on inhibition trials; • Feeling-of-knowing judgments (FoKs; Cultice, Somerville, & Wellman, 1983): correct recognition in 51% of “yes” - FoKs (=monitoring) for somewhat familiar children/photo-items; • Picture-

pairs Learning and Recognition task (Geurten, Willems, & Meulemans, 2015): judgments-of-learning (JoLs) reveal use of the “easily-learned-easilyremembered”-heuristic by giving lower JoLs to hard picture pairs (on average “50% sure”) compared to easy ones (on average “70% sure”). 5 years • Backward Digit Span / Backward Color Recall (updating; Gathercole, Pickering, Ambridge, & Wearing, 2004; Roebers & Kauer, 2009): average span length of 2-3 items; • Fruit Stroop task (inhibition; Archibald & Kerns, 1999; Monette, Bigras, & Lafrenière, 2015; Roebers, Röthlisberger, Neuenschwander, Cimeli, Michel, & Jäger, 2014): on average 30- 50 sec slowing down in the incongruent trial (interference); 33% increase in errors in the incongruent trial; • Flanker task (inhibition; Roebers & Kauer, 2009; Rueda, Checa & Rothbart, 2010): accuracy of 80-90% in the incongruent trials; • Mixed Flanker task (shifting; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2012): about 80% accuracy overall (switch and non-switch trials). • Old-New Recognition Paradigm (Hembacher & Ghetti, 2014): on average “50% sure” for incorrect and “86% sure” for correct recognition (=monitoring); 54% correct “withdraw” decisions when recognition failed; 93% correct maintain decisions when recognition was accurate (=control); • Object Perception task (Lyons & Ghetti, 2013): 55% of “unsure” confidence judgments (2-point scale) for incorrect responses (=monitoring); selective use of the “escape” response in 53% of the trials (=control) leading to improvements in overall accuracy; • Train Track Building task (Bryce & Whitebread, 2012): on average 4.8/min comparisons between own and targeted train track (=monitoring); 2.2/min control actions (changes of strategy, clearing, and block seeking); • Paired-associates learning and recognition task (Destan, Hembacher, Ghetti, & Roebers, 2014): confidence judgments (CJ; =monitoring) differentiate between correct (on average “56% sure”) and incorrect recognition (on average “68% sure”); 59% correct control decisions (withdrawal after incorrect recognition). 6 years • Advanced Dimensional Change Card Sorting task (shifting; Chevalier & Blaye, 2009): about 60-80% of 6 yr olds pass the task; • Go/No-Go task (inhibition; Cragg & Nation, 2008): on average 77% correct trials with an average speed of 450 ms reaction time; • Listening Recall (updating, Gathercole et al., 2004): recall after max. 2 sentences correct. • Paired-associates learning and recognition task (Destan, Hembacher, Ghetti, & Roebers, 2014): on average 0.5 sec more study time for hard than for easy items (=monitoring-based control); • Paired-associates learning and recognition task (Destan & Roebers, 2015): 58% correct control decisions (withdrawal of incorrect and maintenance of correct recognition).

Thoughts on Thinking: Engaging Novice Music Students in Metacognition MEGHAN BATHGATE1 *, JUDITH SIMS-KNIGHT2 and CHRISTIAN SCHUNN1 1 Learning Research & Development Center, University of Pittsburgh, Pittsburgh, USA 2 University of Massachusetts, Dartmouth, North Dartmouth, USA Summary: Achieving expertise in any area requires extensive practice and engagement with the subject one desires to master. As not all practice yields good progress, methods must be found that lead learners to practice effectively. Many experts employ highly tailored practice involving metacognitive processes, but novices rarely engage in frequent and explicit metacognitive strategies during practice. As a result, novice progress may be impeded through repetition of systematic errors and ineffective techniques. Our study provides evidence of the effectiveness of teaching metacognition to novice music students through weekly lessons. Thirty-five adolescent students of six instructors were randomly assigned to metacognitive focus or existing practice teaching conditions. Students receiving metacognitive teaching achieved higher performance ratings when compared with students receiving control instruction, even though practice time did not vary between groups. These results suggest that having students explicitly verbalize and reflect on their learning process produces more efficient practice and greater end performance. The ability of musicians to mentally maintain large, complex pieces of information while performing the dual task of fine motor performance is impressive for both audiences and cognitive scientists alike. The extensive engagement and practice necessary to produce this expert performance offers insight into the cognitive changes involved in learning a complex skill. Thus, expertise and skill acquisition literature has frequently used music education and performance as a platform for understanding the progression from novice to expert (e.g. Eccles & Feltovich, 2008; Ericsson, Krampe, & Tesch-Romer, 1993; Palmer & Meyer, 2000; Sloboda, Davidson, Howe, & Moore, 1996). Similar to other domains such as physics and the medical field, the quality of cognitive strategies in musicians deepens with increasing expertise (Barry & Hallam, 2002; Siegler, 1996; Sternberg, 1998; Lesgold et al., 1988), as does the representation of one's understanding of the domain (Chi, Feltovich, & Glaser, 1981; Cantwell & Millard, 1994; Grumko, 1993; Lehmann & Ericsson, 1997). In addition to performance differences, practice strategies vary between expert and novice musicians, with novices demonstrating less well-defined practice strategies than the organized study techniques experts routinely employ (Ericsson et al., 1993; McPherson & Renwick, 2001). For example, McPherson and Renwick's (2001) longitudinal analysis of young students' practice found that over 90% of novice practice time consisted of playing straight through a piece once or twice without consideration of the deliberate practice techniques routinely utilized by experts. Hallam (2001a) also found this strategy to be most common in beginners. Such basic practice is disparate in depth and quality from expert practice in which one common strategy involves segmenting large sections of music into smaller passages to allow for the development and refinement of specific techniques (Hallam, 2001a, 2001b). Study strategies do vary across expert musicians. In fact, different experts often prefer different practice organization, rehearsal, and performance strategies (Zimmerman, 1998). Nonetheless, one strategic element that experts uniformly use is metacognition (i.e. the active reflective awareness of one's process and progress towards a goal) (Hallam, 2001a, 2001b; Sternberg, 1998). The metacognitive understanding experts apply provides them with an awareness of task requirements, an understanding of appropriate strategies available for selection, and the efficacy of these strategies on their performance and learning (Flavell, 1979; Pintrich, 2002). Specifically in music, the reflective nature of metacognitive practice allows each performer to explicitly understand the task demands of a musical piece, identify potentially difficult passages, select appropriate cognitive and physical strategies that work best for them, and decide how to effectively structure their practice time in relation to such factors. This degree of reflection is initially lacking in novice music students' practice. Hallam (2001b) found discrepancy in the use of metacognition between expert and novice musicians with regard to their practice and performance preparation. Experts were explicitly aware of their techniques, as well as the effectiveness such techniques had on their practice and performance ability. Additionally, experts were highly attuned to specific weaknesses in their playing and explicitly devoted practice time to target weaknesses, often through the use of highly concentrated, meticulous rehearsal. In contrast, novices in Hallam's study generally lacked metacognitive reflection in their practice, preventing the students from defining their weaknesses and developing effective strategies to address them. In turn, this resulted in repetition of errors paired with less systematic and effective strategies drawn into aid in overcoming difficult passages. Such problems are especially pressing for instrumental students, where the majority of their practice and development occurs outside of the lesson. For most of their practice, immediate expert feedback and guidance is not available. Although the importance and impact of frequent practice should not be underestimated (e.g. Ericsson et al., 1993; Sloboda et al., 1996), developing reflective awareness in relation to one's practice appears critical in making practice deliberate, the kind of practice generally argued to most efficiently *Correspondence to: Meghan Bathgate, Learning Research &

