Development of metacognitive skills in young adolescents : a bumpy ride to the high road

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Chapter 1

General introduction

In the last decades, young adolescents, when entering secondary school, increasingly have been placed in the role of active learners with responsibilities for their own learning process. In the Netherlands, this resulted in a secondary-education system in which students have to face more and more responsibilities for their own learning and study success. In order to be successful, students have to be able to plan their learning activities and execute them in a systematic and orderly way, to monitor and to evaluate their own learning and to reflect on it. All afore-mentioned skills are components of metacognitive skillfulness.

This thesis aims to gain insight into the development of metacognitive skillfulness in young adolescents. The development of metacognitive skills will be investigated in relation to intellectual ability and learning performance. Furthermore, it will be investigated whether metacognitive skills are general or domain specific. Metacognitive-skill development of young adolescents, aged 12 to 15 years, will be investigated in both longitudinal and cross-sectional designs.

1.1 Metacognition as a concept

In recent publications *metacognition*, that is, cognition about cognition, has been characterized as a concept that lacks coherence (Veenman, Van Hout-Wolters, & Afflerbach, 2006) and as a concept with 'fuzzy borders' (Zohar & Ben-David, 2009). Besides the problem that the concept of metacognition is not very well-defined, the term metacognition often is used interchangeably with self-regulation (SR) and self-regulated learning (SRL), or considered as intertwined with self-regulation (Dinsmore, Alexander, & Loughlin, 2008; Fox & Riconscente, 2008). SR and SRL are concepts that are rooted in the social-cognitive research tradition and influenced by neobehaviorism, while metacognition has its roots in cognitive developmental research. SR emphasizes the interaction of the person with the environment as well as the motivation of the person (Bandura, 1977). The application of SR to school learning led to the SRL-theory. According to SRL-theory, the interaction between cognition, metacognition, and motivation is very important for learning performance (Zimmerman, 1986). In cognitive developmental studies, however, researchers traditionally are less concerned with the role of motivation in learning. The research in this thesis is conducted from a cognitive developmental perspective and will focus on metacognition in particular.

One of the reasons for the lack of consensus concerning the term *metacognition* is that it is used to refer to both knowledge about cognition and to regulation of cognition. In most descriptions of metacognition two knowledge components can be distinguished: A declarative knowledge component and a procedural knowledge component for the regulation of behavior (Brown, 1987; Schraw & Moshman, 1995; Veenman et al., 2006). Flavell (1976, 1979), as 'founding father' of metacognition, subdivided metacognition into metacognitive knowledge and the active monitoring and regulation of cognitive processes: "Metacognition refers to one's knowledge concerning one's own cognitive processes and products or anything related to them, (…) Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects on which they bear, usually in the serve of some concrete goal or objective." (Flavell, 1976, p. 232). According to Flavell, metacognitive knowledge refers to the declarative knowledge one has about the interplay between person characteristics, task characteristics, and strategy characteristics. For example, a student thinks that s/he is a poor performer (person characteristic) in remembering historical facts and dates (task characteristics) and, therefore, has to write down the important facts and dates several times (strategy characteristics) before knowing them by heart. Procedural metacognitive knowledge is known from the literature by terms of 'executive decisions' (Kluwe, 1987), 'metacognitive control' (Ertmer & Newby, 1996), 'regulation and control' (Brown, 1987; Schraw, 1998), and 'metacognitve skills' (Veenman, 1993). All these terms refer to a person's *skills* for regulating and controlling his/her own cognitive activities. Metacognitive skills refer to the actual regulation of, and control over, one's learning performance (Brown & DeLoache, 1978; Veenman, Elshout, & Meijer, 1997). In many cases, however, metacognitive skills remain covert mechanisms that take place inside the head (Veenman et al., 2006) and have to be inferred from students' overt behavior or utterances, that is, from concrete cognitive activities. For example, when a student starts to reread a paragraph, this activity is probably the consequence of a monitoring or evaluation process. Different components of metacognitive skillfulness (also referred to as 'subscales of metacognitive skillfulness') may come into play either at the onset of task performance (orientation), during task performance (planning, monitoring, evaluation), or at the end of task performance (elaboration and reflection). A more detailed description of metacognitive skills, in particular those in text studying and problem solving, is given in section 1.5.

Some researchers not only separate declarative from procedural knowledge, but they also distinguish conditional knowledge (Brown, 1987; Schraw & Moshman, 1995), resulting in a distinction between a) declarative metacognitive knowledge (knowing that, knowing about); b) conditional metacognitive knowledge (knowing when and why); and c) procedural metacognitive knowledge, also referred to as metacognitive skills (knowing how). Conditional knowledge, however, pertains to declarative knowledge. Even if conditional knowledge is adequate, it does not guarantee the right application of a certain strategy due to the fact that the learner does not necessarily possess the procedural knowledge of *how* to use this strategy (Veenman, 2011). In order to apply metacognitive skills in the right way at the right time, one needs the required repertoire of procedural knowledge, that is, knowing *how* to use these skills effectively. This repertoire can be considered as a program of self-instructions (Veenman, 2011), represented by a production system of condition-action rules (Anderson, 1996; Veenman, 2011; Winne, 2010). The condition part of the rules triggers certain activities (i.e., the action part of the rules) of the learner. For example, IF (condition) you cannot solve the problem on which you are working, THEN (action) see if you can transform it into a familiar problem; or IF (condition) you encounter an unfamiliar word, THEN (action) see if you can deduce its meaning from the context, and if not, look it up in a dictionary. Considering metacognitive skills as condition-action rules implicates that students can be trained to use the condition and the action part as one set of rules belonging to a production system of metacognitive self-instructions within a certain context. Once students recognize the condition part of the rules, they will perform the action part of the rules that is triggered by the conditions. Some of these actions will be automated when students become more experienced learners, others need to be consciously applied and tuned to the task at hand (Veenman, 2011). Finally, Zohar and Ben-David (2009) refer to the 'how, when & why' knowledge as meta-strategic knowledge (MSK), which links MSK to Kuhn's procedural meta-knowing (1999). According to Veenman (2011), MSK "obscures the boundary between metacognitive knowledge and skills. It precludes the notion that metacognitive strategies may fail either due to incorrect or incomplete conditional knowledge, or due to lack of knowledge about how to execute a strategy" (p. 199). Nevertheless, conditional knowledge can be considered as an important factor in the acquisition of metacognitive skills. Knowing when and why to use a certain strategy can be considered as a first step toward the acquisition of metacognitive skills, that is, the cognitive stage of production rules before these rules get transformed into automated skills through proceduralization. Proceduralization is the dropping out of cues from declarative knowledge, resulting in a faster and more automated execution of the strategy (Anderson, 1996).

