LEARNING TO SELF-MONITOR AND SELF-REGULATE

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INTRODUCTION

In the educational literature, the terms metacognition and self-regulated learning are often used interchangeably (Veenman, 2007), although their conceptual roots and theoretical perspectives are quite distinct (Dinsmore, Alexander, & Loughin, 2008; Fox & Riconscente, 2008). Metacognition theory originated from developmental psychology with Piaget (Inhelder & Piaget, 1958) and Flavell (1970) as progenitors. Metacognition initially focused on the “reflective abstraction of new or existent cognitive structures” (Dinsmore et al., 2008, p. 393)—that is, on the developing person’s thinking about cognition. Later, Brown and DeLoache (1978) affixed self-regulatory mechanisms to the conceptualization of metacognition.

Self-regulated learning (SRL), on the other hand, emerged from both metacognition theory and Bandura’s self-regulation theory, however, with a strong emphasis on the regulation of learning processes and learning outcomes. SRL theory attempts to integrate cognitive, motivational, and contextual factors of learning (Dinsmore et al., 2008; Zimmerman, 1995). Metacognition researchers consider self-regulation to be a subordinate component of metacognition, whereas SRL researchers regard self-regulation as a concept superordinate to metacognition—that is, cognitive regulation next to motivational and affective regulation (Veenman, van Hout-Wolters, & Afflerbach, 2006). Dinsmore et al. (2008) rightfully asserted that the boundaries between both theories have grown fuzzy over time and they plead for more clarity in conceptual and operational definitions.

In this chapter, a metacognitive perspective is taken. Hence, when referring to the SRL literature, only cognitive self-regulatory aspects of SRL will be taken into account. Wang, Haertel, and Walberg (1990) concluded from their literature review that metacognition is the most important predictor of learning performance. More specifically, in an overview of studies with learners of different age, performing different tasks in various domains, Veenman (2008) estimated that metacognitive skillfulness accounted for 40% of variance in learning outcomes. Therefore, the main focus of this chapter is on metacognitive skills for the regulation of learning processes, although one cannot
escape a discussion of the role of metacognitive declarative knowledge in the acquisition of metacognitive skills (see also Chapter 10, “Learning to Study Strategically”).

In conceptions of metacognition a distinction is often made between knowledge of cognition and regulation of cognition (Brown, 1987; Schraw & Dennison, 1994). According to Schraw and Dennison (1994), knowledge of cognition consists of declarative knowledge about the cognitive system, procedural knowledge about how to execute cognitive strategies, and (declarative) conditional knowledge about the utility of strategies. Regulation of cognition refers to metacognitive skills for the control over one’s strategy use—that is, to planning, monitoring, and evaluation. Procedural knowledge about how to execute cognitive strategies, however, essentially is cognitive knowledge (Anderson & Schunn, 2000). In order to avoid a circular reasoning of knowledge being cognitive and metacognitive at the same time, cognitive procedural knowledge should be excluded from a conception of metacognition. Thus, only two declarative components (i.e., declarative knowledge and conditional knowledge) remain in knowledge of cognition, referred to in the literature as metacognitive knowledge (Veenman et al., 2006). Regulation of cognition is the procedural component of metacognition, referred to as metacognitive strategies and skills.

This chapter starts out with defining the constructs of metacognitive knowledge and skills from a historical perspective. Next, a comprehensive model of the nature of metacognitive skills and the acquisition of those skills are outlined. Consequences of this model for the assessment and instruction of metacognitive skills will be delineated. Finally, some new directions for metacognition research are highlighted.

HISTORICAL OVERVIEW

Metacognitive Knowledge

Metacognitive knowledge refers to one’s declarative knowledge about the interplay between person, task, and strategy characteristics (Flavell, 1979). For instance, a learner may think that s/he (person characteristic) is not proficient in reading (task characteristic) and, therefore, that s/he should invest more effort in studying a textbook chapter (strategy characteristic). Conversely, another learner may more positively evaluate his/her reading proficiency, thus putting less effort into studying the same chapter. Some researchers implicitly assume that metacognitive knowledge only refers to correct knowledge, derived from earlier experiences (e.g., Schraw & Moshman, 1995; Simons, 1996). The assumption is that metacognitive knowledge can only be truly metacognitive by nature if it is accurate and flawless.

However, metacognitive knowledge can be either correct or incorrect as learners may underestimate or overestimate their competences, relative to the subjectively perceived complexity of the task (Veenman et al., 2006). For instance, a student may erroneously think that s/he only needs to read a chapter once in preparation for an exam, despite repeated failure on earlier exams. In fact, this self-knowledge may prove quite resistant to change, especially when failure is misattributed to external causes, such as poor teachers and unsound exams. Moreover, even correct metacognitive knowledge does not guarantee an adequate execution of appropriate strategies, as the learner may lack the motivation or capability to do so. For instance, Alexander, Carr, and Schwaneveldel (1995) found a discrepancy between children’s knowledge about monitoring and application of monitoring skills during task performance. In a same vein, Winne (1996) stated that knowledge has no effect on behavior until it is actually
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being used. Consequently, metacognitive knowledge often poorly predicts learning outcomes (Veenman, 2005). A good deal of metacognitive knowledge has its roots in a person’s belief system, which contains broad, often tacit ideas about the nature and functioning of the cognitive system (Flavell, 1979). Beliefs are personal and subjective by nature, and so remains metacognitive knowledge when it is not put to the test by the actual execution of strategies or skills.

Since researchers embarked on the study of metacognition in the 1970s, they have identified several subcomponents of metacognitive knowledge. The first component under study was metamemory (Flavell, 1970; Flavell & Wellman, 1977). Initially, metamemory only referred to the declarative knowledge about one’s memory capabilities and about strategies that affect memory processes (Cavanaugh & Perlmutter, 1982). It was assumed that this factual knowledge of memory processes would affect memory performance. Later, especially within the study of Feeling of Knowing (FOK) and Judgment of Learning (JOL), the focus of metamemory research shifted from the knowledge product of metamemory to the process of metamemory (Nelson & Narens, 1990). Both FOK and JOL refer to a person’s predictions about future test performance, either on items that have been studied beforehand (JOL), or on new items that are to be studied (FOK). Learners have to search their memory in order to monitor their understanding of an item. From their answers, indices for accuracy (correspondence between predictions and actual performance) and bias (over- or under-estimation) are calculated (Schraw, 2009). By including monitoring activities, however, metamemory research has crossed the border between metacognitive knowledge and metacognitive skills. Consequently, metacognitive knowledge about the memory system and monitoring skills for evaluating memory cannot be disentangled in the prediction of actual memory performance.

Another component of metacognitive knowledge is conditional knowledge (Schraw & Moshman, 1995). Conditional knowledge pertains to declarative knowledge about when a certain metacognitive strategy should be applied and to what purpose. Poor performers often do not know what strategy to choose, why they should use that strategy, and when to deploy that strategy. Even adequate conditional knowledge, however, does not guarantee the actual execution of a strategy as a learner may still miss the procedural knowledge for how the strategy should be enacted. In fact, conditional knowledge provides an entry to the first stage of skill acquisition, where a metacognitive strategy has to be consciously applied step-by-step and gradually transformed into a skill through proceduralization (Alexander & Jetton, 2000; Anderson & Schunn, 2000). Thus, conditional knowledge is a prerequisite, but not sufficient condition for the acquisition of metacognitive strategies or skills.