Development Center, University of Pittsburgh, 3939 O'Hara St., Pittsburgh, PA 15260, USA. E-mail: meb139@pitt.edu Applied Cognitive Psychology, Appl. Cognit. Psychol. 26: 403–409 (2012) Published online 28 November 2011 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/acp.1842 produce expert performance (Ericsson et al., 1993). Increases in domain knowledge paired with the challenge of increasingly difficult pieces require performers to reflect deeply on the efficacy of their strategies if they are to progress significantly beyond a beginning level. Use of such metacognition has been shown to correlate with skill development, with experts showing substantially more awareness of their strategies than other players (Barry & Hallam, 2002; Hallam, 2001a, 2001b). McPherson (2005) found that in some areas of performance (e.g. playing by memory, sight reading, playing by ear), the use of mental strategies during early learning of the technique was more influential than overall practice time. In general, self-regulative strategies, such as metacognition, allow learners to understand the connection between their strategies and progress, increasing their selection and application of effective strategies to their practice (Zimmerman, 1990). Through this process, students are able to adapt strategies that are beneficial to skill development and their individual learning needs. Furthermore, the use of such self-regulatory strategies is related to increases in self-efficacy and motivation (Zimmerman, 1998), both of which are key predictors in music competence (McPherson & McCormick, 2006). Although metacognitive techniques are not generally people's initial approach to a problem solving, Berardi-Coletta, Buyer, Dominowski, and Rillinger (1995) demonstrated that participants could use metacognitive approaches when prompted. Using problem-solving tasks such as the Tower of Hanoi and Katona card problem, Berardi-Coletta et al. found that groups encouraged to think metacognitively by being asked to verbally reflect on the reasons behind their actions (e.g. 'How are you deciding on a way to work out the order for the cards?', p. 211) performed better than control groups and groups that were encouraged to focus on the problem-area of the task (e.g. 'What is the goals of the problem?' p. 211). Asking participants to describe their mental strategies drove attention away from the immediate problem space and directed it to the process level. Asking individuals about the nature and quality of their actions (e.g. 'How are you deciding what went wrong?') forced them to reflect on their cognitive process, led to increases in the transfer of conceptual knowledge across tasks, and produced the greatest frequency and range of process-level responses. Similar findings have been shown in the realm of music learning. Hallam (2001a, 2001b) and McPherson (2005) explicitly asked both expert and novice musicians to explain their process in learning a new piece, and both the experts and novices were able to provide explanations. However, only the experts were able to express the reasoning for their particular strategy and were clearly aware of their strengths and weaknesses. Although research has delineated these important differences in metacognition and learning, the potential impact of pushing novice students to adopt a metacognitive approach has not been fully explored. A number of researchers have suggested implementing the use of reflective practices when teaching students and encouraging metacognitive thinking to enable them to consciously consider their approach and evaluate its success (Barry & Hallam, 2002; Hallam, 2001a, 2001b; McPherson, 2005; McPherson & Renwick, 2001; Parncutt & McPherson, 2002). Teaching students to ask questions, explain their processes, and reflect on performance may increase their quality of playing, study habits, and their ability to transfer their learning across a variety of musical pieces (Pintrich, 2002). Instrumental teachers vary in the degree to which they explicitly teach practicing techniques, set goals, provide specific versus general feedback, and encourage verbalization in their students (Duke, 1999/2000; McPherson & Renwick, 2001). In light of these findings, our current study seeks to provide evidence that teaching metacognitive practice strategies to beginner music students is beneficial to their practice and performance. METHOD

Participants and recruitment Forty-five music students of six music instructors from two New England music studios were recruited. Lessons consisted of a half hour, private 1:1 instruction conducted weekly. The six instructors had previously attended college for music education and had been teaching between 13 and 41 years (M = 25.2). Students ranged in age from 13 to 19 years old (M = 14.7, SD = 1.4), and gender was relatively even (60% female). All students studied piano, guitar, or bass guitar; most (67%) had been playing for 3 years or less (M = 34.0 months, SD = 21.3 months). All students were able to read basic music notation. Materials Metacognitive brochure Instructors were trained in metacognitive teaching with the use of a 'Metacognitive Brochure'. The brochure was constructed for the purpose of this study and reviewed the concept of metacognition related to music and provided concrete examples taken from Hallam (2001a, 2001b) and Berardi-Coletta et al. (1995). Lesson forms Instructors were given a 'Post-Lesson Form' asking the degree to which they believed they taught metacognitive teaching in their lesson ('yes', 'somewhat', 'no') and if they believed each student was receptive to the teaching ('yes', 'somewhat', 'no'). Additionally, instructors were encouraged to write down any remarks, questions, or problems that arose during the lessons. Students also received a weekly 'Practice Sheet' asking the number of times they practiced that week and the length of time they practiced each session. Following metacognitive teaching lessons only, the practice sheet also asked the student if they felt they used metacognition during their lesson ('yes', 'somewhat', 'no'). Only 25 students (55%) completed the metacognitive debriefing information. Digital recorders Digital recorders were provided for the teachers to record students' performances. Surveys Students received Ritchie and Williamon's (2007) General Musical Self-efficacy Scale, on the basis of the 'General Self-Efficacy Scale' of Sherer et al. (1982), with alterations 404 M. Bathgate et al. Copyright © 2011 John Wiley & Sons, Ltd. Appl. Cognit. Psychol. 26: 403–409 (2012) adapted specifically for music. Specifically, we focused on the 17 items regarding students' perceptions of their ability to learn their instrument (a = .91). These questions asked students about their belief in their ability to learn their instrument, in addition to questions regarding how students proceed with difficulties when learning. Performance pieces Each condition consisted of three pieces at different difficulty levels (easy, medium, difficult), resulting in a total of six pieces to be played across the two conditions. An expert music teacher selected all pieces so that the pieces in both conditions were comparable. Students' instructors selected the difficulty level for each student. Being that each student played one song per condition, this resulted in two performance pieces per child at his or her difficulty level. Procedure Music instruction For control instruction, teachers were asked to teach as they had been prior to our training, which consisted largely of instructor guidance and modeling, with the instructor providing most of the input and discussion. In a typical control lesson, instructors would review that week's song/lesson with the student, model proper playing, allow the student to practice certain techniques or passages (generally specified by the instructor), and decide whether to move on to a new piece or assign the song again in the coming week. Teachers were trained in metacognitive teaching directly prior to teaching using the metacognitive instruction method. The topic of metacognition was thoroughly discussed with instructors, and training was performed through a 1:1 discussion session with the use of a 'Metacognitive Brochure', which provided instructors a guide with examples to help in their teaching. Overall, teachers had control over exactly how they integrated the metacognitive steps into their lessons, as would be the case in broader applications of metacognitive instruction. Further, an exact script to be used by all teachers in all settings was thought to be potentially disruptive of particular teacher–student dynamics that were already established, especially across instrument types and various levels of playing. The next paragraph describes the common elements that the instructors were asked to include. During instruction, the metacognitive training involved multiple activity stages, as shown in Figure 1. The 'Planning' stage included analyzing a piece prior to performing, identifying key features, finding patterns, and naming parts that may seem difficult. Students were continuously encouraged to provide examples and verbalize the strategies they might use to play sections of the piece. 'Playing' consisted of the student playing the song while being encouraged to actively listen to the sound they were producing. The 'Evaluation' stage consisted of the student identifying difficulties and successes, discussing the strategies she or he employed, and assessing whether they were successful in helping the student learn the song. 'New strategies' were discussed by having students describe new ways they could approach/practice parts of the song if their strategies were not successful. The student then planned how these new strategies could be incorporated into their playing and subsequently replayed the song. This overall cycle of metacognitive stages was implemented several times throughout the lesson, and students were encouraged to use this reflective process during their home practice. Throughout the training, instructors were told to encourage students to verbalize their process and discuss possible strategies they could use during playing and practicing. Design The study used a within-subjects design for instructional approaches with order counter-balanced across the six instructors, with three instructors randomly assigned to begin with control teaching and the other three instructors beginning with metacognitive teaching. Those first assigned to metacognitive teaching (Order 1) were trained at this point, whereas the three remaining teachers (Order 2) were not trained until after the control condition instruction to minimize contamination of instructional approach. Using their assigned technique, instructors introduced the teaching using the musical piece the student had been currently learning prior to the study. After 2 weeks of teaching, students were given a piece of music to learn for a recorded performance. Each piece had an easy, medium, and difficult level, and the students' instructors chose the level best suited to each student. Following 2 weeks of practice with this piece, each student performed their piece while being audio recorded by their instructor. After the first recording was collected, the instructors were asked to switch instruction approach. That is, those who had begun with control teaching switched to metacognitive teaching (and received training on metacognitive teaching at this point), and those who had begun with metacognitive teaching returned to their standard (control) teaching. Consistent with the first instructional phase, the first 2 weeks of this second instructional phase involved students learning a piece of music as part of their instructor's usual lesson plan, with the inclusion of the particular teaching techniques. Following these 2 weeks, students were given a second performance piece. After 2 weeks of practice with this piece, the students were recorded while performing their second piece (see Figure 2). In this counterbalanced experimental design, there are three key contrasts: (i) between condition at Time 1 tests the benefit of instructional method; (ii) from Time 1 to Time 2 within Order 2 to provide a second test of the benefits of instructional method; and (iii) from Time 1 to Time 2 within Order 1 to test the retention of the intervention. The contrast Figure 1. Basic design of metacognitive teaching structure Thoughts on thinking 405 Copyright © 2011 John Wiley & Sons, Ltd. Appl. Cognit. Psychol. 