As stated above, metacognitive declarative knowledge refers to factual knowledge one has about the cognitive system in general and one's own cognition in particular. Like knowledge about other things, one's knowledge about the cognitive system can have shortcomings. It can be insufficient, inaccurate, not reliably retrieved, etc. (Flavell, 1992). Conditional knowledge is declarative knowledge about when and why certain metacognitive strategies should be applied. Although some researchers (Schraw &

Moshman, 1995; Simons, 1996) assumed that metacognitive knowledge is correct knowledge based on earlier experiences, it can be argued that metacognitive knowledge, just like any other type of declarative knowledge, is not always correct, available and/or applied when necessary. As Campione (1987, p. 134) formulated: "Availability of knowledge, either declarative or procedural, does not in itself guarantee flexible access to and use of those resources". Alexander, Carr and Schwanenflugel (1995) found a discrepancy between children's knowledge about monitoring and applying monitoring skills during task performance. Winne (1996) stated that knowledge has no effect on behavior until this knowledge is actually needed and actually used. So, it is quite possible that students have knowledge of a certain strategy at their disposal, but still not spontaneously use this strategy during task performance (Barnett, 2000; Focant, Grégoire, & Desoete, 2006; Pressley, Yokoi, Van Meter, Van Etten, & Freebern, 1997; Veenman, Kok, & Blöte, 2005). According to the findings of the afore-cited studies, metacognitive (conditional) knowledge does not automatically lead to an adequate use of metacognitive strategies. Consequently, metacognitive knowledge often poorly predicts learning outcomes, whereas metacognitive skills appear to have a much stronger predictive value (Veenman, 2005). Based on a review of studies, Wang, Haertel, and Walberg (1990) concluded that metacognition is the most important predictor of learning performance. In an overview of studies, Veenman (2008) estimated that metacognitive skillfulness accounted for 40% of variance in learning performance. Therefore, this thesis will focus on metacognitive skills in relation to learning performance.

1.2 Metacognition from a developmental perspective

Roughly spoken, research into the development of metacognition has focused on two issues: 1) Where does metacognition come from? And 2) when does it first emerge and how does it develop from there? Although the question 'where does metacognition come from?' is an issue of great interest, this issue goes beyond the scope of this thesis. Therefore, it will be discussed only very briefly. Some evidence has been found that "theory of mind" (ToM) can be considered as a precursor of metacognitive knowledge (Lockl & Schneider, 2006), while metacognitive knowledge can be considered as a necessary precursor of one's metacognitive skills (Annevirta & Vauras, 2006). In both studies, metacognitive competencies of very young children (preschoolers) were assessed. Results of both studies indicate that individual differences in the development of these competencies are already existent at an early age.

In this thesis the focus will be on the discussion about the second issue, the developmental trajectory of metacognition, in particular of metacognitive skills.

According to Piaget (Inhelder & Piaget, 1958), children younger than seven years are not able to keep a record of their own problem-solving attempts due to shortcomings in storing a record of their own cognitive activities. Piaget claimed that the egocentrism of young children prevents them from introspection or treating their own thinking as an object (Flavell, 1992). He assumed that egocentric perspective would change at the age of 11 – 12 years "when the child moves into thinking characterized by formal operations or hypothetico-deductive reasoning. Now the child becomes capable of metacognition in the sense of awareness of and reflective knowledge regarding her own thoughts and thought processes" (Piaget, 1964/1968, p. 64).

The earliest work on metacognitive development, however, dealt almost exclusively with metamemory, that is, awareness and monitoring of memory strategies. Evidence was found that children younger than 11 – 12 years have knowledge or at least awareness of their own memory and memory-strategy use. Flavell, Friedrichs, and Hoyt (1970) investigated the ability to predict one's own immediate memory span in preschool through fourth grade students. Results showed strong developmental differences. Accuracy in predicting the memory span increased significantly with age. In a longitudinal study between 2 and 20 years, Schneider and Pressley (1997) found evidence that memory-strategy development begins before elementary school and continues into adulthood. Furthermore, older children predict their own (memory) performance better than preschoolers, who often overestimate their own performance (Flavell & Wellman, 1977). Despite the fact that preschoolers display some metacognitive knowledge, (e.g., they understand that increasing the number of items makes a memory test harder; Kreutzer, Leonard, & Flavell, 1975), it is not before middle childhood that they understand that a memory strategy like categorization of objects will help them remember the objects better (Moynahan, 1978). Furthermore, young children tend not to apply strategies spontaneously in contexts where they would be useful. Improvements in this respect occur during the middle childhood years, but even by the end of childhood (strategy use or memory) performance is far from infallible (Brown et al., 1983; Schneider, 1985). Not only in the field of metamemory evidence was found against Piaget who related the onset of metacognition to the formal-operational stage of development (11 – 12 years). Researchers in other domains (e.g., problem solving and text comprehension) also found evidence of metacognitive activities in younger children, even preschoolers. Kluwe (1987) investigated how children of different ages could cope with changing problem-solving conditions. Results showed that 4-year-olds knew when an originally selected approach to the problem was no longer adequate. These young children appeared to be able to effectively regulate their own search for a solution. Whitebread et al. (2009) observed 3- to 5-year olds while interacting in playful problem-solving situations, e.g., distributing dolls over a limited number of chairs. The children revealed elementary forms of planning, monitoring, and reflection. Markman (1979) investigated elementary school children's awareness of their own comprehension failure by presenting them inconsistent information. Results showed that third through sixth graders do not spontaneously carry out the monitoring processes that they are capable of. Only modest improvements could be observed through the school years. If the students were alerted that something in the passage might not make sense, Markman found that the performance of sixth graders exceeded that of third graders. Veenman et al. (2006) argue that it is most likely that metacognitive skills develop alongside metacognitive knowledge during preschool and early-school years at a very basic level and that these skills become more sophisticated and academically oriented when needed in formal educational settings. In a cross-sectional study, Veenman et al. (2004) investigated the metacognitive skillfulness of fourth-, sixth-, and eighth-graders, and university students (aged 9 – 22 years). When performing four inductive-learning tasks in different domains, students' metacognitive skillfulness was assessed with logfile analysis and thinking-aloud protocols. A linear increase of metacognitive skillfulness with age was found. In the same vein, Veenman and Spaans (2005) assessed the metacognitive skillfulness of first-year and third-year secondary school students performing a problem-solving task in math and an inductive-learning task in biology. Veenman and Spaans (2005) found that high-intelligent students exhibited more metacognitive activities relative to low-intelligent ones, while third-year students showed more metacognitive activities than first-year students did.

From the afore-cited it becomes clear that metacognition develops gradually, that is, it does not appear from one moment to the other like a rabbit from a magician's hat. As Kuhn (2000, p. 178) formulated: "metacognition emerges early in life, … and follows an extended developmental course during which it becomes more explicit, more powerful, and hence more effective, as it comes to operate increasingly under the individual's conscious control." In order to understand better how metacognitive development can be facilitated, it is important to know more about the developmental trajectory of metacognition. As could be learned from the afore-cited studies, the development of metacognition is quite a long trajectory. It appears that even very young children exhibit metacognitive competencies to a certain extent (Brown, 1997), while the metacognition of adults still reveals serious weaknesses (Kuhn, Garcia-Mila, Zohar, & Anderson, 1995). As stated earlier, Brown et al. (1983) and Schneider (1985) found that children not always apply strategies spontaneously in contexts where they would be useful. Kuhn (1999) said that not a great deal is known about the development of metastrategic (memory) skills in school contexts. Therefore, the focus in this thesis is on spontaneous use of metacognitive skills, without any training or intervention, during the performance of ecologically valid school tasks.