In order to circumvent this conceptual problem, Kuhn (1999) and Zohar and Ben-David (2009) postulated the notion of metastrategic knowledge, which encompasses both conditional knowledge and procedural knowledge for how to use a strategy. The concept of metastrategic knowledge, however, obscures the boundary between metacognitive knowledge and skills. It precludes the notion that metacognitive strategies may fail either due to incorrect and incomplete conditional knowledge, or due to lack of knowledge about how to execute a strategy.

**Acquisition of Metacognitive Knowledge**

Where does metacognitive knowledge come from? As noted, the belief system, which contains naïve theories and tacit ideas about cognitive functioning, provides a source
of information from which metacognitive knowledge is built. Other information sources are judgments and feedback from other people, and metacognitive experiences (Efklides, 2006; Flavell, 1979). According to Efklides (2006), metacognitive experiences are non-analytic, non-conscious inferential processes that are driven by affective experiences, such as liking, interest, curiosity, disappointment, and being startled. Hence, metacognitive experiences are truly subjective by nature. For instance, while a task may have an externally defined objective level of difficulty or cognitive load, the learner’s feeling of difficulty is determined by subjective estimates of task difficulty, which depend on person characteristics, such as cognitive ability, and affective factors, such as mood and fear of failure (Efklides, 2006). Metacognitive experiences may directly affect task performance through motivational self-regulation, in particular through time on task and effort expenditure.

What metacognitive experiences and metacognitive knowledge have in common is that both originate from a monitoring process. Metacognitive knowledge, however, refers to memory-retrieved knowledge, whereas metacognitive experiences concern on-line feelings, judgments, estimates, and thoughts that people have during task performance. Although metacognitive experiences arise from unconscious inferential processes, as soon as learners become consciously aware of them, they may feed into the cognitive system and become more or less stable metacognitive knowledge. Thus, metacognitive experiences are a major source for building up metacognitive knowledge.

What is the developmental timeline of metacognitive knowledge? Flavell (1992) related his conceptualization of metacognition to Piaget’s developmental stage of formal-operational thinking. At this stage children are capable of hypothetico-deductive reasoning, which requires a child to take a metacognitive perspective. Flavell indicated that Piaget would not expect metacognition to show up before the stage of formal-operational thinking as “young children’s egocentrism prevents them from being able to introspect or treat their own thought processes as an object of thought” (Flavell, 1992, p. 118; see also Fox & Riconscente, 2008; Inhelder & Piaget, 1958). Flavell further adhered to Piaget’s theory by postulating an early developmental level of proto-metacognition, at which level children do acknowledge that different people may see different things, although they cannot handle the various perspectives other people may take. Therefore, metacognitive awareness may arise at the age of 4–6 years as an inclination that something is wrong (Demetriou & Efklides, 1990; Istomina, 1975; Kluwe, 1987; Kuhn, 1999).

Indeed, recent research accounted for the missing link between Theory of Mind (TOM) and metamemory as a starting point of metacognitive development (Bartsch & Estes, 1996; Flavell, 2004; Kuhn, 1999; Larkin, 2006; Lockl & Schneider, 2006). TOM pertains to children’s knowledge about the mind and, in particular, knowledge about the existence of mental states such as beliefs, desires, and intentions. Crucial to the development of TOM is the understanding of a child older than 4 years that another person may not know what the child knows. Longitudinal studies of Lockl and Schneider (2006) have shown that TOM at the age of 4 to 5 years is a precursor of later metamemory performance at the age of 5 to 6 years. Apparently, the development of metacognitive knowledge has its roots in earlier cognitive development. As the children’s knowledge of cognitive processes, strategies, and task variables expands during the early school years, integration of this knowledge instigates the formation of metacognitive conditional knowledge (Alexander et al., 1995; Berk, 2003; Kuhn, 1999). Further growth of metacognitive knowledge occurs in the years thereafter. The formation
of conditional knowledge is the overture to metacognitive skill development in successive years, though strategic behavior initially is impeded by the incompleteness and inappropriateness of conditional knowledge (Annevirta & Vauras, 2006; Kuhn, 1999).

**Metacognitive Skills**

Metacognitive skills pertain to the acquired repertoire of procedural knowledge for monitoring, guiding, and controlling one’s learning and problem-solving behavior. There is some consensus of what learning activities are typical for metacognitive skills. The overview presented here is by no means exhaustive. For instance, Pressley and Afflerbach (1995) distinguished some 150 different metacognitive activities in detail for reading, while Meijer, Veenman, and Van Hout-Wolters (2006) derived a taxonomy of 65 activities for solving physics problems from analyzing thinking-aloud protocols. This chapter merely presents a global description of what kind of activities are regarded as being representative of metacognitive skills.

Quite often, a distinction is made between activities at the onset of task performance, during task performance, and at the end of task performance (Schraw & Moshman, 1995; Veenman, 2013a). At the onset of task performance one may find activities, such as reading and analyzing the task assignment, activating prior knowledge, goal setting, and planning (Brown, 1987; Veenman, 2015a). These activities are preparatory to actual task performance. Indicators of metacognitive skillfulness during task performance are systematically following a plan or deliberately changing that plan, monitoring and checking, note taking, and time and resource management (Brown, 1987; Veenman, 2015a). These activities guide and control the execution of the task at hand. At the end of task performance, activities such as evaluating performance against the goal, drawing conclusions, recapitulating, and reflection on the learning process may be observed (Butler, 1998; Veenman, 2015a). The function of these activities is to evaluate and interpret the outcome, and to learn from one’s course of action for future occasions.

The execution of metacognitive skills before, during, and after reading is a cyclic process, rather than being strictly linear (Veenman, 2013a; Zimmerman, 2000). For instance, when the execution of a task runs ashore, monitoring may elicit reorientation in order to adjust goals and plans. In the same vein, evaluation at the end of task performance may require the learner to review the task assignment and set additional goals and plans. Metacognitively proficient learners have incorporated these cycles of monitoring or evaluation, and renewed goal setting and planning in their executive behavior (Veenman, 2013a).

**General vs. Domain-Specific Metacognitive Skills**

At first glance, the metacognitive activities of learners may vary from task to task, and from one domain to another. For instance, orienting activities for text studying include reading the title and subheadings, scanning the text to get an overview, activating prior knowledge, goal setting for reading, and getting hold of test expectations (Pressley & Afflerbach, 1995; Veenman, 2015a). Orientation during problem solving encompasses reading the problem statement, activating prior knowledge, goal setting, making a drawing representing the problem, establishing what is given and what is asked for, and predicting a plausible outcome (Meijer et al., 2006). Similarly, the process of planning in reading looks different from planning while solving physics problems. When
studying a text, planning activities concern decisions about what parts of the text should be focused on and how to navigate through the text (Veenman & Beishuizen, 2004). Planning in problem solving refers to the design of a step-by-step action plan of problem-solving activities (Mettes, Pilot, & Roossink, 1981). Monitoring in reading primarily pertains to text comprehension (Brown, 1987), while monitoring in problem solving mainly concerns the detection and repair of errors (Meijer et al., 2006). Kelleman, Frost, and Weaver (2000) argue that differences in task demands may yield variation of metacognition within the individual.