26: 403–409 (2012) between conditions at Time 2 is more complex because it mixes transfer and intervention components. Practice information from the students (number of sessions and length of sessions that week) and Post-Lesson Forms from the instructors were gathered at the conclusion of each lesson throughout the study. Practice sheets were collected weekly from students by all but one teacher, who collected them only once at the start of each condition. Of the possible 160 collection sheets, 123 were returned for the metacognitive condition (77%) and 113 of the 160 were returned in the control condition (71%). Survey and self-efficacy measures Self-efficacy was measured three times: prior to starting the first teaching condition and following each teaching condition. The full music survey (including the metacognitive questions; described above) was given to students following the metacognitive condition. Ratings of performed pieces Three professional musicians were chosen to rate the recorded performances, using the same rating scale across all instrument types. Each musician had a background in music education and was blind to condition and purpose of the study. Recordings were randomly presented and rated on rhythm (how consistently did the student kept the beat of the song?, Cronbach a for ratings by the three musicians = .80), errors (did the student make many errors throughout the recording, a = .68), and overall musicality (the overall 'feel' and articulation of the song, a = .85). All scales were on a 1–7 Likert scale ranging from very poor to excellent. Performance and practice data from students from one teacher were removed because of mislabeling of files. RESULTS Use of metacognition manipulation check The metacognitive post-lesson form was analyzed to examine whether instructors followed the metacognitive instruction plan in that condition. Instructors reported doing so overall: instructors responded 'yes' to using metacognitive teaching during their lessons 72% of the time, 'somewhat' 24% of the time, and 'no' 4%. Additionally, instructors reported 'yes' students were receptive to the metacognitive teaching 67% of the time, 'somewhat' 27% of the time, and 'no' 6% of the time. The students who completed the metacognitive debriefing survey reported feeling that ('yes') they had used metacognition during a lesson 55% of the time and at least 'somewhat' 40% of the time, with 5% saying 'no.' Interestingly, the instructors' responses were not significantly correlated with the students' perception of the use of metacognition. Nonetheless, whether student or teacher perspectives were more accurate, both groups reported using the metacognitive strategies at least some of the time as instructed. Ruling out practice time as a confound with condition Self-reports of practice amounts were examined to see whether condition was confounded with amount of practice. Between subject t-tests showed no differences in reported practice amount at recording Time 1 [number of practice session: $t(33) < 1$; length of practice sessions: $t(33) = 1.15$, p = ns] nor Time 2 [number of practice sessions: $t(33) < 1$; length of practice sessions: $t(33) < 1$]. Table 1 presents means and standard deviations. Furthermore, within subject t-tests showed students in Order did not change the number of practice sessions per week between conditions [Order 1: $t(12) = 1.7$, p = ns; Order 2: $t(22) = 1.95$, p = ns] nor length of practice session between conditions [Order 1: $t(12) = .547$, p = ns; Order 2: $t(22) = 1.18$, p = ns] (see Table 1). Thus, performance differences by condition could not be attributed to differences in amount of practice. Examination of the raw data (see Table 2) reveals that very few students are practicing more than an hour a week. Ratings of performance recordings Between-subject t-tests at recording Time 1 showed that students first receiving metacognitive teaching (Order 1) significantly outperformed students who received control teaching first (Order 2) in rhythm [$t(33) = 2.08$, $p = .05$, $d = .75$] and marginally in musicality [$t(33) = 1.9$, $p = .06$, $d = .65$], but not in errors [$t(33) < 1$]; see Table 3 for means and standard Figure 2. Design and procedure of teaching conditions Table 1. Average practice sessions and lengths per week in metacognitive and control conditions Order 1 (metacognitive–control) Order 2 (control–metacognitive) Meta Control Meta Control Number of practice sessions M 3.3 3.0 3.0 3.2 SD 0.8 0.9 0.8 0.8 Length of practice session M 2.6 2.5 2.6 2.7 SD 0.6 0.8 0.6 0.6 Note: Number of session coding: 1 = no practice, 2 = 1–2 sessions, 3 = 3–4 sessions, 4= 5–6 sessions, 5= 7+ sessions. Length of session coding: 1 = 0 minute, 2= 1–20minutes, 3= 21–40minutes, 4= 51–60 minutes, 5= 61+ minutes. Meta 406 M. Bathgate et al. Copyright © 2011 John Wiley & Sons, Ltd. Appl. Cognit. Psychol. 26: 403–409 (2012) deviations and Figure 3. However, at recording Time 2, after all students received metacognitive teaching, these differences were no longer found, as the groups performed equally well {rhythm: [$t(33) < 1$]; error: [$t(33) < 1$]; musicality: [$t(33) < 1$]; see Table 3}. Although there may be some variation in ratings across instruments that could be part of between condition performance differences, the small sample size per condition per instrument does not allow for analyses of condition effects at the instrument level. To better understand these between condition differences and address potential baseline group differences or instrument effects, within sample t-tests showed that students in Order 2 (control–metacognitive) improved significantly following the metacognitive teaching in all rating categories {rhythm: [$t(22) = 4.53$, $p = .001$, $d = .76$]; error: [$t(22) = 3.87$, $p = .001$, $d = .77$]; and musicality: [$t(22) = 4.40$, $p = .001$, $d = .65$]; see Figure 3 and Table 3 for means and standard deviations}. However, Order 1 (metacognitive–control) performed equally in all category ratings through both conditions {rhythm: [$t(12) < 1$]; error: [$t(22) < 1$]; and musicality: [$t(22) < 1$]; see Table 3 for means and standard deviations}. Overall, the data are consistent with a general performance benefit of being exposed to metacognitive instruction whether it occurs early or late and that is maintained later during traditional instruction. Instructor post-lesson comments Overall, comments from instructors noted the positive impact of metacognitive teaching on their students. Comments shown in Table 4 are most representative of descriptions provided by teachers regarding the implementation of metacognitive teaching: many but not all students were reported to benefit from the metacognitive teaching. Self-efficacy A portion of the students did not return all three self-efficacy measures (baseline, post-metacognitive teaching, post-control teaching) and had to be excluded from this analysis, resulting in 26 full sets of data. Contrary to predictions, self-efficacy did not change specifically following metacognitive teaching, nor did it change in general with instruction. Although the groups were significantly different at baseline measurements with those in the metacognitive–control order having higher baseline self-efficacy ($M = 92$, $SD = 26$) than the control–metacognitive students ($M = 71$, $SD = 36$) [$t(43) = 2.31$, $p = .03$], an ANCOVA yielded no significant change in self-efficacy across conditions for either Order, F's < 1; see Table 5 for means and standard deviations. DISCUSSION Relatively few intervention studies have been conducted in real learning environments. Much of what is known about practical applications of the cognitive psychology of expertise Table 2. Practice information from teaching conditions Metacognitive Control N % N % Ave. number of practice sessions per week 0 3344 1–2 22 20 15 14 3–4 51 46 52 49 5–6 25 22 29 27 7+ 11 10 7 7 Total 112 100 107 100 Ave. length of practice session (minutes) 0 3344 1–20 47 42 39 36 21–40 56 50 59 55 41–60 6 5 4 4 60+ 0 0 1 1 Total 112 100 107 100 Note: Based on students of five teachers, resulting in 112/140 returned sheets for Metacognitive and 107/140 for Control. Table 3. Means and standard deviations of performance ratings Order 1 (metacognitive–control) Order 2 (control–metacognitive) M SD M SD Rhythm Metacognitive 4.1 1.1 4.2 1.3 Control 4.3 0.8 3.3 1.1 Error Metacognitive 3.7 0.8 4.2 1.2 Control 4.0 0.7 3.4 .9 Musicality Metacognitive 3.9 0.9 4.0 1.3 Control 4.0 0.8 3.2 1.2 b. error c. musicality a. rhythm Figure 3. Mean performance ratings on rhythm, error, and musicality across Time 1 and Time 2 recordings M N Thoughts on thinking 407 Appl. Cognit. Psychol. 