One of the weaknesses of research on metacognitive development so far is the frequent use of cross-sectional designs. Despite the risk of participants dropping out from a longitudinal study before data collection has ended, there are serious arguments in favor of a longitudinal design relative to a cross-sectional design. In a longitudinal design continuous changes in frequency and quality of metacognitive skillfulness can be detected and followed with more precision than in a cross-sectional design. Moreover, in a cross-sectional design there is the problem of error variance due to comparing different age groups. Given the large individual variability in brain structure among individuals, especially during development, Casey, Tottenham, Liston, and Durston (2005) advocate a more frequent use of longitudinal designs in evaluating cortical changes with age. Considering the pros and cons of the two designs, for this thesis a longitudinal design is preferred to the more frequently used "cross-sectional, frozen, one shot looks at age changes" (Brown, 1987, p. 107) design.

1.3 Metacognitive skills and intellectual ability

Veenman (1993; Veenman & Beishuizen, 2004; Veenman, Elshout, & Meijer, 1997; Veenman & Verheij, 2003) described three, mutually exclusive models concerning the relation between intellectual ability and metacognitive skillfulness as predictors of learning performance. The *intelligence* model regards metacognitive skillfulness as an integral part of intellectual ability. In this model metacognitive skillfulness does not contribute to learning performance on top of intellectual ability. According to this model, metacognitive skills cannot have a predictive value for learning performance independent of intellectual ability. Sternberg (1990), for instance, advocates such an inclusive position of 'metacomponents' in his triarchic theory of intelligence. Support for the intelligence model was found by Elshout and Veenman (1992) in a study with university students working in a computer-simulated environment. Other researchers found significant differences concerning the application of metacognitive strategies between gifted and non-gifted students (Cheng, 1993; Hannah & Shore, 1995; Shore & Dover, 1987; Span & Overtoom-Corsmit 1986; Zimmerman & Martinez-Pons, 1990). The second, contrasting model is the *independency* model, in which intellectual ability and metacognitive skillfulness are regarded as entirely independent predictors of learning performance. Support for the independency model was found by Allon, Gutkin, and Bruning (1994). They found a correlation of .15 between metacognition scores and WISC-R scores of adolescents performing several cognitive tasks. In a study with children performing Piagetian tasks, Swanson (1990) reported that intelligence and metacognition were unrelated. In another study, however, Swanson, Christie, and Rubadeau (1993) found that metacognition appeared to be only partly independent of intelligence. In the third model, the *mixed* model, intellectual ability and metacognitive skillfulness are correlated, but metacognitive skillfulness has its own, unique contribution to the prediction of learning performance, on top of intellectual ability. Support for the mixed model was found in several studies, either with computer simulations in the domains of physics, statistics, and behavioral psychology, with text-studying tasks in the domains of law, geography, or with problem-solving tasks in the domains of math, biology and physics (Elshout &Veenman, 1992; Veenman, 1993; Veenman & Beishuizen, 2004; Veenman & Elshout, 1991, 1999; Veenman, Elshout, & Busato, 1994; Veenman, Elshout & Meijer, 1997; Veenman, Prins, & Elshout, 2002; Veenman & Spaans, 2005; Veenman & Verheij, 2003; Veenman, Wilhelm, & Beishuizen, 2004). Results of a study in which primary-school students performed arithmetic problems (Van der Heijden, 1989) corroborated the mixed model as well. The same applied for the results of Maqsud (1997) with secondary-school students performing math and reading tasks. Berger and Reid (1989) concluded from their study with students ranging from mentally retarded to normal achieving individuals that "IQ mediates metacognition, but does not explain it". Stankov (2000) argued that metacognition is partly independent of fluid intelligence. Minnaert and Janssen (1999), on the other hand, rejected the intelligence model, but could not decide between the independency model and the mixed model when predicting first-year university students' learning performance, while using a questionnaire to measure regulatory study activities.

Although over the last decades support has been found for each of the three models, the results of studies with complete data sets, that is, data sets containing measures of metacognition, intelligence, and learning performance, seem to be in favor of the mixed model. Most of the studies, however, are difficult to compare due to dissimilarities in methods for assessing metacognitive skillfulness (thinking aloud, observation, questionnaires), in participants (age, educational background, intelligence), and in tasks and domains. Another limitation for comparing the studies concerns the fact that the focus of some studies is restricted to the relation between intellectual ability and metacognitive skillfulness, thereby excluding the relation of both predictors with learning performance. Moreover, many of the afore-cited studies concern university students, that is, students who are used to apply their metacognitive skills in an academic context for quite a period of time. Because of these limitations, it still remains uncertain whether the mixed model can be generalized to younger students with less developed metacognitive skills. From a developmental perspective not only the question to what extent intellectual ability and metacognitive ability are related as predictors of learning performance is interesting, but also the question how both predictors develop in relation to each other. Alexander et al. (1995) formulated three developmental hypotheses with regard to the relation between intellectual ability and the development of metacognition, excluding the relation of both predictors with learning performance. The *ceiling* hypothesis assumes that effects of intelligence on the development of metacognition diminish over time. Initially, gifted children might develop their metacognitive skills faster than non-gifted children, but later the non-gifted children 'catch up'. In line with the *ceiling* hypothesis, Schneider and Pressley (1997) argue that during cognitive development the effects of some limitations of the information processing system in young children, for example their memory capacity, are being reduced. This would result in more resources becoming available with age for applying metacognitive skills. Conversely, the *acceleration* hypothesis assumes that the impact of intelligence on the development of metacognition increases with age. If this were the case, intellectual development would reinforce the development of metacognitive skills. When regulatory activities demand more complex and/or more abstract activities with age (e.g. reflecting), a higher intellectual level is required to do so. At the same time one could argue that more complex cognitive tasks require more and better metacognitive skills. Finally, the *monotonic* development hypothesis assumes that both intelligence and metacognition show a monotonic growth over age, while intellectual ability does not affect the development of metacognitive skills. Linking the models proposed by Alexander et al. (1995) to the three models described by Veenman (1993), it can be argued that both the acceleration hypothesis and the ceiling hypothesis relate to the intelligence model as the influence of intellectual ability on metacognition either increases or diminishes with age. In the ceiling hypothesis the intelligence model will fit less with age, whereas in the acceleration hypothesis the intelligence model will fit more with age. The monotonic hypothesis, on the other hand, predicts a parallel growth of both intellectual and metacognitive abilities. Such a parallel, monotonic development requires that the development of metacognition does not interact with the intellectual development, as would be the case in a non-monotonic development. The monotonic development hypothesis would suggest a link with the mixed model, where metacognitive skills do not develop merely as a component of intellectual ability, but have their own unique contribution to learning performance on top of intellectual ability. Finally, the independency model fits none of Alexander's hypotheses, since it predicts that there is no relation between intelligence and metacognition at all. In their literature overview, Alexander et al. (1995) found support for the monotonic development of metacognitive knowledge. Gifted children showed a general superiority in their declarative metacognitive knowledge. Giftedness effects were persistent throughout childhood with gifted early elementary school children showing a similar superiority in this knowledge relative to their non-gifted peers as junior high school students did. With regard to metacognitive skills, however, the results were inconclusive. Alexander et al. (1995) did not address intellectual and metacognitive ability as predictors of learning performance. In several studies, Veenman (2006), Veenman and Spaans (2005), and Veenman et al. (2004) addressed this issue using inductive discovery-learning tasks or problem-solving tasks in a cross-sectional design. Overall results fitted the mixed model. Metacognitive skills develop alongside, but not entirely as part of intellectual ability. Moreover, support was found for a monotonic maturation effect of both intellectual ability and metacognitive skillfulness in a parallel mode across age groups.