Even when the same learner performs the same type of tasks, say text studying, learner behavior may vary across content domains. For instance, Glaser, Schauble, Raghavan, and Zeitz (1992) found different patterns of learner activities for three discovery-learning tasks in the domains of physics and microeconomics. Glaser et al. argue that differences between tasks in the frequencies of predictions generated, controlled experiments, and notebook entries, among others, are due to differences in domain content and task demands. Since learners improved when moving from one learning task to the other, Glaser et al. did not rule out the role of general strategies of a larger grain size, such as planning and evaluation. “However, these general skills take on specific value as they are differentially useful in varying contexts” (Glaser et al., 1992, p. 370). Thus, finding support for domain-specific vs. general metacognitive skills may depend on the grain size of analysis: Domain specific for the lower-order activities in task performance, but general and stable across tasks for the higher-order metacognitive skills that instigate these activities (Veenman, Elshout, & Meijer, 1997).

Although different task requirements may evoke specific overt activities, there is evidence that these different activities spring from similar metacognitive grounds, especially in more matured learners. In a longitudinal design, Van der Stel and Veenman (2014) followed 12-year-olds for three successive years, while they performed a reading task in history and a problem-solving task in mathematics each year. Principal component analysis on the metacognitive-skill measures, obtained from separate analyses of think-aloud protocols for both tasks, revealed a steadily increasing general component over the years (accounting for 41% to 49% of variance) and a weaker domain-specific component, fading out over the years (accounting for 22% down to 14% of variance). In the same vein, Veenman and Spaans (2005) contrasted discovery learning in biology with problem solving in mathematics for two age groups. Metacognition skills for both tasks correlated 0.27 in 12-year-olds and 0.61 in 14-year-olds.

Consistent support for the general nature of metacognitive skills has been reported for learners in the age of 9 to 22 years performing four discovery-learning tasks in biology and geography (Veenman, Wilhelm, & Beishuizen, 2004); for undergraduate students performing three discovery-learning tasks in the domains of physics, statistics, and chemistry (Veenman et al., 1997); for undergraduates from a technical university who performed a mathematical model construction task and a discovery-learning task in chemistry (Veenman & Verheij, 2003); and for undergraduate students studying two texts about geography and criminology (Veenman & Beishuizen, 2004). In the latter four studies, principal component analysis yielded only a general component, accounting for 62% to 83% of variance, while correlations among measures of metacognitive skillfulness for different tasks and domains ranged between 0.67 and 0.86. Finally, Schraw, Dunkle, Bendixen, and Roedel (1995) obtained support for a general monitoring skill in undergraduate students during test answering for five different content domains. Accuracy of students’ confidence ratings on the five tests was moderately
correlated (.19 on the average), but principal component analysis yielded one general component accounting for 37% of variance.

In conclusion, the metacognitive skills of younger learners are general, as well as domain specific to a lesser extent. “[Their] metacognitive skills may initially develop on separate islands of tasks and domains that are very much alike” (Veenman & Spaans, 2005, p. 172). After the age of 12 years, metacognitive skills increasingly become more general, a transition process that is completed at the age of 15 years (Van der Stel & Veenman, 2014). Moreover, a cross-sectional study with 119 secondary-school students (13 to 16 yrs.) performing the same discovery-learning task for biology revealed that females run one year ahead of males in this transition process (Veenman, Hesselink, Sleeuwaegen, Liem, & Van Haaren, 2014). Although females may temporarily benefit from early maturation, gender effects do not persist beyond the age of 16 (Bakracevic Vukman & Licardo, 2010; Leutweiler, 2009). Older, more mature learners have a stable personal repertoire of metacognitive skills that they tend to apply whenever they encounter a new learning task.

**Development of Metacognitive Skills**

The development of metacognitive skills is generally thought of as commencing at the age of 8 to 10 years (Berk, 2003; Veenman et al., 2006). However, research by Whitebread et al. (2009) has shown that the behavior of young children may reveal elementary forms of planning, monitoring, and evaluation if the task is appropriated to their interest and level of understanding. They observed 3- to 5-year old children interact in playful situations, such as distributing dolls over a limited number of chairs. Children were capable of initiating an orderly sequence of actions (e.g., one doll per chair to start with), of self-correcting faulty actions (e.g., taking back an incorrectly placed doll), and of reviewing the outcome (e.g., noticing that the dolls are equally distributed over the chairs). According to Whitebread et al., earlier studies underestimated metacognitive processing in preschool children because assessment methods relied too much on children’s verbal ability.

Similarly, Larking (2006) observed elementary metacognitive strategy use in 5-year-old children collaboratively performing age-appropriate tasks, such as sorting out buttons by shape. Protocols of two children showed that they could break the task down into steps, plan how to go about, monitor progress, and evaluate success or failure. These results indicate that initial models of metacognitive development may need some revision.

Most likely, metacognitive skills already develop alongside metacognitive knowledge at a very basic level during preschool or early-school years. The roots of early metacognitive-skill development may be found in executive functions (EF), which refer to the ability to control thoughts and actions in order to attain goals (Fernandez-Duque, Baird, & Posner, 2000). Typical EFs are inhibitory control (suppressing impulsiveness), mental flexibility (shifting in sets of categorization), working memory, elementary planning, and error detection (Best, Miller, & Naglieri, 2011; Bryce, Whitebread, & Szücs, 2015). EFs start to develop at the age of 2 (Fernandez-Duque et al., 2000), but growth continues throughout adolescence (Best et al., 2011). Blair and Razza (2007) established that, when controlled for intelligence, especially inhibitory control is a strong predictor of early mathematical and reading ability in 3- to 5-year-old children. In a study with 5- and 7-year-olds, Bryce et al. (2015) assessed inhibitory control with a Stroop-like task, working memory with a standard recall task,
and metacognitive skills from observations of children building a wooden train-track. EF indices were more related to metacognitive skills in 5-year-olds than in 7-year-olds. Moreover, metacognitive skill was a far better predictor of educational achievement than EF across both age groups.

Despite the similarities between both types of skills (cf. Fernandez-Duque et al., 2000), the study of Bryce et al. shows that EFs and metacognitive skills are not identical. Bryce et al. postulate that EFs are necessary but not sufficient antecedents to metacognitive-skill development. Until recently, EFs and metacognitive skills were investigated in separated research strands of neuroscientists and developmental/educational psychologists, respectively. Therefore, more research is needed to elucidate, both conceptually and empirically, how EFs serve as stepping-stones for later metacognitive development (Veenman, 2015b).

Metacognitive skills become more sophisticated and academically oriented whenever formal education requires the explicit utilization of a metacognitive repertoire (Veenman et al., 2006). During primary and secondary education, learners reveal a steep incremental development in both frequency and quality of metacognitive skills (Alexander et al., 1995; Li, Zhang, Du, Zhu, & Li, 2015; Van der Stel & Veenman, 2014; Veenman et al., 2004). Nevertheless, huge individual differences in developmental pace can be observed. Within each age group, some learners are virtually devoid of metacognition, while others are ahead of their peers (Veenman et al., 2004), and they maintain their relative positions in the course of development (Van der Stel & Veenman, 2014).