26: 403–409 (2012) development comes from intervention studies in the lab and correlational studies in the field. This study has bridged those divides to find actual learning benefits of a cognitive-based intervention in the field with traditional instructors and traditional learners. The effect of metacognitive teaching presented here produced several key results. First, metacognitive teaching had a positive effect on student performance. Students significantly improved their scores following metacognitive teaching, outperforming control (business as usual) teaching, and maintained their performance gains even when external instruction returned to the control format. Second, although students at this level of musical development did not previously seem to employ reflective skills during practice, they benefited from explicit guidance towards the reflection and evaluation of their process and progress. That is, developing a focus on the 'process-level' of playing (Berardi-Coletta et al., 1995) is attainable in novices rather than being only possible with experts who have richer domain representations. Metacognitive monitoring seems pivotal because the majority of student practice occurs outside of the lesson. As many novices are often found to be unaware of errors in their learning and practice (Hallam, 2001a, 2001b; Kruger & Dunning, 1999; Tobias & Everson, 2002), coming to actively monitor one's knowledge and progress can help learners more accurately evaluate the material and skills. Awareness of these factors allows novices to direct their practice towards developing new skills more efficiently in the time between their lesson instructions, moving them towards expertise (Tobias & Everson, 2002). Interestingly, during the training sessions, a few instructors mentioned feeling that they were already using some metacognitive teaching in their lessons. Such misalignments between teacher statements and student perceptions have previously been found in literature relating to practice and may also be occurring in metacognitive instruction. Jorgensen (2000) found that 40% of students entering a music academy reported their instrumental instructors placing 'very little' or 'no' emphasis on practice strategies. In contrast, instructors report 'always' or 'almost always' teaching specific techniques for practice (Barry & McArthur, 1994). A shared perspective on the teaching process may be crucial for students to effectively integrate the techniques proposed by the instructors into student practice. Although teachers were likely using some degree of metacognitive instruction, the results suggest that students were not adopting such strategies in either sufficient complexity or frequency. It was not until metacognitive processes and reflective practice were made regularly explicit to students that their performance improved. Perhaps although instructors are aware of each student's strengths and weaknesses and may adjust their teaching accordingly, the student does not necessarily perceive these considerations and then do not transfer these elements to their own practice. Having students become more active in guiding their own learning—verbalizing their progress and identifying strategies that work best for their musical development—appears to result in more successful achievement. It is worth noting that the benefit in performance was achieved without a change in the reported quantity of practice, suggesting that metacognition leads to more efficient practice rather than simply more practice overall. We are not suggesting that metacognition is more important than practice amount nor that high levels of performance can be reached without additional practice. Rather, these data allow us to conclude that the use of metacognitive strategies produces efficiency gains in learning, whereas other forms of improved study methods might require significantly more total time to produce advantages. Deepening the structure and thoughtfulness involved in student practice is likely especially useful in the population that was studied. Given the overall low practice time that results from the various challenges to practice typically faced by adolescents (e.g. increased peer relations, alternative activity choices, schoolwork), increasing the potency of their practice may greatly influence their musical achievement. Additionally, students involved in less formal music education than students in highly rigorous musical training often have less frequent contact with their instructors (e.g. once a week versus daily). Promoting reflection during practice processes can help students benefit more from their instructional experience both in and out of the lesson. Contrary to our hypothesis, self-efficacy did not increase following metacognitive teaching. An increase in students' reflection and verbalization of the effective strategies was expected to cause a boost in self-efficacy once students were able to clearly understand how practice might be most effective for their needs. However, this self-efficacy gain was not found, possibly for a number of reasons. First, few students returned all self-efficacy forms, limiting our comparison power. Secondly, students in our current population may have poorly estimated their performance ability initially, some too high and some too low, with increases in reflection simply correcting these biases rather than shifting overall estimates in one direction. Indeed, the overall mean self-efficacy at baseline was relatively high (5 s and 6 s on a seven-point scale); the Table 4. Instructor comments from post-lesson forms Comment from post-lesson form '[This student] never practiced before until we began the metacognitive lessons.' 'She was very receptive to the metacognitive study and was thrilled to find a new way to 'see' music' 'Metacognitive skills helped him to see the patterns and he was able to play the first piece.' 'This student plays various instruments and excels in each one. Metacognitive ideas and strategies were not very well received.' '...she has been in performances and employs metacognitive skills often to memorize and perform music.' '...she loved the metacognitive challenge, as she performed in this study.' 'I'm finding with the metacognitive technique, students are most resistant to practicing the different part [breaking the song into pieces].' Table 5. Self-efficacy means and standard deviations for baseline and post-conditions Order 1 (metacognitive–control) Order 2 (control–metacognitive) Baseline Meta Control Baseline Meta Control M 5.7 5.4 5.5 4.9 4.7 4.6 SD 0.8 0.9 0.9 0.7 0.8 0.9 Note: Order 1 based on 16 full sets; Order 2 based on 10 full sets. 408 M. Bathgate et al. Copyright © 2011 John Wiley & Sons, Ltd. Appl. Cognit. Psychol. 26: 403–409 (2012) metacognitive literature in general notes that novices are often over-confident (Kruger & Dunning, 1999). Through more careful metacognitive evaluations, students may have appropriately adjusted their self-efficacy ratings downward. Third, perhaps the duration of the study was too short to capture significant changes in self-efficacy that will result from improved practice strategies accumulating and performance growth becoming more noticeable. Additional measurements collected later as metacognitive practice continues may be necessary to demonstrate these potential differences. Future directions In this study conducted in real music practice contexts, we did not obtain direct measures of student practice strategies. A lab study would be required to more precisely document the learning strategies students used in their lessons and practice before and after metacognitive teaching. A related follow-up study goal involves examining the ways in which interaction between instructor and student change through encouraging metacognition in students. Before suggesting broad implementation of metacognitive teaching on the basis of our results, replications are needed across various performance songs, student populations, and teacher populations to examine the robustness and reliability of our observed effect. Perhaps some kinds of performance pieces benefit more from metacognitive reflection than other pieces, and perhaps some student or teacher populations have trouble implementing metacognitive processes. Importantly, although music students were selected as an instance of how metacognitive teaching may improve performance, our study design may be applicable to other domains, as well, such as mathematics learning or sports practice. Although metacognition is typically developed later in one's progression towards expertise, our results suggest that prompting novice students to be explicitly reflective earlier may produce deeper learning and better skill advancement. Additionally, through helping students practice and perform well, perhaps their overall enjoyment and persistence may increase and affect future practice down the road (Costa-Giomi, Flowers, & Sasaki, 2005). Further studies will help illuminate the potential impact metacognitive teaching may have on students' internal factors, practice time, and practice techniques. REFERENCES Barry, N. H., & Hallam, S. (2002). Practice. In R. Parncutt, & G. E. 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B. J. Music Ed. page 1 of 19 C Cambridge University Press 2016 doi:10.1017/ S0265051716000267 The Role of Metacognitive Strategies in Learning Music: A Multiple Case Study Barbara Colombo 1 and Alessandro Antonietti 2 1 163 S. Willard St., Burlington, VT 05402 USA 2 Largo Gemelli 1, 20123 Milano, Italy bcolombo@champlain.edu, alessandro.antonietti@unicatt.it The positive role of metacognition in music learning and practice is well assessed, but the role of musicians' metacognitive skills in such a context is not yet clear. Teachers often state that they apply a metacognitive approach during their lessons, but students fail to acknowledge it and report that they become metacognitive learners thanks to their own practice. In this multiple case observational study the spontaneous metacognitive behaviour of a teacher during four piano lessons with expert and novice students was analysed. Data supported the notion that teachers use metacognitive strategies during their teaching practice, but students are not aware of this because a metacognitive focus on strategies, as well as a strong emphasis on monitoring, appears to be lacking. Teachers are also able to differentiate their teaching behaviour between expert and novice students. Students' age, however, affects teachers' behaviour more deeply than expertise. Implications for music education are discussed, highlighting the main issues that can be derived from the results and how they can be effectively used to enhance professional development and improve practice in music education. Introduction This multiple case study is focused on metacognition, a complex concept that refers to the 'knowledge about knowledge' that learners can develop during the process of acquiring new information. To be more precise, we can refer to Kuhn's definition of this concept: Metacognition concerns 'cognition that reflects