In this thesis not only participants' intellectual and metacognitive abilities will be assessed each year for three consecutive years, but also their learning performance. In this way, the relation between intellectual ability and metacognition as predictors of learning performance will be addressed and at the same time the relation between the first two variables will be studied from a developmental perspective. After entering secondary school young adolescents will perform two series of different tasks in two widely varying domains for three consecutive years.

1.4 Generality vs. domain-specificity of metacognitive skills

A frequently discussed issue is whether metacognitive skills are domain specific or general by nature. Prior studies concerning this issue of metacognitive skills being general or domain specific have yielded contradictory results. By using four metacognitive tasks (ease of learning judgments, feeling of knowing judgments, judgments of learning, and text-comprehension monitoring), Kelemen, Frost, and Weaver (2000) investigated whether university students' metacognitive monitoring ability is a general, domain-independent ability. They concluded that metacognitive memory accuracy was not stable across tasks and sessions, which they interpreted as evidence against a general metacognitive ability. Also Glaser, Schauble, Raghavan, and Zeitz (1992) found evidence against the generality of metacognitive skills. They investigated the generality vs. domain-specificity of metacognition in discovery-learning tasks. University freshmen performed three discovery-learning tasks in different domains (physics and economics).

Results showed that metacognitive activities of university students varied across different discovery-learning tasks, which can be interpreted as evidence in favor of domain specificity. Nevertheless, Glaser et al. (1992) did not rule out the role of general strategies of a larger grain size, since learners improved when performing one learning task after the other. In a study of Veenman et al. (1997), metacognitive skills of students performing discovery-learning tasks in three different domains (calorimetry, statistics, and a fictitious one) appeared to be general rather than domain specific. In another study (Veenman et al., 2004), the metacognitive skillfulness of fourth-, sixth-, and eighth-graders, and university students appeared to be a general, person-related characteristic for all age groups, ranging from 9 to 22 yrs. All participants performed four computerized inductive-learning tasks, that is, two tasks in the domain of biology and two tasks in the domain of geography. In Veenman and Verheij (2003), technical university students performed two tasks, a mathematical model-construction task that was part of their curriculum and a discovery-learning task in a fictitious domain. Their results supported the generality of metacognitve skills across tasks and domains. Veenman and Beishuizen (2004) found support for the general nature of metacognitive skills of undergraduate students studying two texts in different domains (geography vs. forensic psychology). Schraw, Dunkle, Bendixen, and Roedel (1995) investigated the nature of metacognitive skills, in particular monitoring skills, during test taking. In a first experiment, Schraw and colleagues (1995) found support for the domain-specific hypothesis. In this experiment, they used eight tests that differed with respect to several dimensions, like content, length, difficulty, and test format. In a next experiment, tests were used that differed only on one dimension, that is, only content domain was varied. Once tests were matched on dimensions other than content knowledge, findings were consistent with the domain-general hypothesis. Schraw et al. (1995) suggested a compromise between domain-specific and domain-general hypotheses. They argued that "domain-general monitoring skills emerge late in development, are preceded by modularized monitoring skills, and emerge only after considerable effort has been devoted…to integrating monitoring skills across domains" (p. 441). In the same vein, Veenman and Spaans (2005) assumed that metacognitive skills initially develop on separate islands of tasks and domains and that after the age of 12 years these metacognitive skills become more and more general. In their study, 12- and 15-year olds performed two tasks in two different domains (solving math word problems and an inductive-learning task for biology). Metacognitive skills of the 12-year-olds appeared to be rather domain specific, whereas those of the 15-year-olds turned out to be general. It can be argued that in the afore-cited studies differences in tasks and domains were not large enough in order to answer the question whether metacognitive skills are general or domain specific by nature, and whether age is involved. By maximizing the difference in both tasks and domains at the same time, the opportunity for finding a domain-specific factor will be optimized, relative to prior studies in which domains and/or tasks differed to a lesser extent. Therefore, in the research for this thesis, history vs. mathematics are contrasted as domains because they additionally allow for a substantial difference in tasks, that is, text studying vs. problem solving. Moreover, both tasks are ecologically valid as all students are to a certain extent familiar with and trained in these domains since elementary school. In a longitudinal design in which the same participants are followed for several years, it also is possible to draw conclusions about the nature of metacognitive skills along the developmental trajectory. The question is whether metacognitive skills will develop from being domain specific into general skills, as argued by Schraw et al. (1995) and Veenman & Spaans (2005).

1.5 Metacognitive skills in text studying and problem solving

Many studies on metacognitive skills pertain to one particular domain or task. Presumably, the most frequently used tasks are problem-solving tasks and text-studying or text-comprehension tasks. As shown in section 1.4, there is still no consensus among researchers whether metacognitive skills are general of domain specific. As argued by Veenman et al. (2006, p. 7), “one of the reasons for these equivocal results may be found in the grain of analysis used by researchers. At first glance, metacognitive activities may differ from one task to the other, say text studying vs. problem solving”. In a hierarchical model three levels of specificity of metacognitive activities were distinguished for any task (Meijer, Veenman & Van Hout-Wolters, 2006). Based on a very detailed list (Pressley & Afflerbach, 1995) of some 150 concrete metacognitive reading activities, Meijer et al. (2006) made a list of some 65 metacognitive activities for problem-solving tasks in physics. Activities in the detailed list of Pressley and Afflerbach as well as in the one of Meijer et al. can be considered as metacognitive activities at the lowest level. Looking at metacognitive activities in different tasks, they could be perceived as different from task to task. At the surface level, they differ indeed, but they stem from the same metacognitive behavior at the intermediate level. For example, prior to the actual reading of a history text, a student may scan the subtitles of all paragraphs in order to get an idea about what the text is about, while prior to a math problem, s/he will make a sketch of the problem in order to build a mental representation of the problem. In both cases, the student applies a metacognitive skill that guides the initial execution of the task, that is, the preparatory activity of orienting on the task prior to execution. Other examples of orienting activities for text-studying tasks are scanning the text, goal setting for reading, and thinking about what to expect in an upcoming test (Pressley & Afflerbach, 1995; Veenman & Beishuizen, 2004). Examples of orienting activities for problem-solving tasks are reading the problem statement, establishing what information is given and what is asked for, and predicting a plausible outcome (Meijer et al., 2006). Like the orienting activities, concrete planning activities for text-studying tasks also differ from planning activities for problem-solving tasks at the lowest level. For example, deciding what to read first and how to navigate through the text pertains to text-studying tasks, while designing a step-by-step action plan in order to solve the problem is distinctive of problem-solving tasks. In short, concrete, task-specific self-regulatory activities at the lowest level have a common denominator at the intermediate level. In this thesis, four components of general metacognitive skillfulness are distinguished at the intermediate level: *Orientation*, that is, preparatory metacognitive activities prior to task performance; *Planning,* that is, having an orderly sequence of planned actions instead of working by trial- and-error; *Evaluation*, that is, monitoring and checking in order to keep track of good task performance; *Elaboration and Reflection*, that is, reflecting on what has been learned, and relating this to one's own prior knowledge. These four components have been based on the *Effective working method* by Veenman (1993), which is an organized set of self-regulatory activities for passing through the phases (prior, during, and after) of task performance. Each of these activities not only seems to contribute to good task performance, but they also appear to be highly interdependent (Veenman & Spaans, 2005). When orienting thoroughly on a task, a student probably will build a deeper representation of the problem or the task requirements. Consequently, the student will be able to build a detailed plan instead of working by trial-and-error, which further enables him/her to monitor and control the learning process. Finally, this set of activities provides an opportunity for learning through reflection (Veenman et al., 1997). As formulated in section 1.4, the difference in both tasks and domains in this thesis is maximized relative to other studies, in order to answer the question whether metacognitive skills are general or domain specific by nature. By maximizing the difference in both tasks and domains at the same time, the opportunity for finding a domain-specific factor will be optimized. Because the scores at the intermediate level are composed of scores at the lowest level, scores at the intermediate level allow for finding both general and domain-specific tendencies. In the case of metacognitive skills being general by nature, there has to be a stability in *intra-individual* differences across different tasks in different domains. For example, if a student is metacognitively active in text studying, s/he will show this active metacognitive behavior in problem solving too. If metacognitive skills would be domain specific by nature, however, no stability in intra-individual differences across tasks would be found. Thus, a student that is metacognitively active in text studying, not necessarily will show the same metacognitve behavior in problem solving.