Intelligence does not account for individual differences in pace of metacognitive development. In an overview of research, Alexander et al. (1995) gathered evidence in favor of the monotonic development hypothesis with a continuous parallel growth of intelligence and metacognition, thereby dismissing the acceleration hypothesis in which intelligence and metacognition would mutually enhance each other in the course of development. Accordingly, correlations between intelligence and metacognition remain stable over the years (Veenman et al., 2004; Veenman & Spaans, 2005). In an overview of research with 439 learners from different age groups, performing different tasks in different domains, Veenman (2008) established that intelligence uniquely accounted for 10% of variance in learning performance, metacognitive skillfulness uniquely accounted for 18% of variance, and both predictors shared another 22% of variance in learning performance. Hence, metacognitive skills cannot be equated with intelligence. A study with 153 students in eleventh grade of secondary education revealed that intellectually gifted learners are equally susceptible to metacognitive deficiencies as their less intelligent classmates (Veenman, 2015b). About half of the learners with an IQ ≥ 130 attained a metacognition score below the average of the non-gifted group (95 ≤ IQ < 130). Possibly, these gifted learners rely purely on their intelligence when performing tasks, as a result of which they fail to see the necessity of developing metacognitive skills. Conversely, some low-intelligence learners acquire high levels of metacognitive skillfulness with age, thus compensating for their lower cognitive ability (Van der Stel & Veenman, 2014).

THEORETICAL FRAMEWORK

Metacognitive Skills and Cognitive Processing

A process model of metacognitive skills ought to make a distinction between metacognitive and cognitive activity. Incidentally, this distinction becomes manifest in the
behavior of learners when they explicitly express their intention to apply a metacognitive skill. Most of the time, however, metacognitive skills remain covert operations in the mind. Consequently, these metacognitive skills cannot be directly assessed, but have to be inferred from their behavioral consequences (Veenman et al., 2006; Veenman, 2013b). For instance, when a learner spontaneously recalculates the outcome of a mathematics problem, it is assumed that a monitoring or evaluation process must have preceded this overt cognitive activity of recalculation.

A perennial issue, then, is that higher-order metacognitive skills heavily draw on lower-order cognitive processes (Brown, 1987; Slife, Weiss, & Bell, 1985). A few examples may elucidate this tight connection between metacognitive and cognitive processes. Analysis of a task assignment requires reading and reasoning processes; activating prior knowledge is driven by memory processes; planning involves the processes of serialization and sequencing; comprehension monitoring while reading relies on lexical access and other verbal processes; checking the outcome of a calculation requires numerical processes; note-taking depends on writing processes; drawing conclusions entails inferential reasoning; both evaluation and reflection imply cognitive processes of making comparisons. Metaphorically speaking, metacognitive skills represent the driver, while cognitive processes form the vehicle for employing those metacognitive skills.

The problem of disentangling higher-order from lower-order skills is deeply rooted in psychological theory of human consciousness. Conceptualizations of metacognition have in common that they take the perspective of higher-order cognition about cognition (Flavell, 1979; Nelson, 1999). These conceptualizations stress the supervisory role of metacognition in the initiation of and control over cognitive processes. A higher-order agent is overlooking and governing the cognitive system, while simultaneously being part of it. This is the classical homunculus problem (Elshout, 1996), otherwise referred to as Comte’s paradox (Nelson, 1996): One cannot split one’s self in two, of whom one thinks while the other one observes that thinking. What then is the higher-order nature of metacognitive skills? This issue is addressed in the next section.

Metacognitive Skills as Self-Instructions

Nelson (1996; Nelson & Narens, 1990) gave an initial impetus to a unified theory of metacognition. Basically, he distinguished an object level from a meta-level. At the object level lower-order cognitive activities take place, usually referred to as execution processes. For instance, cognitive processes at the object-level for reading include decoding, lexical access, parsing, and relating concepts. At the meta-level, higher-order executive processes of evaluation and planning govern the object level. Two general flows of information between both levels are postulated. Information about the state of the object level is conveyed to the meta-level through monitoring processes, while instructions from the meta-level are transmitted to the object level through control processes. Thus, if errors occur on the object level, monitoring processes will give notice of it to the meta-level, where the incoming information is evaluated and control processes are activated or planned to resolve the problem. This seems an elegant model, including both metacognitive knowledge through the information flows and metacognitive skills in subsequent processes of monitoring, evaluation, and planning.

According to Nelson’s model, metacognition can be seen as a bottom-up process, where anomalies in task performance trigger monitoring activities, which in turn activate control processes on the meta-level. A limitation of this bottom-up model is that it does not clarify how monitoring processes themselves are triggered (Dunlosky, 1998).
Moreover, the model does not account for spontaneous activation of control processes without prior monitoring activities, thus neglecting the goal directedness of problem-solving and learning behavior (Veenman, 2015b). As an extension to Nelson’s model, metacognition could also take the perspective of a top-down process of self-instructions for the control over and regulation of task performance (Veenman, 2008). Apart from being triggered by task errors, the latter top-down process can also be activated as an acquired program of self-instructions whenever the learner is faced with performing a task the learner is familiar with to a certain extent. Either the task has been practiced before or the task resembles another familiar task. Such a program of self-instructions could be represented by a production system of condition-action rules (Anderson, 1996; Anderson & Schunn, 2000; Butler & Winne, 1995):

IF you encounter a task, THEN look for the task assignment and take notice of it;
IF you have an idea about the task assignment, THEN try to dig up from memory as much as you know about the subject matter;
IF you understand the task assignment, THEN formulate the goal to be achieved;
IF you have set your goal, THEN design an action plan for attaining that goal;
IF you have an action plan, THEN follow that plan in a systematical way; or
IF you are executing your action plan, THEN keep a close watch on what you are doing and detect any anomalies; etcetera (see Veenman, 2013a).

This production system embodies a set of self-induced metacognitive instructions to the cognitive system. Thus, in line with Nelson’s model, self-instructions from the meta-level evoke various cognitive activities at the object level. At the object level, these general self-instructions must be tailored to the context of the specific task. The goal of a reading task may differ from that for writing, so the plan of action also needs to be different. Consequently, the learner must translate the general instructions from the meta level into task- or domain-specific activities at the object level, a process that is contingent on the available prior knowledge (Veenman & Elshout, 1999). In novices, the resulting activities at the object level remain rather general (e.g., sorting out relevant information) as they lack domain-specific knowledge of the task at hand. With increasing expertise, activities on the object level become more specific (e.g., looking for particular keywords that point to a certain theory). Glaser and Chi (1988) argue that experts are more proficient in orientation, planning, and monitoring than novices, but the proficiency of experts may be due to a more advanced level of linking general metacognitive skills to domain-specific knowledge on the object level (Veenman & Elshout, 1999). When confronted with new, unfamiliar tasks or domains, experts have to resort to their general repertoire of self-instructions.

How do humans acquire such a production system of metacognitive self-instructions? According to ACT-R theory (Anderson, 1996), skill acquisition passes through three successive stages. In the cognitive stage, declarative knowledge of condition and actions is interpreted and arranged in order to allow for a verbal description of a procedure (What to do, When, Why, and How; Veenman, 2013a; Veenman et al., 2006). The execution of the procedure progresses slowly because all activity needs to be consciously performed step-by-step, while being prone to error. During the acquisition of metacognitive skills at this stage, metacognitive knowledge, in particular conditional knowledge, is incorporated in a verbal description of the procedure. In fact, conditional knowledge contains information about the Why and When (Schraw, Crippen, & Hartley, 2006), defining the IF-side of a production rule. The What and How constitute
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the Then-side of a production rule. The conscious execution of the procedure at this stage explains why the initial acquisition of metacognitive skills through instruction or training requires extra effort, which may temporarily interfere with cognitive performance (Veenman et al., 2006).

In the second, associative stage, verbal descriptions of the procedure are transformed into a procedural representation through compilation. Errors in the procedure are eliminated, separate procedures are assembled into an organized set through composition, and references to declarative knowledge are removed through proceduralization. Consequently, the execution of procedures becomes faster and more accurate, requiring less effort.