on, monitors or regulates first order cognition' (Kuhn, 2000, p. 178). Metacognition can be divided into metacognitive knowledge (knowledge about declarative knowledge) and metacognitive control (or metastrategic knowledge, that is, knowledge about strategies and their effective uses) (Kuhn, 2000). All these metacognitive aspects play important roles in music learning and practice. Metacognition allows performers and music students to understand the task demands of a musical piece (metacognitive knowledge), identify potentially difficult passages (metacognitive control), select appropriate cognitive and physical strategies (metastrategic knowledge) that work best for them (metacognitive knowledge about themselves as musicians), and decide how to effectively structure learning/ practice/performance in relation to such factors (metacognitive control). Students and performers also monitor and regulate the real effectiveness of their chosen strategies (metacognitive monitoring). These phases of the metacognitive process are well summarized in the model proposed by Fogarty (1994). He suggests that metacognition can be divided into three phases. The first   one concerns planning, and this is where an individual develops a plan before approaching a learning or a teaching task. For example, in this phase, a person may ask questions like: 'What prior knowledge will help me (or the student) with this task? What should I (or the student) do first? In what direction do I want my thinking to take me (or the student)?' This planning phase is followed by a monitoring phase, closely linked to metacognitive control, where individuals monitor their understanding and their progresses and use 'fix-up' strategies as needed. The final phase is an evaluation phase: During this phase individuals evaluate their thinking process and their performance. In case of the teachers, the evaluation can be both self-directed (to evaluate the effectiveness of their teaching) or directed to the students, to support their learning process. Historically, starting with the work of Flavell in the 1970s (e.g., Flavell, 1971), metacognition was studied in relation to memory and was operationalized as metamemory. Even if metamemory itself was found to be highly influential in promoting different types of knowledge – such as strategic thinking, monitoring, self-efficacy, and knowledge about emotional states (Hertzog, 1992) – nowadays metacognition is studied in many more contexts linked not only to memory itself but, more generally, to reasoning (Kuhn, 2000), problem solving (Antonietti, Ignazi & Perego, 2000), and decision making (Colombo, Iannello & Antonietti, 2010). Metacognition is also studied in relation to learning, including learning that is supported by technological tools (Antonietti, Colombo & Lozotsev, 2008). A good example of a topic that requires all these skills is learning music, on which this study is focused. Metacognition appears to be a key factor for musicians, since the use of metacognitive strategies (e.g., planning, monitoring, and evaluation) during practice improves the performance of both novices and experts (Hallam, 2001). Musicians spontaneously use strategies that enhance their performance (Antonietti, Cocomazzi & Iannello, 2009), so they appear to be able to self-regulate their own behaviour. How and when do musicians acquire these metacognitive skills? We know that metacognition can be fostered by teachers (Brown, 1997), so we can assume that musicians acquired these skills during their training. As Brown (1997) claimed, reflective processes (at both levels: knowledge and control) can be internalized and become more effective with an appropriate metacognitive guide by teachers or experts. This point suggests that students with higher expertise should show a higher level of metacognition. This multiple case study aims at exploring this idea with specific reference to music training. This topic is particularly relevant because, if music teachers report using metacognitive strategies related to students' learning and prompting students to use the same strategies during their lessons, there is no explanation for why music students complain of the lack of these strategies in their training (Bathgate, Sims-Knight & Schunn, 2012). It is not clear if this gap is due to a lack of awareness (in the sense that learners are trained according to a metacognitive approach, but they fail to realise it) or if metacognition is acquired by music students while they are working alone on their practice. We intend to explore these possibilities. Literature provides some interesting starting points. Considering classical studies on metacognition, we see that the role of an adult/teacher/expert is highlighted as fundamental for fostering a more adequate use of metacognition. This has been recognized, for example, by Brown (1997) in her model for improving metacognition within a learning community. Teachers and experts act as key figures providing learners with role models for thinking and adequate use of reflective strategies. More experienced teachers can improve their effectiveness as a role model by critically introducing new ideas and principles, explicitly modelling self-thinking, and suggesting ad hoc reflections. Studies specifically focused on teaching metacognition to music students (e.g., Hallam, 2001; Bathgate, Sims-Knight & Schunn, 2012; Burwel & Shipton, 2013) supported Brown's position, showing the efficacy of the metacognitive teaching programs. Yet, most of them are lacking in ecological validity, since the learning situation is artificial. Teachers were usually asked to use metacognitive programs developed by the researchers. Such investigations provided evidence of the general efficacy of metacognition, but they cannot answer the question of how music students acquire metacognition in 'real life'. Moreover, self-reported strategies are employed to assess metacognition: These measures rely on a high level of verbal understanding that may not always be present (Veenman, 2005), especially in music students, since music is a discipline where many strategies can be coded using mental images without the support of verbal code (as demonstrated by the efficacy of mental practice techniques in piano players: Bernardi et al., 2013). These methodological limits may reduce the generalizability of the findings and also account for the discrepancies between teachers' beliefs (according to which they follow a metacognitive approach) and students' opposite beliefs (namely, that they have to learn metacognitive practices alone starting from their individual experiences) as reported by Bathgate, Sims-Knight and Schunn (2012). In order to avoid these problems and investigate metacognition in music teaching more accurately, an important point is to find a proper way to operationalize and analyse metacognition in such a context. In this study we decided to refer to Whitebread et al.'s (2009) model. In their study, the authors, building a model on existing literature, investigated three dimensions of metacognition: (i) metacognitive knowledge, (ii) metacognitive monitoring and control (declined into planning behaviours, monitoring the ongoing outcomes, and evaluating the partial and final outcomes of the applied behaviours), and (iii) monitoring and control of emotions and motivation during a learning task. We decided to focus mainly on the teacher's metacognition, since this allows us to study, in addition to metacognition itself, 'other regulation'. 'Other regulation' refers to a situation where, within an interaction linked to a learning task, one person masters one or more key elements of the task, while another does not (Iiskala, Vauras & Lehtinen, 2004): When the first actor uses his/her expertise to regulate the other person's learning behaviour (as should happen in teacher-student interaction), we can observe other regulation. This information should help answer our research questions related to the teacher's role in music training to promote metacognitive skills in novice and advanced students. What could be considered a proper method to investigate these aspects? We already argued that self-reported measures are not adequate. Thinking aloud would be inappropriate as well: It causes overload of working memory and leads to interference in performance (Garner, 1988; Thorpe & Satterly, 1990). We can assume that this would be especially true for piano practice, where working memory is already loaded by reading music, coordinating right and left hand actions, keeping the rhythm, and applying specific execution techniques. Observational methods appear to be a better choice because they do not rely on participants' verbal abilities (Winne & Perry, 2000) and they allow researchers   to record and then analyse what people (teachers and students) do, and not what they believe they do. Observation has been used extensively over the past decades to study teacher and pupil behavior in instrumental teaching, both in classroom and one-to-one contexts (for reviews see Rosenshine et al., 2002; Hallam, 2006; Creech, 2012). Starting from these assumptions, the present multiple case observational study, using an ecological setting, tries to understand if teachers do use metacognitive strategies to promote learning in their everyday teaching practice and if students respond to metacognitive prompts while learning. We are also interested in understanding what kind of metacognitive strategies an experienced teacher uses while teaching, and if he differentiates between novice and expert students. Method Design An experienced piano teacher taught four lessons to four different adult students, balanced by gender, expertise, and length of time that they have been attending piano lessons. Each lesson took place in the same room, at approximately the same time of day and had the same length and structure: (1) introduction/greetings; (2) presentation of the learning task: Beginners had the same learning task (learning the C major scale) and advanced students had the same learning task (learning improvisation jazz/blues techniques on the piano); (3) focus on learning; (4) end of the lesson/greetings. A pilot lesson was scheduled and video recorded, both to test the procedure and to have material helpful to better define the coding scheme.