1.6 Assessing metacognitive skills

In the past decades, different methods for assessing metacognitive skills have been developed. These methods differ regarding the way and the moment the assessment takes place. With respect to the way of assessing metacognitive skills, a main distinction is made between off-line and on-line methods (Veenman et al., 2006). Off-line methods are assessment methods that are used before or after task performance. Questionnaires (e.g., MSLQ, Pintrich & De Groot, 1990; MAI, Schraw & Dennison, 1994) and interviews (Zimmerman & Martinez-Pons, 1990) are examples of off-line methods. Both questionnaires and interviews can be administered before (prospective) or after (retrospective) task performance (Veenman, 2005). On-line methods, on the other hand, are concurrent methods. In these methods the assessment of metacognitive skills takes place during task performance. Systematic observations (Veenman et al., 2005; Whitebread et al., 2009), think-aloud protocol analysis (Azevedo, Greene, & Moos, 2007; Pressley & Afflerbach, 1995; Veenman, 1993; Veenman & Spaans, 2005), and computer logfile registrations (Hadwin, Nesbit, Jamieson-Noel, Code, & Winne, 2007; Veenman et al., 2004) are examples of on-line methods. The essential difference between off-line and on-line methods is that off-line methods measures merely rely on self-reports from the learner, whereas on-line measures concern the coding of learner behavior on externally defined criteria (Veenman, 2011). Studies with multi-method designs have shown that off-line measures hardly correspond to on-line measures. In a review study, Veenman (2005) found hardly any correspondence between off-line self-reports and various on-line assessment methods. In the same vein, Hadwin et al. (2007, p. 119) reported that "self-reports were poorly calibrated with actual traceable studying events" during text studying in G-Study, a computerized reading environment. Cromley and Azevedo (2006) also compared off-line and on-line methods. Three parallel strategy-use measures were administered to a sample of 30 ninth-grade students: a prospective self-report measure (Metacognitive Awareness of Reading Strategies Inventory, MARSI), a concurrent multiple-choice measure which required students to apply the strategies to specific passages, and students were asked to think aloud during text studying. Two measures of reading comprehension, a standardized measure and free recall scores, were collected as well. Results showed that the concurrent multiple-choice and think-aloud data were both significantly correlated with the comprehension scores and with each other, whereas the prospective self-report data had non-significant correlations with all of the other measures. Cromley and Azevedo (2006) recommended using concurrent measures to study strategy use in reading comprehension. On-line methods appear to be more predictive of learning performance relative to off-line methods (Bannert & Mengelkamp, 2008; Sperling, Howard, Miller, & Murphy, 2002; Veenman, 2005). In his review study, Veenman (2005) found that correlations with learning performance range from slightly negative to .36 for off-line measures, and from .45 to .90 for on-line measures. The external validity of on-line measures appears to be better than that of off-line measures. Furthermore, low convergent validity among off-line self-report measures, and high convergent validity among different on-line measures are reported (Veenman, 2005). The relatively high convergent and external validity of online-measures for metacognition led to the use of online-measures in this thesis. In case of thinking aloud, students verbalize their actual, ongoing thoughts during task performance. This requires not only a certain level of (language) development of the students, but also a certain level of task difficulty. If the task is very easy, cognitive processes will be automated and ongoing thoughts will not be verbalized. If the task is too complex, students probably will fall silent. Therefore, if students are quite young or the task is not suitable, the obtained protocols will be rather shallow, that is, incomplete and not very well elaborated. Considering the fact that participants in this thesis are old enough to verbalize their own thoughts, that the tasks are suitable for their age, and that both quantitative and qualitative scores are required, the think-aloud method was appropriate for research in this thesis. Having students thinking aloud during task performance makes it possible to measure metacognitive behavior in the most direct way. Studies by Bannert and Mengelkamp (2008), Ericsson and Simon (1993), and Veenman, Elshout, and Groen (1993) show that using the think-aloud method neither affects the learning process, nor learning performance. Bannert and Mengelkamp interpret this as indirect evidence that thinking aloud does not interfere with metacognition, and therefore, they recommend this type of verbalization as an online-assessment method (2008, p. 54). Veenman (1993) compared students' logfile measures with think-aloud protocols. Results showed that thinking aloud does not interfere with metacognitive processes, although it may slow down those processes a bit.

1.7 Objectives and expectations of this thesis

The first objective of this thesis is to establish whether metacognitive skills will increase in frequency/quantity (QN) and quality (QL) during early adolescence. Based on prior studies (Veenman et al., 2004; Veenman & Spaans, 2005), a linear growth in both the quantity and quality of metacognitve skillfulness is expected. The second objective relates to the development of the relation between metacognitive skills and intellectual ability as predictors of learning performance. It is expected that metacognitive skills develop alongside, but not fully dependent on intellectual ability, in line with the mixed model (Veenman, 1993) and the monotonic development hypothesis (Alexander et al., 1995). As a third, and last objective, the generality vs. domain-specificity of metacognitive skills is investigated over age. In line with results of Veenman and Spaans (2005), it is expected that metacognitive skills tend to generalize along the developmental trajectory.