Finally, in the autonomous stage, the execution of productions is fine-tuned and automated. Many metacognitive skills will never reach this stage, as they need to be consciously applied and tuned to the task at hand (Nelson, 1996). Monitoring processes, however, may run in the background until an error or anomaly is detected (Brown, 1987; Butler & Winne, 1995; Reder & Schunn, 1996). In the same vein, elements of the planning process may become automated, thus requiring less deliberate and conscious activity until an obstacle prevents a plan from being executed (Pressley, Borkowski, & Schneider, 1989). Consequently, there is a trade-off between strategic flexibility in attuning to task demands, which requires metacognitive skills to be consciously executed, and the effortless application of metacognitive skills that are partly automated.

It is important to acknowledge that both the metacognitive self-instructions and the cognitive processes involved in the execution of those instructions are part of the same cognitive system. Metacognitive and cognitive activities, however, serve different goals and functions within the cognitive system (Brown, 1987; Butler, 1998; Veenman et al., 2006). Cognitive activities are needed for the execution of task-related processes on the object level, whereas metacognitive activity represents the executive function on the meta-level for regulating cognitive activity. Thus, metacognitive self-instructions are much like a general who cannot win a war without cognitive soldiers. On the other hand, an unorganized army will neither succeed. It is my experience from studying many thinking-aloud protocols that successful learners easily shift from a cognitive performance mode to a metacognitive self-instruction mode, and vice versa.

CURRENT TRENDS AND ISSUES

Assessment of Metacognitive Skills

In the assessment of metacognitive skills a distinction is made between off-line and on-line methods (Veenman et al., 2006). Off-line methods refer to questionnaires (e.g., MSLQ, Pintrich & De Groot, 1990; MAI, Schraw & Dennison, 1994), interviews (Zimmerman & Martinez-Pons, 1990), and learning diaries (Schmitz & Perels, 2011) that are administered to the learner either prior or retrospective to task performance. Off-line methods address the learner with questions about his/her (frequency of) strategy use and skill application. On-line methods, on the other hand, pertain to assessments during actual task performance, such as observations (Whitebread et al., 2009), think-aloud protocols (Azevedo, Greene, & Moos, 2007; Pressley & Afflerbach, 1995; Veenman, Elshout, & Groen, 1993), eye-movement registration (Kinnunen & Vauras, 1995), and computer logfile registrations (Greene & Azevedo, 2010; Veenman, 2013b). Recordings of the learner’s behavior are then coded according to a standardized coding
system. The essential difference between off-line and on-line methods is that off-line measures merely rely on self-reports from the learner, whereas on-line measures concern the coding of learner behavior on externally defined criteria.

Off-line methods have their pros and cons. Questionnaires are easy to administer in large groups and, therefore, assessments with questionnaires are omnipresent in metacognition research (Dinsmore et al., 2008; Veenman, 2005). Interviews, on the other hand, need to be administered on an individual basis, which is time-consuming. Off-line self-reports of metacognitive skills suffer from various validity problems (Veenman, 2011). The first problem relates to the nature of self-reports as response to questionnaires or interviews. In order to answer questions about the relative frequency of certain activities (“How often do/did you . . .?”), learners have to compare themselves to others (peers, teachers, parents). The individual reference point chosen, however, may vary from one learner to the other, or even within a particular learner from one question to the other (Prins, Busato, Elshout, & Hamaker, 1998; Veenman, Prins, & Verheij, 2003). Even though measurement reliability may be high when individual learners consistently choose the same reference points, variation in the choice of reference points among learners may yield disparate data.

Another validity problem with off-line methods pertains to the prompting effect of questions, which may interfere with spontaneous self-reports of metacognitive activity by learners (Veenman, 2011). Questions may not only elicit socially desirable answers; questions may also evoke an illusion of familiarity with the strategies or skills that are queried and learners may be triggered to label their behavior accordingly. For instance, when asked after their summarizing activities, learners may mistake occasional paraphrasing for making a summary. Thus, questions may prompt the recall of strategy use or skill application that in fact never occurred. Learners with poor metacognitive knowledge are likely to be more susceptible to prompting effects than learners with adequate metacognitive knowledge.

Finally, a fundamental validity problem concerns the off-line nature of self-reports. While answering questions, learners have to consult their memory and reconstruct their earlier performance. This reconstruction process might suffer from memory failure and distortions (Ericsson & Simon, 1993; Nisbett & Wilson, 1977). In retrospective assessment, reconstructive interpretations may be elicited along with, or instead of correct recollections. Learners not only know more than they tell, they sometimes “tell more than [they] can know” (Nisbett & Wilson, 1977, p. 247). These memory problems can be partially relieved by means of stimulated recall. Learners are then prompted to reflect on their thoughts and behavior while watching a video recording of their task performance (Artzt & Armour-Thomas, 1992; Peterson, Swing, Braverman, & Buss, 1982). Although supporting retrospective reconstruction, stimulated recall may still yield incomplete memory traces and biased reconstructions. Memory problems get even worse for off-line assessments administered prior to or entirely separated from actual performance, as learners have to base their answers on earlier experiences in the past. In conclusion, off-line self-reports may not accurately reflect the learner’s metacognitive skills.

On-line assessments of the learner’s actual metacognitive behavior have their own merits and limitations. The think-aloud method differs from off-line self-reports or introspection in that learners are merely verbalizing their on-going thoughts during task performance. Learners do not reconstruct or interpret their thought processes. Merely verbalizing of one’s thoughts does not interfere with thought processes in general (Ericsson & Simon, 1993) or, more specifically, with ongoing regulatory processes.
Thinking aloud, however, may slightly slow down those processes. Nevertheless, the think-aloud method is neither suited for assessing highly automated processes (e.g., routines in expert performance), nor for processes that are extremely difficult or effortful. In these cases, learners fall silent and protocols are likely to be incomplete. This is referred to as the tip-of-the-iceberg phenomenon (Ericsson & Simon, 1993).

The think-aloud method requires learners to have an adequate level of verbal proficiency in order to avoid interference of the second, verbalization task with the target task (Cavanaugh & Perlmutter, 1982; Garner, 1988; Thorpe & Satterly, 1990). For instance, reading protocols of young children are likely to be incomplete or even distorted, because basic reading processes occupy all working memory available. Consequently, assessment of metacognition in younger, less verbally fluent children often relies on observational methods (Alexander et al., 1995; Whitebread et al., 2009). Observations only yield quantitative estimates of overt behavior, of which the metacognitive nature has to be inferred by the observers. Unless combined with thinking aloud, observations do not give access to mental processes underlying behavior. For instance, recalculation of a math problem may be due to different reasons. Either recalculation is a manifestation of metacognitive evaluation, or the outcome of an earlier calculation was not written down and forgotten (i.e., metacognitively sloppy). Observers need to scrutinize the learner’s behavior in order to detect such subtle differences. Hence, coding from videotapes is preferred over direct on-line observations. Observation and think-aloud methods are both labor-intensive as they are administered on an individual basis, and the videotapes or transcribed protocols have to be coded by multiple judges.