Details about the pilot lessons and the use of these specific data are reported in the 'Coding' section. Participants The piano teacher who volunteered to join the experiment had more than 20 years of teaching experience. The four students who volunteered were divided into: • 'Beginners' (BS1 and BS2) were 2 students (1 man and 1 woman, balance by age, with one older and one younger student) who attended just one introductory piano lesson before the experimental one; • 'Advanced' (AS1 and AS2) were 2 students (1 man and 1 woman, balance by age, with one older and one younger student) who had both been studying piano with a private teacher, once a week for 10 years. We decided to balance the sample according to gender and age in order to be able to exclude their role as possible confounding variables. 4 The Role of Metacognitive Strategies in Learning Music Materials/Apparatus Lessons took place in a room equipped with a table, two chairs, and an electronic keyboard with weighted keys. In front of the keyboard the teacher arranged a blackboard on which he wrote the C major scale for beginners' lesson and different chords/progressions for advanced students. The video camera used to record the lessons was placed in a hidden corner of the room in order to not disturb participants. Since the lessons had to have the same duration, a timer was located in a place where the teacher could easily see it and arrange the timing accordingly. Procedure Before starting the sessions the researcher met with the teacher and explained to him that the study was aimed at investigating teaching strategies in music lessons. She explained to him that his role would be to teach four lessons using the same approach he normally uses. She gave him a consent form to read and sign. Two suitable topics for the lessons (one for beginner and one for advanced students) were chosen with the support of the teacher. A pilot lesson was planned, performed, and recorded in order to enable researchers to test the efficacy of the lesson timing and of the coding (see below for details about how we used this recording to debug the coding). We selected a participant that was similar in expertise to one of our experimental students: He was an adult beginner piano student. He attended a lesson with the same teacher of the experimental lessons. The lesson's topic was the same as that presented to the beginner students in the experimental group and the timing and the apparatus of the lesson were scheduled in order to exactly mirror the experimental ones. After the first pilot recording, during which no problem emerged, the four experimental lessons were scheduled. After reading and signing the informed consent form, students were asked to join the lesson. The researcher gave them written instructions explaining the general aim of the research and stressing that they would just have to attend the lesson as any other normal lesson. Each lesson lasted 30 minutes. Lessons were video recorded. Participants knew that they were video recorded (information about this point was included in the informed consent). After the lesson, the researcher asked each student if she/he had any questions and thanked her/him for her/his collaboration. Coding Recorded lessons were integrally transcribed (taking away any reference to students' and teachers' real names in order to protect their privacy) and coded by two independent judges. Inter-rater reliability was calculated to be 89%. The complete transcripts with coding are reported in the Appendix. Coding categories were derived from Whitebread et al.'s (2009) observational procedure. We used the pilot lesson mentioned above to test the adequacy of categories 5 Barbara Colombo and Alessandro Antonietti Figure 1. (Colour online) Beginner student 1-teacher's use of metacognitive strategies. for our specific data, to be sure that, even if Whitebread and colleagues already used and validated them in their study, they were still descriptive of metacognitive behaviours, mutually exclusive, and internally homogeneous when applied to our data. After this pilot coding, we decided not to apply the 'Knowledge of persons' category (within the more general 'Metacognitive Knowledge' category), used in Whitebread et al.'s study, because it was never used by the teacher or the students. We kept the other two sub-categories referring to Metacognitive Knowledge (Knowledge of Task – KoT, and Knowledge of Strategies – KoS), all the subcategories for Metacognitive Regulation (Planning – P, Monitoring – M, Control – C, Evaluation – E) and the two categories used to code Emotional and Motivational Regulation (Emotional/Motivational Monitoring – E/M M, and Emotional/Motivational Control – E/M C). A detailed description of each sub-category is reported in Table 1. Results We will first present data from each single student individually. We will focus both on the teacher's use of metacognitive strategies while teaching and on the student's response to them during his/her learning experience. Beginner student 1 We started by considering the teacher's metacognitive behaviour while teaching to the first beginner student. Examining the transcript of the lesson with the first beginner student, we can notice the teacher focused mostly on metacognitive regulation and on metacognitive knowledge while teaching. The use of Emotional/Motivational regulation strategies was not frequent. More differences emerged considering the specific subcategories (Figure 1). While working with this beginner student, the teacher used metacognitive regulation mainly to focus on planning and monitoring the student's understanding of the task and less time was devoted to evaluation. The teacher also constantly checked with the student by the way 6 The Role of Metacognitive Strategies in Learning Music Table 1. Coding scheme with explanation–derived from Whitebread et al. (2009). Category Explanation Code Knowledge of task A verbalization demonstrating the explicit expression of one's own long-term memory knowledge in relation to elements of the task. • Compares across tasks identifying similarities and differences • Makes a judgment about the level of difficulty of cognitive tasks or rates the tasks on the basis of pre-established criteria or previous knowledge KoT Knowledge of strategies A verbalization demonstrating the explicit expression of one's own knowledge in relation to strategies used or performing a cognitive task, where a strategy is a cognitive or behavioural activity that is employed so as to enhance performance or achieve a goal. • Defines, explains or teaches others how she/he has done or learned something • Explains procedures involved in a particular task • Evaluates the effectiveness of one or more strategies in relation to the context of the cognitive task. KoS Planning Any verbalization or behaviour related to the selection of procedures necessary for performing the task, individually or with others • Sets or clarifies task demands and expectations • Sets goals and targets • Allocates individual roles and negotiates responsibilities • Decides on ways of proceeding with the task • Seeks and collects necessary resources P Monitoring Any verbalization or behaviour related to the ongoing on-task assessment of the quality of task performance (of self or others) and the degree to which performance is progressing towards a desired goal • Self- commentates • Reviews progress on task (keeping track of procedures currently being undertaken and those that have been done so far) • Rates effort on-task or rates actual performance • Rates or makes comments on currently memory retrieval • Checks behaviours or performance, including detection of errors • Self-corrects • Checks and/or corrects performance of peer M 7 Barbara Colombo and Alessandro Antonietti Table 1. Continued. Category Explanation Code Control Any verbalization or behaviour related to a change in the way a task had been conducted (by self or others), as a result of cognitive monitoring • Changes strategies as a result of previous monitoring • Suggests and uses strategies in order to solve the task more effectively • Applies a previously learned strategy to a new situation • Repeats a strategy in order to check the accuracy of the outcome • Seeks help • Copies from or imitates a model C Evaluation Any verbalization or behaviour related to reviewing task performance and evaluating the quality of performance (by self or others). • Reviews own learning or explains the task • Evaluates the strategies used • Rates the quality of performance • Observes or comments on task progress • Tests the outcome or effectiveness of a strategy in achieving a goal E Emotional/ motivational monitoring Any verbalization or behaviour related to the assessment of current emotional and motivational experiences regarding the task • Express awareness of positive or negative emotional experience of a task • Monitors own emotional reactions while being on a task E/M M Emotional/motivational Control Any verbalization or behaviour related to the regulation of one's emotional and motivational experiences while on task • Controls attention and resists distraction or returns to task after momentary distraction • Self-encourages or encourages others • Persists in the face of difficulty or remains in task without help E/M C 8   Figure 2. (Colour online) Beginner student 1-student's use of metacognitive strategies. Figure 3. (Colour online) Beginner student 1-teacher's use of metacognitive strategies. of using metacognitive prompts focused on the knowledge of the task. Periodically he