1.8 Outline of this thesis

In this first chapter (Chapter 1), a theoretical background of the empirical studies conducted as part of this thesis has been given. The four chapters (Chapters 2-5) that report about the empirical studies examined metacognitive skillfulness in young adolescents aged 12 – 15 years. In Chapters 2 – 4, results for each year of a three-year-longitudinal study are reported. Chapter 5 describes the results of a cross-sectional study. The first year of the longitudinal study (Chapter 2), however, is limited to the first two research questions as formulated in section 1.7. Since there were no data of other years available in the first year of the longitudinal study, in Chapter 2, the two main issues were to establish whether metacognitive skills have their own, unique contribution to learning performance on top of intellectual ability, and whether metacognitive skills are general or domain-specific. Chapter 3 and 4 share all three research question (see section 1.7). Since the cross-sectional study (Chapter 5) was restricted to the domain of mathematics, the third research question concerning the generality vs. domain-specificity of metacognitive skills had to be left out. In Chapter 6 some methodological issues are discussed that could not be fully addressed in the articles due to limited space. Finally, in Chapter 7, the findings described in the Chapters 2 – 5 are summarized and discussed. Chapters 2 – 5 have been published in, or submitted to peer-reviewed journals.

To acknowledge the contributions of the co-authors the full references are presented below:

- Van der Stel, M., & Veenman, M.V.J. (2008). Relation between intellectual ability and metacognitive skillfulness as predictors of learning performance of young students performing tasks in different domains. *Learning and Individual Differences, 18*, 128-134. (Chapter 2)

- Van der Stel, M., & Veenman, M.V.J. (2010). Development of metacognitive skillfulness: A longitudinal study. *Learning and Individual Differences,20*, 220-224. (Chapter 3)
- Van der Stel, M., & Veenman, M.V.J. (submitted). Metacognitive skills and intellectual ability of young adolescents: A longitudinal study from a developmental perspective. (Chapter 4)
- Van der Stel, M., Veenman, M.V.J., Deelen, K., & Haenen, J. (2010). The increasing role of metacognitive skills in math: A cross-sectional study from a developmental perspective. *ZDM The International Journal of Mathematics Education, 42*, 219-229. (Chapter 5)

Chapter 2

Relation between intellectual ability and metacognitive skillfulness as predictors of learning performance of young students performing tasks in different domains

Abstract

The first objective of this study was to establish the relation between intellectual ability and metacognitive skillfulness as predictors of learning performance in young students (aged 12 years). Furthermore, the generality vs. domain specificity of metacognitive skillfulness was investigated. Thirty-two first-year secondary-school students participated in this study. While thinking aloud, they performed two different tasks representing two different domains: A text-studying task for history and a problem-solving task for mathematics. Participants' intellectual ability, metacognitive skillfulness, and learning performance were assessed. Results show that metacognitive skillfulness contributed to learning performance (partly) independent of intellectual ability. Results also show that metacognitive skills predominantly appear to be general. Domain-specific metacognitive skills, however, played a substantial, but minor role as well.

2.1 Introduction

"Things are always difficult at first" is heard frequently in education. Nevertheless, some students are more successful in acquiring expertise in a domain than others. Elshout (1983) and Schoenfeld (1983) simultaneously introduced the concept of the 'expert-novice'. These students are able to gain expertise rather rapidly compared to others. Does this rapid progression occur because of their intellectual ability, their metacognitive skills, or because of a combination of both?

This study addresses the issue of how intellectual ability and metacognitive skills contribute to the prediction of learning performance. Furthermore, the generality vs. domain specificity of metacognitive skillfulness is investigated. By using two very different tasks (text studying and problem solving) in widely varying domains (history vs. mathematics) the results of Veenman and Spaans (2005) are further elaborated upon. They found that young secondary-school students have rather strong domain-specific metacognitive skills.

Compared to earlier studies on the generality vs. domain specificity of metacognitive skills (Prins, 2002; Veenman, 1993; Veenman & Beishuizen, 2004; Veenman & Spaans, 2005; Veenman & Verheij, 2003), however, participants in the present study are young students (12 years), and the differences in tasks and domains are maximized.

2.1.1 Intellectual ability

Although researchers diverge in their conceptions of intelligence (see e.g., Brody, 1992; Carroll, 1993; Resnick & Glaser, 1976; Sternberg, 1990), they often relate intelligence to learning. We adopted the rather pragmatic point of view on intelligence from Elshout (1983): Intelligence may be perceived as the magnitude and quality of the human cognitive toolbox, which contains basic cognitive operations. The content of this toolbox is determined by the biological substratum (e.g., hereditary factors or brain damage), but also by the opportunities for acquiring useful cognitive strategies at school or at home (Veenman & Spaans, 2005). In the same vein, Humphreys, (1968, 1989) and Snow (1989; Snow & Lohman, 1984) regard intelligence as the acquired repertoire of intellectual or cognitive skills that is available to a person at a particular point of time.

2.1.2 Metacognitive skillfulness

Since Flavell (1979) introduced the concept 'metacognition', many studies have addressed the issue of the influence of metacognition on learning performance (for an overview, see Wang, Haertel, and Walberg, 1990). Metacognitive *knowledge* refers to the declarative knowledge one has about the interplay between personal characteristics, task characteristics, and available strategies in a learning situation (Flavell, 1979), while metacognitive *skills* concern the procedural knowledge that is required for the actual regulation of, and control over one's learning activities (Brown & DeLoache, 1978). Task analysis, planning, monitoring, checking and recapitulation are manifestations of such skills. An interesting question is whether metacognitive skills are part of the intellectual toolbox or repertoire; or as Slife, Weiss, and Bell (1985) formulated …"whether metacognition can be reduced to cognition".

2.1.3 Relation between intellectual ability, metacognitive skillfulness, and learning performance

Veenman (1993; Veenman & Beishuizen, 2004; Veenman, Elshout, & Meijer, 1997; Veenman & Verheij, 2003;) described three, mutually exclusive models concerning the relation between intellectual ability and metacognitive skillfulness as predictors of learning performance. The *intelligence* model regards metacognitive skillfulness as an integral part of intellectual ability. In this model metacognitive skillfulness does not contribute to learning performance on top of intellectual ability. According to this model, metacognitive skills cannot have a predictive value for learning performance independent of intellectual ability. The second, contrasting model is the *independency* model, in which intellectual ability and metacognitive skillfulness are regarded as entirely independent predictors of learning performance. Finally, in the *mixed* model intellectual ability and metacognitive skillfulness are correlated, but they also have their own, unique contribution to the prediction of learning performance.

Over the last decades, support has been found for each of these models (for an overview, see Veenman & Spaans, 2005; Veenman, Wilhelm & Beishuizen, 2004). Many studies, however, are difficult to compare, due to dissimilarities in assessing metacognitive skillfulness (thinking aloud, observation, questionnaires), in participants (age, level of intellectual ability), and in tasks and domains. Moreover, the focus of some studies is restricted to the relation between intellectual ability and metacognitive skillfulness, thereby excluding the relation of both predictors with learning performance. The evidence found seems to be highly in favor of the mixed model, but many of these studies concerned the metacognitive skillfulness of older secondary-school or university students. It remains to be ascertained more thoroughly whether the mixed model can be generalized to younger students with less developed metacognitive skills, performing different tasks in different domains (see Veenman & Spaans, 2005; Veenman et al., 2004).

Therefore, the first objective of the present study is to establish the relation between intellectual ability and metacognitive skillfulness as predictors of learning performance in young students. We hypothesize that the mixed model can be generalized to first-year secondary-school students, regardless of tasks or domains.