More recently, researchers have advanced the on-line registration of metacognitive activities in computer logfiles (Greene & Azevedo, 2010; Kunz, Drewniak, & Schott, 1992; Li et al., 2015; Veenman, Bavelaar, De Wolf, & Van Haaren, 2014; Veenman et al., 2004). Apart from logging frequencies of metacognitive activities, trace data in logfile registrations can also be used to detect meaningful patterns in the sequence of activities (Hadwin, Nesbit, Jamieson-Noel, Code, & Winne, 2007; Veenman, 2013b; Winne, 2014). Obviously, the task should lend itself to a computerized version, or otherwise it would impair the ecological validity of assessments. For instance, studying text from a computer screen may put demands on the learner that are different from studying a hard copy. Logfile registration is restricted to concrete, overt behavior on the object level, without the learner’s metacognitive deliberations. Prior to logfile registration, one has to select a restricted set of relevant metacognitive activities on rational grounds and to validate this potential set of activities against other on-line measures (Veenman, 2013b; Veenman et al., 2014). Validation ahead is necessary because the coding of learner activities during task performance is automated. The advantage of logfile registration, however, is that the method in itself is minimally intrusive, and that it can be administered to large groups at the same time (Dinsmore et al., 2008; Veenman, 2013b). In conclusion, the quality of on-line assessment depends on the adequacy of the coding system.

Studies with multi-method designs have shown that off-line measures hardly correspond to on-line measures (Veenman, 2005). In a study of Veenman et al. (2003) the Inventory Learning Styles (ILS) questionnaire was administered to 30 students from a technical university, prior to studying a text about earth sciences while thinking aloud. The Self-Regulation scale from the ILS correlated 0.22 with think-aloud measures of activities corresponding to the ILS scale. Cromley and Azevedo (2006) compared another off-line self-report measure, the Metacognitive Awareness of Reading
Strategies Inventory (MARSI), with think-aloud measures of studying a text about the Civil War, and with an on-line test where respondents had to apply reading strategies to text fragments. The strategies involved in all three measures were the activation of prior knowledge, generating hypotheses, self-questioning, summarizing, and making inferences. MARSI scores of 30 secondary-school students correlated $-0.02$ with scores obtained from the think-aloud protocols, and $0.18$ with scores from the on-line questionnaire.

In a study with 66 undergraduates studying an electronic text on meteorology, Winne and Jamieson-Noel (2002) found that retrospective self-reports of students overestimated their actual strategy use, which was assessed with logfile registrations of goal setting, planning, and reviewing activities in the electronic environment. Moreover, self-reports were poorly calibrated with the logfile measures. In the same vein, Hadwin et al. (2007) showed that self-reports on MSLQ items were not well calibrated with logfile traces of 8 students studying an electronic text on educational psychology. On the average, MSLQ items only had $27\%$ in common with specific activities in the logfile traces that pertained to those items. In a study with 48 graduate students who studied a hypertext on operant conditioning, Bannert and Mengelkamp (2008) reported that think-aloud measures of orientation, planning, and monitoring were not significantly correlated to retrospective self-reports of the same activities.

So far, the evidence is limited to text studying. Veenman and Van Cleef (2007) administered the MSLQ and ILS to 30 secondary-school students, prior to mathematical problem solving while thinking aloud. The Cognitive Strategy Use and Self-Regulation scales from the MSLQ and the Self-Regulation scale from the ILS correlated 0.11 on the average with measures for metacognitive skillfulness, rated from think-aloud protocols. Additionally, scores on a retrospective task-specific questionnaire, administered immediately after solving the math problems, correlated 0.28 with protocol measures, although both instruments addressed the same detailed set of metacognitive skills. Desoete (2008) administered a metacognitive-skill questionnaire to 20 primary-school children, one day before and directly after solving math problems, while think-aloud protocols and computer assessments were gathered online during the math task. Offline measures correlated 0.15 on the average with online measures. Finally, Li et al. (2015) found an overall correlation of 0.18 between planning assessed on-line with a computerized puzzle task and self-reports of planning by 321 secondary-school students aged 9 to 14 years and 119 college students. Apparently, learners do not actually do what they say they will do, nor do they recollect accurately what they have done.

Moreover, correlations among off-line measures are often low to moderate (Artelt, 2000; Muis, Winne, & Jamieson-Noel, 2007; Peterson et al., 1982; Sperling, Howard, Miller, & Murphy, 2002; Veenman, 2005), whereas correlations among on-line measures usually are moderate to high (Cromley & Azevedo, 2006; Veenman, 2005). Apparently, off-line measures yield diverging results, while on-line measures converge in their assessments of metacognitive skills. Finally, off-line and on-line measures differ with respect to their external validity for learning performance. External validity is an important issue as metacognitive skills are expected to predict learning performance according to metacognition theory (Veenman, 2007). On the average, off-line measures are poor predictors of learning outcomes, relative to on-line measures (Bannert & Mengelkamp, 2008; Cromley & Azevedo, 2006; Sperling et al., 2002). In a review study, Veenman (2005) found that correlations with learning performance range from slightly negative to 0.36 for off-line measures, and from 0.45 to 0.90 for on-line measures.
What is there to be learned from this overview of assessment methods? It appears that off-line methods do not adequately assess learners’ metacognitive skills. Perhaps, off-line measures capture elements of metacognitive knowledge or metacognitive conditional knowledge, but that remains to be ascertained in further research. Even though learners may acknowledge the relevance of using certain metacognitive skills in their self-reports, this does not imply that learners have those skills on an operational level at their disposal, or that they will actually apply those skills when appropriate. Someone can tell you perfectly well how to prepare a meal, but that does not necessarily make this person a perfect cook. With on-line methods, the proof of the pudding is in the eating. On-line measures are based on actual learner behavior. They show concurrent validity with other on-line measures, and they substantially predict learning outcomes. For these reasons, the utility of off-line methods for the assessment of metacognitive skills should be reconsidered (cf. Dinsmore et al., 2008) and, for the time being, on-line methods should be preferred over off-line methods.

**Instruction and Training of Metacognitive Skills**

There are three principles fundamental to effective instruction of metacognitive skills: a) the synthesis position, b) informed training, and c) prolonged instruction (Veenman et al., 2006; Veenman, 2013a). According to the synthesis position (Volet, 1991), metacognitive instruction should be embedded in the context of the task at hand in order to relate the execution of metacognitive skills to specific task demands. In fact, embedded instruction will enable the learner to connect task-specific conditional knowledge of which skill to apply when (the IF-side) to the procedural knowledge of how the skill is applied in the context of the task (the THEN-side of production rules).

The second principle is informed instruction (Campione, Brown, & Ferrara, 1982). Learners should be informed about the benefit of applying metacognitive skills in order to make them exert the initial extra effort. When learners do not spontaneously utilize metacognitive skills, the execution of the instructed skills initially requires effort and occupies working-memory space. This may result in cognitive overload, especially if the task at hand is demanding. Learners may be inclined to abandon the instructed skills, unless they appreciate why the application of metacognitive skills facilitates task execution.

Finally, the third principle refers to prolonged instruction. Instruction and training should be stretched over time, thus allowing for the formation of production rules and ensuring smooth and maintained application of metacognitive skills. Opinions differ about the preferred length of instruction. The instruction period may be relatively short for mastering a limited set of metacognitive skills (Kramarski & Mevarech, 2003; Veenman, Kok, & Blöte, 2005). For establishing enduring effects on spontaneous metacognitive functioning, however, the instruction period may cover a year or more, especially for learners with a learning disability (Mettes et al., 1981; Pressley & Gaskin, 2006). Any successful instructional program abides with these three principles.