also encouraged the student by the way of using emotional/motivational control. The way the first beginner student used metacognitive strategies while learning was mainly as control strategies (Figure 2). Most of the times he answered to the teacher's metacognitive prompt adopting a control strategy to check on his/ her own learning. Beginner student 2 Moving to the second beginner student, we can notice how the overall uses of metacognitive categories stay the same (see Figure 3). Focusing on subcategories, we notice that the teacher appeared to behave differently when interacting with this student who, incidentally, was older. The teacher has been constantly using planning during the lesson, as he did with the first beginner student, but this time the use of evaluation was as high as it will be with the advanced students. Looking at the transcript, we can notice that, during the first part of the class, the use of metacognitive strategies follows trend 9   Figure 4. (Colour online) Beginner student 1-student's use of metacognitive strategies. similar to the other beginner class. In the second half, mainly in response to the student's metacognitive control prompts (see Figure 4), the teacher starts using evaluation strategies more often. Similarly to what he has been doing when teaching to the other beginner student, the teacher tends to use strategies that check the knowledge of the task more frequently. The use of emotional/motivational strategies is almost absent, possibly because, as it emerges clearly from the transcript, the student was extremely motivated. As noted above, the student was prompt in answering to the teacher's metacognitive communication by the way of using quite frequently metacognitive control strategies (see Figure 8). Advanced student 1 Frequencies of use of the different metacognitive activities are reported in Figure 5. As happened while teaching to beginner students, the teacher focused mostly on metacognitive regulation and on metacognitive knowledge while teaching. The use of Emotional/Motivational regulation strategies was not frequent. Exploring more in details the subcategories (Figure 5), we can highlight some differences. Within the category of metacognitive regulation, the teacher spent most time using evaluation strategies. These are useful, while teaching, to promote a metacognitive attitude in the learner, since they are aimed at reviewing task performance and evaluating the quality of performance (Table 1). The teacher also used planning strategies quite often to support his teaching. This approach appears to be useful in supporting a metacognitive attitude during a class, since it makes explicit task demands and expectations, sets goals and targets clearly, and, especially working with advanced students, fosters a decision-making process on ways of proceeding with the task and supports seeking and collecting necessary resources. The teacher supported the use of these strategies by periodically monitoring the teaching process (6 per cent of the strategies). Metacognitive knowledge was fostered   Figure 5. (Colour online) Advanced student 1-teacher's use of metacognitive strategies. Figure 6. (Colour online) Advanced student 1-student's use of metacognitive strategies. during the class and the teacher especially focused on knowledge of strategies. This can be helpful to support the student while performing a required task (e.g., improvising in a specific key), but also fosters the use of adequate strategies during independent home practice. As noted above, the teacher did not used emotional/motivational strategies very often, and used monitoring and control to the same extent. The student was mainly focused on following the teacher's directions and applied them playing the piano. Yet, it was possible to highlight the occurrence of metacognitive behaviours (Figure 6). Most of the student's strategies, as happened with beginners' students, were control strategies: They were mostly used in response to the teacher's planning strategies, highlighting a good response to the teacher's metacognitive demands.   Figure 7. (Colour online) Advanced student 2-teacher's use of metacognitive strategies. Advanced student 2 When analysing the metacognitive behaviours the teacher adopted while interacting with the second advanced student, a similar pattern to the one found in the previous transcripts could be highlighted (Figure 7). If the main categories of strategies (metacognitive regulation, metacognitive knowledge, and emotional/motivational regulation) were used to a very similar extent, the analysis of subcategories allowed highlighting some differences. The teacher spent more time using evaluation strategies and slightly less planning. Looking at the transcript (see Appendix), we can see that this advanced student was ready to act on the teacher's suggestion, hence the evaluation of her performance was useful, while planning would have been sometime redundant. Yet, the teacher kept using planning and monitor strategies, possibly to foster the use of the same metacognitive process later during independent learning. With this student the teacher also focused equally on the knowledge of the task and knowledge of strategies. Examining the transcript, we can see that strategies linked to the knowledge of the task were mainly directed at the student, checking her specific knowledge. Regarding emotional/motivational strategies, the teacher did not use them a lot either, but showed a clear preference for the emotional/motivational control over the monitoring. These emotional/motivation strategies were used especially during the second part of the lesson and were aimed at checking the student's motivation and interest. Once again the student was more focused on playing than on verbalizing metacognitive strategies. Yet, some metacognitive behaviour emerged (Figure 8). The student tended to use control strategies to be sure she was executing what the teacher suggested the right way. She also responded to the teacher's emotional/motivational control by using emotional/motivational monitoring herself. Overall Evaluation of the Lessons A first general question that this study tried to answer was whether the teacher did use any metacognitive strategies during his lessons and, if so, which ones. Analysis of the four 12   Figure 8. (Colour online) Advanced student 2-student's use of metacognitive strategies. Figure 9. (Colour online) Teacher's use of metacognitive strategies (general categories) during the four lessons. lessons showed that the teacher has been constantly using metacognitive strategies while teaching. Analysing the four cases under exam, it was possible to clearly highlight that the teacher has been constantly using mainly regulation strategies. Emotional/motivational regulation strategies were the least used (Figure 9). To have a more precise report of the strategies used and to see if, within the general categories, specific sub-categories had been used more than others, we considered, for each single case, the occurrences of the different sub-categories. A summary of the results discussed in the previous paragraphs is reported in Figure 10. We can see that, within regulation strategies, the teacher used evaluation and planning most often, while 13   Figure 10. (Colour online) Teacher's use of metacognitive strategies (subcategories) during the four lessons. monitoring and control strategies were seldom used. Within the metacognitive knowledge category, the teacher referred especially to knowledge of the task. Emotional/motivational monitoring was used, even if not often, while Emotional/motivational control was almost never used. Yet, while examining the single cases, we were able to highlight some differences in the teacher's use of metacognitive strategies when teaching novices and experts. A summary of the results is reported in Figure 11. The teacher used more planning strategies when he was working with novices: He started used evaluation with the second novice as a direct response to the student's response to his use of the planning strategies. He also referred more often to the knowledge of the task while working with beginners. Evaluation was constantly present in every part of the class when teaching to advanced students. Literature suggests that music students do not recognize metacognitive practices in their music teachers. To understand if this perception may be related to students' behaviours, we focused on students' metacognitive behaviours. They were not so frequent (students mostly played the piano or listened to the teacher), but some differences emerged, as reported in Figure 12. Students mainly used Control strategies. The older students used control strategies four times more than the younger ones did. Moreover, the older students were the only ones who used evaluation strategies, even if they did so sparingly. 