2.1.4 Generality vs. domain specificity of metacognitive skillfulness

A second objective of this study is to establish whether metacognitive skillfulness is general (i.e., domain independent), or domain specific. Earlier studies concerning this issue have yielded contradictory results. On the one hand, researchers have found evidence for general, domain-independent metacognitive skills (Schraw, Dunkle, Bendixen, & Roedel, 1995; Schraw & Nietfeld, 1998; Veenman & Beishuizen 2004; Veenman & Verheij 2003; Veenman et al., 1997, 2004). Despite this considerable number of studies with comparable results, it should be kept in mind that participants, tasks, and domains varied substantially. On the other hand, other reseachers (De Jong, 1992; Glaser, Schauble, Raghavan, & Zeitz, 1992; Kelemen, Frost, & Weaver, 2000) found evidence against a general metacognitive ability.

Veenman et al. (2004) found support for the generality of metacognitive skills among young students (9- to 22-year olds) performing discovery-learning tasks in different domains. Recently, this support for young students' general metacognitive skills could not be corroborated by a study of Veenman and Spaans (2005). In this study 12- and 15-year olds performed two tasks in different domains (solving math word problems and an inductive-learning task for biology). Metacognitive skills of the younger students appeared to be rather domain-specific, whereas those of the older ones turned to be general by nature.

Based on earlier studies, the onset of metacognitive *skill* development for academic tasks is not to be expected before the age of 8 – 10 years (Alexander, Carr, & Schwanenflugel, 1995; Berk, 2006; Kuhn, 1999; Siegler, 1998; Veenman, et al., 2004). The academic metacognitive skills of 12-year olds are still premature and developing, which may explain why these skills may diverge on notably different tasks.

Participants in the present study are rather young and inexperienced in applying academic metacognitive skills. Therefore, we expect their metacognitive skills to be in a transitory phase of development. We hypothesize that children, slightly over the age of 12 years, will use general as well as domain-specific metacognitive skills. In order to allow domain-specific metacognitive activities, the differences in tasks and domains were maximized (see section 2.2.3).

2.2 Method

2.2.1 Participants

Thirty-two first-year secondary-school students (12 boys, 20 girls; average age 12 years and 8 months) participated in this study. They were recruited from 85 students of three different tracks (pre-university education, higher general education and pre-vocational education)[1] of an urban school in the Netherlands.

A history pretest was administered to all 85 students. This test consisted of 16 multiple-choice questions about American history (Cronbach's alpha = .71). Students were instructed not to guess the right answer. The pretest was administered for reasons of selection and played no further role in data analysis. One boy was excluded from further participation due to prior knowledge of the topic, that is, he correctly answered more than 75% of the 16 MC questions. Next, 40 participants were selected out of the remaining 84 students on their intellectual ability (see section 2.2.2). Eight low intelligent students, however, were excluded from the study due to learning or conduct disorders (e.g., dyslexia or ADHD). The mean score on the history pretest for the remaining 32 participants was 4.0 (*sd* = 2.4), i.e., 25% of the maximum score. For mathematics no pretest was administered. Here students need a certain amount of lower-level mathematics knowledge in order to solve more complex problems.

Consent was requested from and given by the participants' parents. After completing the tasks, participants received a small financial reward for their participation.

2.2.2 Intellectual ability

The intellectual ability of 84 students was assessed by a series of ability tests. Three subtests from the Groninger Intelligence test for Secondary Education (GIVO, standardized Dutch intelligence test; Van Dijk & Tellegen, 1994) were selected: Number Series, Verbal Analogies and Unfolding Figures. With these subtests a number of the primary intelligence factors (Carroll, 1993) is assessed: Inductive and deductive reasoning abilities, both verbal and quantitative, and visuospatial ability.

The GIVO, however, lacks a test for assessing memory abilities, another primary factor in Carroll's (1993) model highly relevant to text studying. Therefore, a fourth test (Names & Professions; see Veenman & Beishuizen, 2004) was added. An overall Intellectual Ability score was obtained by transforming the scores on all tests into z-scores and then calculating the mean z-score (Cronbach's alpha = .76).

[1] In Dutch: VWO, HAVO and VMBO-T respectively

To guarantee sufficient variance in intellectual ability the median of the Intellectual Ability scores was calculated and participants were denominated as high (1^{st} quartile), average (2^{nd} and 3^{rd} quartile) or low (4^{th} quartile) in intelligence. Finally, 13 high, 13 average and 6 low intelligent students were selected as participants. In the 4^{th} quartile there were relatively many students with learning or conduct problems. That is the reason why only six students could be selected as participants in the low range of intelligence.

2.2.3 Tasks

Students performed two different tasks representing two different domains. One task was a text-studying task in the domain of history and the other one was a problem-solving task in the domain of mathematics.

2.2.3.1 History task

In an individual session of 50 minutes, participants were asked to study a history text in the same way as they usually do when preparing for a test. They had to read aloud and think aloud while reading the text and answering the questions or assignments embedded in the text. Participants were allowed to study the text for 30 minutes and in the remaining 20 minutes the post-test was administered (see section 2.2.5).

The history text was composed of parts from two of the most frequently used Dutch schoolbooks for history: "MeMo" (Van Boxtel & Schrover, 1998) and "Sprekend verleden" (Buskop, Dalhuisen, & Geest, 1998). To avoid prior knowledge of the subject on the one hand, and to appeal to the zone of tolerable difficulty on the other hand, the text was based on a subject of the second-year curriculum, instead of the first-year curriculum.

The text about slavery and the civil war in the United States of America contained 76 concepts and 1479 words. In the text, three questions or assignments were embedded. These questions were not meant for testing the students' knowledge, but to elicit (more) metacognitive activities (e.g., 'There are several reasons why the north and the south were at war with each other. Describe in your own words at least two of these reasons'). From a pilot-study we learned that if a text does not contain such questions, many participants just tend to read linearly.

2.2.3.2 Mathematics task

In another individual session of 50 minutes, participants had to solve five mathematical word problems in 20 minutes. Several categories of problems were presented (e.g., distance, fraction, surface area, percentage problems). For instance, a fraction problem was 'My brother received two bags of marbles. Each bag contains 48 marbles in four different colors: 1/6 is yellow; 3/8 is blue; 1/3 is green and the rest is red. Of which color does my brother have most marbles?' Together with the assignments, participants received a sheet containing the answers and a brief stepwise explanation of how to solve the problems. Participants were free to consult this sheet whenever and as much as they liked. The first 20 minutes were considered as a learning-by-doing phase. Next, the participants handed in all materials and received another series of five parallel problems, which had to be solved without any help in the remaining 30 minutes. This second part is considered as a post-test assessment of learning performance (see section 2.2.5). All problems had to be solved while thinking aloud.

2.2.4 Metacognitive skillfulness

The transcribed thinking-aloud protocols for both tasks were analyzed on spontaneous use of metacognitive skills according to the procedure of Veenman (1993; Veenman & Beishuizen, 2004; Veenman, Kerseboom, & Imthorn, 2000). Metacognitive skillfulness was divided into four subscales: Orientation (O), Planning and Systematic orderliness (P), Evaluation (Ev), and Elaboration (El). Some metacognitive activities are general across both tasks and domains, whereas other metacognitive activities seem to be more domain-specific (see Table 2.1).