Veenman (2013a) refers to these principles as the WWW&H rule for complete instruction of metacognitive skills, meaning that learners should be instructed, modeled, and trained when to apply what skill, why, and how in the context of a task. Not all learners, however, are alike in their need for instruction. Learners who exhibit a poor level of metacognitive skillfulness may suffer from either an availability deficiency or a production deficiency (Brown & DeLoache, 1978; Flavell, 1976; Mayer, 1992; Veenman et al., 2005). Learners with an availability deficiency do not have metacognitive
skills at their disposal. For instance, they do not know how to plan or monitor their actions. Cues or prompts that merely remind these learners of applying metacognitive skills during task performance neither affect their metacognitive behavior, nor result in enhanced learning performance (Veenman, Kerseboom, & Imthorn, 2000). Learners with an availability deficiency need to receive complete instruction and training of metacognitive skills from scratch.

Learners with a production deficiency, on the other hand, have metacognitive skills at their disposal but they do not spontaneously execute the available skills for some reason. For instance, they do not know when to plan or monitor their actions, they do not recognize the relevance of those skills for a particular task, or test anxiety prevents them from applying those skills (Veenman et al., 2000). Metacognitive cues may help these learners to overcome their production deficiency, reminding them of what to do when during task performance (Connor, 2007; Muth, 1991; Veenman et al., 2000, 2005). Production-deficient learners need not be fully instructed and trained in how to apply those skills.

For the implementation of metacognitive instruction, often step-by-step action plans are used (Veenman, 2013a). Such a step-by-step plan contains a series of questions or keywords, addressing metacognitive actions that should be undertaken in the course of task performance. Typically, activities of task analysis, activating prior knowledge, goal setting, and planning are promoted at the onset of task performance. Orderly execution of plans, monitoring, and note taking are encouraged during task performance, while evaluation, recapitulation, reflection are endorsed at the end of task performance. As these descriptions of activities are rather abstract to learners, they need to be translated into concrete activities that apply to the task at hand. For instance, goal setting and planning require different concrete activities for problem-solving and text-studying tasks (see Veenman, 2013a). The application of such a concrete step-by-step plan is explained, modeled, and practiced with the learner according to the principles delineated above.

One of the first successful step-by-step plans was the Systematical Approach to Problem solving in physics (Mettes et al., 1981), although metacognition was not explicitly referred to at the time. SAP instruction provided students with an orderly sequence of problem solving activities, with the sequence broken down into three successive stages of orientation, execution, and evaluation. During orientation, students carefully read the problem, made a drawing or scheme of the problem that included the relevant data and the unknown, used prior knowledge to determine whether it was a known problem, used multiple strategies to convert a complex problem to a known problem, and estimated the outcome. In the execution phase, standard operations were carried out, of which the outcome was checked in the evaluation phase against the problem statement and the earlier estimation. Throughout SAP, checks were built in, which could lead to backtracking. After implementation of SAP in an existing thermodynamics course at a technical university, average course grades went up from 5.8 to 6.8 (on a 10-point scale).

IMPROVE (Kramarski & Mevarech, 2003; Mevarech & Fridkin, 2006) is a more recent program for teaching learners to address themselves with metacognitive questions during problem solving in mathematics. These self-questions pertain to understanding the nature of the problem, relating the problem to prior knowledge, planning solution steps, and evaluating outcomes. In a study of Mevarech and Fridkin (2006), pre-college students who failed on a mathematical entry test for university followed a 50-hour course on mathematical functions. The group receiving the IMPROVE
training significantly enhanced their mathematical knowledge and reasoning from pretest to posttest by 18% on the average, whereas the control group did not improve despite the content instruction. Kramarski and Mevarech (2003) further showed that IMPROVE training in a cooperative setting of small workgroups yielded better mathematics results, relative to individualized IMPROVE training.

Veenman et al. (2005) asked secondary-school students of 12 to 13 years old to solve a series of mathematical word problems without support and, subsequently, another series with metacognitive cueing. Cues prompted students to set goals, to select relevant data, to plan problem-solving steps, to monitor progress, to check outcomes, and to draw conclusions related to the problem statement. Students displayed significantly better metacognitive skills and mathematics performance on cued problems, relative to non-cued problems, even after correction for a learning curve over the two series of problems.

In a study by Azevedo et al. (2007), undergraduate students learned about the blood circulatory system with hypermedia. Half of them received metacognitive prompts from a human tutor who encouraged them to set goals, to activate prior knowledge, to plan time and effort, to monitor comprehension and progression towards the learning goals, and to apply strategies such as summarizing, hypothesizing, and drawing diagrams. Compared to the control group without prompts, the prompted group employed more self-regulatory activities and showed higher gains in content knowledge from pretest to posttest. The prompted group also attained a higher level of sophistication in their mental model of the circulatory system.

What these studies have in common is that they promoted proper metacognitive activities at the right time in the context of a given task. With the introduction of computers in education, computer programs have also been used for metacognitive instruction during task performance (Winters, Greene, & Costich, 2008). Most computer programs provide a fixed array of metacognitive scaffolds, much like the step-by-step plans (e.g., Kapa, 2001; Kramarski & Hirsch, 2003; Manlove, Lazonder, & de Jong, 2007; Teong, 2003; Veenman, Elshout, & Busato, 1994). Scarcely out of the egg are attempts to provide scaffolds adapted to the learner’s needs through an intelligent tutoring system, such as tailored navigation support in a hypertext (Puntambekar & Stylianou, 2005). Promising is the work by Roll, Alevin, McLaren, and Koedinger (2011), where positive effects of an intelligent tutoring system with metacognitive feedback on students’ help-seeking behavior transferred to new tasks without metacognitive support. An obvious advantage of such intelligent systems is that learners with adequate metacognitive skills are not disrupted or annoyed by superfluous instructions.

Another line of inquiry is regulation support during collaborated learning. Metacognitive scaffolding of peer questioning in small-group online discussions (Choi, Land, & Turgeon, 2005) is reminiscent of reciprocal teaching (Brown & Palincsar, 1987), albeit with mixed results. Only recently, research of collaborative learning focused on regulatory processes (Järvelä & Hadwin, 2013). Two levels of metacognitive regulation are distinguished in collaborated learning (Liskala, Vauras, Lehtinen, & Salonen, 2011). At the lower level of co-regulation, the individual learner’s regulation is supported or inhibited by other members of the group. The more advanced level of socially shared regulation refers to co-construction and negotiation of shared perceptions, goals, and strategies. Molenaar, Sleegers, and Van Boxtel (2014) provided triads of primary-school students with metacognitive scaffolds for orientation, planning, and monitoring during six 1-hour collaborative-learning sessions. Triads received structuring scaffolds (clarifying and supporting metacognitive activities), problematizing
scaffolds (stimulating metacognitive activity, without further explanation), or no scaffolds (control). From the analysis of conversation protocols it appeared that scaffolds fostered social metacognitive interactions, with problematizing scaffolds yielding a higher level of socially shared regulation than structuring scaffolds. Results corroborated the findings of an earlier study with a similar design (Molenaar, Van Boxtel, & Sleegers, 2010), although a third study failed to establish scaffolding effects on posttest domain knowledge (Molenaar, Van Boxtel, & Sleegers, 2011). More research is needed to clarify how self-regulation, co-regulation, and shared regulation interact during collaborative learning (Järvelä & Hadwin, 2013).