14   Figure 11. (Colour online) Teacher's use of metacognitive strategies (subcategories) with novices vs. experts. Figure 12. (Colour online) Older vs. younger students' use of metacognitive strategies. Discussion and Conclusions This multiple case study focused on the role of metacognition in teaching music. Literature supports the relevant role of metacognition in reinforcing the teaching/learning process and also stresses the importance of metacognitive skills for musicians, both expert and novice 15   (Hallam, 2001). Yet it is not clear how metacognitive skills are acquired by musicians, since teachers state that they use them during their lessons, but students complain of a lack of them and report that they learn them during their own practice (Bathgate, Sims-Knight & Schunn, 2012). There are two main reasons for these contradictory results. The first is a simple lack of awareness on the part of either students or teachers, which leads to a misconception of the real use (or lack of use) of metacognitive strategies during music lessons. A second reason is methodological and is linked to the use of self-reported measures in previous studies. These measures, as discussed in the Introduction, rely on a high level of verbal understanding that may not always be present (Veenman, 2005), especially in music students. Moreover, in previous studies, metacognition was assessed in artificial settings, where teachers were asked to adopt a metacognitive program developed by researchers. Thus data could not provide any information about the real use of metacognition in everyday teaching practice. We tried to address these problems by exploring the spontaneous use of metacognitive strategies during four music lessons adopting observational methods. Differences between novices and experts had been taken into account. As a first step, we investigated the use of metacognitive strategies during the spontaneous teaching practice. Data highlighted a strong and constant use of different metacognitive strategies, supporting teachers' beliefs that they are using metacognitive strategies while teaching. Yet, whereas teachers report using metacognition explicitly to teach specific music-related techniques (Jorgensen, 2000, cited in Bathgate, Sims-Knight & Schunn, 2012), in this study the teacher used mostly Regulation strategies (namely Evaluation and Planning) and then referred quite often to the Knowledge of the Task, but seldom used Knowledge of Strategies. This finding can partially explain the discordance between teachers' and students' beliefs. We can hypothesise that students may have read the teacher's statement linked to the performance or to the planning of a specific aspect of the lesson as referring only to the specific setting of the lesson. This would prevent them from generalising these indications to their daily practice. This could also be reinforced by the fact that monitoring strategies were rarely used by the teacher. Encouraging music teachers to use more open monitoring strategies while teaching could be a first operative suggestion: This metacognitive behaviour could enhance students' regulation within the music lesson setting, helping the students to recognise and transfer metacognitive strategies used by the teacher to their own learning and everyday practice. Bathgate, Sims-Knight and Schunn (2012), in commenting on their data, hypothesised that teachers are probably aware of students' characteristics and modify their teaching behaviour accordingly, but students tend not to perceive these changes, and consequently do not apply any transfer from the specific setting of the lesson to any other setting when they have to self-monitor their learning. Therefore they do not apply these elements to their own practice. Our data also seem to support this idea, since we highlighted that the teacher did modify the use of metacognitive strategies according to students' responses. He used more Planning strategies when teaching novice students, but applied Evaluation strategies in response to specific metacognitive prompt derived from beginner students. We would have expected higher monitoring levels when addressing novice students, but the use of these strategies did not differ among the four cases. This could explain why novice music students are often found to be unaware of their errors (Hallam, 2001; Tobias & Everson, 2002). So, a second practical implication we can derive from this data and use to enhance metacognitive music teaching is related to students' expertise. Monitoring appears to be a key element again: Using it more, especially with beginners, would probably help these students become more metacognitively aware of their mistakes and more likely to try to actively correct them both during lessons and practice. Since differences between novices and experts were not so sharp, we also explored the possibility that differences were driven not by students' music expertise, but by students' age. As we saw in the Introduction, students tend to ascribe the development of their metacognitive skills to their personal cognitive development, rather than to the influence of their music teachers. If this is true, older students should be more metacognitively competent even as beginners, and this could prompt greater use of metacognitive skills from the teacher. Even if it is obviously hard to generalise any data collected from a multiple case study, our findings seem to support this hypothesis since differences existed in the teacher's use of metacognitive strategies with students in different age cohorts, and these differences seemed to be led by students' metacognitive learning behaviours during class. This suggests a third practical indication for teachers. When working with older students they can rely on the students' metacognitive skills, whereas they should spend more time fostering metacognition per se when working with younger students. One possibility, in order to have a more metacognitively centred teaching approach, could be introducing a 'metacognitive corner' at the end of the lessons. In this very last part of the lesson the teacher could explicitly reflect with the student on the lesson, prompting him/her to become more aware of the strategies used, of the possible mistakes, and suggesting openly how to apply this metacognitive knowledge to everyday practice. Considering globally what emerged from this study, teachers use metacognitive strategies during their everyday teaching practice, but students are probably not aware of this because they tend not to use metacognitive strategies, do not respond/reciprocate metacognitive prompts used by the teacher, and focus only on monitoring their behaviours. In addition teachers are able to differentiate between expert and novice students. As a direct implication for music education, this study suggests that, even if experienced teachers frequently use metacognitive strategies in their teaching, the efficacy of these strategies should be enhanced and the use of the same metacognitive skills in the students' practice should be promoted. Such goals might be achieved through training programs addressing teachers' awareness so as to prompt them to integrate their usual method with monitoring strategies and to focus explicitly on strategies (KoS), not solely on the task (KoT). Bathgate, Sims-Knight and Schunn (2012) reported that students' self-efficacy did not increase following metacognitive teaching. Our data can help to explain this finding. Apart from the specific practical indications provided above, we also noticed that the teacher we observed almost never used emotional/motivational regulation strategies during the four lessons, whereas these could be the key element to modifying students' self-efficacy. The present multiple case study, even if it allowed us to highlight interesting aspects, has several limitations that can be read as possible hints for future researchers. First of all, we focused on only one teacher and thus we cannot generalise our findings to all music teachers, because some behaviours we observed may be due to his personal habits. Analysing teaching habits of more teachers is a necessary step to confirm the present data. The sample of students was not large, especially if the aim would be to compare novices   and experts and younger and older students. Even if this sample is coherent with the specific type of study and the amount of data analysed is noticeable (we analysed the full transcripts of the four lessons), obviously the characteristics of individual students could have affected our data. Collecting data from a larger sample is needed. As a last point, by adopting a between-subjects design we analysed only one lesson for each student. Following a student for a few lessons could help investigators to highlight a more sophisticated model of the use of metacognitive strategies both by teachers and students. Yet, even with this limitation, these findings allow us to derive direct implications for music teaching. From these implications we were able to provide specific practical hints, useful to improve music teaching and learning, enhancing both teachers' metacognitive behaviour while teaching and students' metacognitive awareness during their learning experience. Supplementary material To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S0265051716000267 References ANTONIETTI, A., COCOMAZZI, D. & IANNELLO, P. (2009) Looking at the audience improves music appreciation. Journal of Nonverbal Behavior, 33, 89–106. ANTONIETTI, A., COLOMBO, B. & LOZOTSEV, Y. (2008) Undergraduates' metacognitive knowledge about the psychological effects of different kinds of computer-supported instructional tools. Computers in Human Behaviour, 24, 2172–2198. ANTONIETTI, A., IGNAZI, S. & PEREGO, P. (2000) Metacognitive knowledge about problem-solving methods. British Journal of Educational Psychology, 70, 1–16. BATHGATE, M., SIMS-KNIGHT, J. & SCHUNN, C. (2012) Thoughts on thinking: Engaging novice music students in metacognition. Applied Cognitive Psychology, 26, 403–409. BERNARDI, N. F., SCHORIES, A., JABUSH, A. C., COLOMBO, B. & ALTENMUELLER, E. (2013) Mental practice in music memorization: An ecological-empirical study. 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