Teachers can also provide for metacognitive instruction in natural classroom settings. Teachers, however, tend to give implicit instruction rather than explicit instruction. That is, they spontaneously use examples of metacognitive activity in their lessons, but they are not inclined to explain the metacognitive nature of these activities and the benefit of using these activities to their students. After observing 17 lessons of various teachers, Veenman, de Haan, and Dignath (2009) concluded that metacognitive instruction was given, but that 96% concerned implicit instruction and only 4% was explicit. By doing so, teachers unintentionally violate the principle of informed instruction. There are, however, successful training programs for classroom settings (Dignath & Büttner, 2008; Stoeger & Ziegler, 2008; Zohar & Ben David, 2008).

More recently, Pressley and Gaskins (2006; Pressley, Gaskins, Solic, & Collins, 2006) described the teaching method of a special Benchmark school for students with a very low reading ability, where teachers of all school disciplines address the students with a broad array of metacognitive reading instructions throughout the day. Teachers incessantly explain, model, and prompt the use of comprehension strategies, such as determining the purpose for reading, grasping the theme and main ideas of the text, making predictions about further developments in the text, relating new information to prior knowledge, monitoring understanding through self-questioning, resolving incomprehension by re-reading or looking for additional information sources, summarizing the text, and reviewing the reading process. Instruction explicitly addresses when and how strategies are to be used. After spending 4 to 8 years at Benchmark school, students typically return to regular education with “scores in the upper end of the distribution of [reading] achievement for same-age students” (Pressley & Gaskins, 2006, p. 103).

Many studies on the effectiveness of metacognitive instruction fall short of a complete design. Studies may lack a measure for learning outcomes (Winters et al., 2008), or they fail to report the effects of instruction on the actual metacognitive behavior (Veenman, 2007). In order to account for the effectiveness of metacognitive instruction, a causal chain of instruction leading to improved metacognitive behavior and, thus, leading to better learning outcomes should be established. When the mediating metacognitive behavior is not assessed, attribution of instructional effects on learning outcomes to various confounding variables cannot be excluded, such as extended time-on-task due to compliance with the instructions or enhanced motivation due to extra attention. When learning outcomes are not assessed, on the other hand, it remains unclear whether the intended metacognitive behavior actually supports the learning process. As discussed, metacognitive instruction sometimes has detrimental effects on learning performance, either because initial compliance with instruction may yield a temporary cognitive overload, or simply because instruction may divert the learner’s attention from the task at hand (Puntambekar & Stylianou, 2005).
PRACTICAL IMPLICATIONS

First, the benefit of the present theoretical framework for metacognitive skills should be addressed. Obviously, Nelson’s (1996) model helps us to understand how learners react to errors and anomalies in task performance. Errors trigger monitoring processes, which in turn activate the selection of control processes for dealing with errors. Extension of Nelson’s (1996) model with a top-down program of self-instructions, appreciates that learners are not passively waiting for an error or anomaly to occur. They actively employ their acquired repertoire of metacognitive skills whenever appropriate (Veenman, 2015b). Moreover, linking metacognitive self-instructions to Anderson’s ACT-R theory provides us with a framework for the teaching and learning of metacognitive skills. Complete metacognitive instruction should address the What, When, Why, and How of metacognitive skills (WWW&H).

The cognitive phase of metacognitive-skill acquisition initially draws on declarative conditional knowledge of What, When, and Why. Metacognitive knowledge, however, is fallible, which raises two questions. The first question pertains to the issue of how to assess conditional knowledge. Limitations of off-line methods were discussed earlier. For instance, the MAI (Schraw & Dennison, 1994) has a separate subscale for assessing conditional knowledge. A score on the MAI subscale, however, does not provide us with sufficient and sufficiently correct information for entry into the cognitive phase of skill acquisition. Therefore, the question should be rephrased to ask how it can be determined whether the learner’s conditional knowledge is correct and sufficient enough for the acquisition of a specific metacognitive skill.

The second question is related to the first one: How can we remedy incorrect or incomplete conditional knowledge upon entry into the cognitive stage? In fact, ACT-R (Anderson, 1996; Anderson & Schunn, 2000) has a feedback loop for repairing flawed skills. Once a skill has been proceduralized, however, the correction of errors requires the cumbersome process of skill decompilation, which means that the tags of declarative knowledge need to be reinstated. Learners spontaneously acquiring metacognitive skills cannot but rely on this feedback loop. Learners receiving metacognitive instruction, on the other hand, need to be provided with correct conditional knowledge from the start and potential errors should be addressed before skills are fully proceduralized.

The answer to both questions lies in the responsiveness of instructors and teachers. They have to set the example in an early stage of skill acquisition, and they have to do so explicitly (Veenman, 2013a). Furthermore, in order to remedy incorrect or incomplete conditional knowledge during the cognitive stage, they have to be sensitive of its presence in learners.

The general nature of metacognitive skills was discussed earlier. The implication is that metacognitive instruction preferably should be given simultaneously by all teachers from all school disciplines in order to attain transfer across tasks and domains (Veenman et al., 2004). The Benchmark school of Pressley and Gaskins (2006) shows what such a synchronized teaching program may achieve. Certainly, it requires teacher commitment and administrative coordination, but the long-term results are precious.

FUTURE DIRECTIONS

Most studies on metacognitive instruction or training investigate the effects of a relatively short instruction on one single task, only measuring near transfer if any. Given the general nature of metacognitive skills, we are awaiting research that establishes to
what extent prolonged metacognitive training on one task might transfer to metacognitive behavior on another task, and under what conditions (Salomon & Perkins, 1989), given the developmental constraints (Van der Stel & Veenman, 2014). Adequate identification of the causal pathways of instructional effects would then require the assessment of metacognitive skills and learning performance for the training task, as well as the transfer task.

Veenman (2005; Veenman et al., 2006) and Dinsmore et al. (2008) pleaded in favor of using multi-method designs for assessing metacognitive skills. During the last decade a number of multi-method studies has been carried out and results have been overly negative for off-line assessment methods. Nevertheless, off-line methods are still predominantly used for the assessment of metacognitive skills (or strategy use, in terms of SRL). In a review of about 200 studies, Dinsmore et al. (2008) established that for the assessment of metacognition 37% relied on off-line measures (24% self-reports and 13% interviews), while for the assessment of SRL 68% relied on off-line measures (59% self-reports and 9% interviews). Multi-method designs could provide converging evidence from different assessment sources, which would strengthen the results and conclusions from metacognition research.

Neuropsychological research has shown that the development of the pre-frontal lobe in the brain is related to an increase of action control and executive functioning during childhood and adolescence (Casey, Tottenham, Liston, & Durston, 2005; Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006). Metacognitive development runs parallel to maturation of the pre-frontal lobe (Fernandez-Duque et al., 2000), although direct evidence that prefrontal activity in the brain reflects metacognitive processes is scarce (e.g., Fleming, Huijgen, & Dolan, 2012). In the past, this kind of research had to rely on patients with brain damage or dementia, but now researchers can look in vivo into the brain of normally functioning people. We are far from connecting specific cognitive processes to particular brain activities, as the disparity between fine-grained analysis of (meta-) cognitive processes and complex patterns of activity in various parts of the brain is still huge. According to Fernandez-Duque et al. (2000, p. 300), “it is unlikely that cognitive systems can be reduced to one brain area . . . the brain implements cognition via interconnected networks of specialized areas.” Therefore, it is an understatement to say that it will take a while before neuropsychological methods will be available for the assessment of metacognitive skills as a diagnostic instrument. Although this kind of research is still in its infancy, its potential role in the future should not be ignored.

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