To obtain a reliable score for metacognitive skillfulness, scoring criteria were formulated for both tasks. For each subscale it was described which criteria should be met in order to receive a certain rate for the quality[2] of metacognitive skillfulness. This resulted in a method, which allowed assessing general as well as domain-specific metacognitive activities. The scoring method consisted of two steps for each protocol. First, each utterance was coded in the margin as belonging to one of the four subscales (O, P, Ev or El). Secondly, each subscale received a qualitative score according to the formulated criteria. This score was a total score per subscale per protocol. A five-point scale (ranging from 0 to 4)[3] was used for each subscale. It was the quality, not merely the quantity of metacognitive activities that determined the scores. For example, a participant received a higher score for 'deeper' Elaboration (e.g., drawing a conclusion

[2] The data in the tables relate to the quality of metacognitive skillfulness. The same analysis was performed with the quantitative scores of metacognitive skillfulness. Quantitative scores were obtained by counting the frequency of metacognitive activities of each subscale (e.g., if a student evaluated five times, his quantitative Evaluation score was five).The results are comparable with the results of the qualitative data. They follow the same pattern, but are somewhat less pronounced.

[3] Results of a CatPCA (formerly PRINCALS) show that it is permitted to treat the scores for metacognitive skills as interval variables.

in one's own words) than for a superficial one (e.g., summarizing a paragraph almost literally).

Table 2.1 Examples of domain-specific and general metacognitive activities

	History-specific	Math-specific	General
Orientation			
a.			Activating prior knowledge
b.			Goal setting
c.	Predicting the content of the text	Estimating the answer	
d.	Reading titles of paragraphs prior to reading the entire text	Making a sketch of the problem in order to represent the problem	
Planning & systematic orderliness			
a.			Subgoaling
b.			Time management
c.	Designing a reading plan and deciding upon which text parts to pay attention to	Designing a step-by-step action plan, instead of working by trial-and-error	
d.	Note taking (self-instruction for doing so)	Writing down calculations step by step	
Evaluation			
a.			Expressing non-understanding
b.			Comment on own activities
c.	Monitoring text comprehension during reading	Monitoring action plan	
d.	Self-correction after rereading (parts of) the text	Checking an answer by recalculating	
Elaboration			
a.			Recapitulating and drawing conclusions
b.			Relating the answer to the question or problem
c.	Paraphrasing (parts of) the text	Paraphrasing the problem	
d.	Summarizing (self-instruction for doing so); Making inferences during reading	Drawing conclusions while referring to the problem statement	

It is important to emphasize that the judges intentionally avoided the confounding of metacognition scores by the correctness or incorrectness of the content matter. So, an incorrect, but highly elaborated conclusion could equally generate a high score for 'Elaboration' as long as it was in line with the participant's own reasoning.

For each task Cronbach's alpha was calculated over the four subscales: (History .72; Mathematics .83). Sum scores on the subscales were calculated, representing the quality of metacognitive skillfulness for each task. Furthermore, six protocols for each task were simultaneously rated by two judges. This resulted in an alpha interrater reliability of .97 for history and .89 for math.

2.2.5 Learning performance

After the learning phase of both tasks, the learning performance of participants was assessed by a post-test, as was explained to them in advance. For history the post-test consisted of five multiple-choice questions and six essay questions. The MC questions assessed reproductive knowledge (facts and dates, e.g., 'when did the Americans officially abolish slavery?') and the essay questions were meant to assess overall text comprehension (e.g., 'Explain in your own words why Lincoln changed his opinion about slavery several times'). Participants were not allowed to consult the text or their notes while answering the questions.

According to a rating system, points were given for the correctness of answers to each question. MC questions could render one point, while essay questions could render a maximum of four points. A total score was calculated and used as a measure of learning performance in history (Cronbach's alpha = .58).

For math a post-test with five math word problems was administered. For each of the five math post-test problems an equal amount of points could be earned: two points if both the procedure and the answer was correct; one point if either one of them was correct; and zero points if neither of them was correct. A total score was calculated and used as a measure of learning performance in mathematics (Cronbach's alpha = .71).

2.2.6 Procedure

The intellectual-ability test and the history pretest were administered during a group session of 100 minutes. The individual sessions took place during school time. The experiment had a counterbalanced design with respect to task order, meaning that 16 students started with history and 16 students with mathematics. Participants could make use of a pen, pencil, text highlighter, ruler, calculator, and blank sheets of paper for making notes.

All participants were instructed to think aloud while working on both tasks. The experimenter was not allowed to help the students in any way. To encourage the student to keep on thinking aloud the experimenter used standard prompts (e.g., 'please, keep on thinking aloud') whenever the student fell silent. All the utterances of the participants were audio-taped, transcribed, and analyzed in relation to metacognitive skillfulness.

2.3 Results

All participants (*N* = 32) performed the tasks, so there are no missing values in the data.In Table 2.2 the means and standard deviations of the Learning measure and Metacognitive skillfulness for both tasks are depicted, as well as the maximum obtainable score.

Table 2.2 Means and standard deviations

	Mean	Std. deviation	Maximum score
MetatotHis*	5.03	3.40	16.0
Learning measureHis	8.47	3.28	20.0
MetatotMath*	6.09	3.31	16.0
Learning measureMath	4.44	2.54	10.0

**Note*: MetatotHis means the total score on the quality of metacognitive activities during history task; MetatotMath means the total score on the quality of metacognitive activities during math task.

2.3.1 Relation between intellectual ability, metacognitive skillfulness and learning performance

Correlations between intellectual ability, metacognitive skillfulness, and learning performance on both tasks were calculated (see Table 2.3). As far as the math task is concerned, Intellectual ability correlated significantly with both Metacognitive skillfulness and the Learning measure. The same applies for the correlation between Metacognitive skillfulness and the Learning measure for math. The results on the history task differ partly from the results on the math task. A significant correlation was found between Intellectual ability and the Learning measure, but the correlation between Intellectual ability and Metacognitive skillfulness was not significant. Metacognitive skillfulness, however, correlated significantly with the Learning measure for history.

Table 2.3 Correlations between Intellectual ability, Metacognitive skills and Learning performance for both history and mathematics

	Intellectual ability	MetatotHis	Learning measureHis	MetatotMath
MetatotHis	.27			
Learning measureHis	.40*	.65**		
MetatotMath	.62**	.35*	.38*	
Learning measureMath	.75**	.27	.49**	.72**

* $p < 0.05$ ** $p < 0.01$

To determine whether correlations for both tasks deviate significantly from each other, Fisher-*z* ratios were calculated (Guilford, 1965). There is no difference in correlations between both tasks as long as Metacognitive skillfulness is involved (Fisher-*z* ratio = 1.71, n.s., for the correlations between Intellectual ability and Metacognitive skillfulness, and 0.50, n.s., for the correlations between Metacognitive skillfulness and Learning measures). Intellectual ability, however, plays a more important role in predicting the learning performance for mathematics relative to history (Fisher-*z* ratio = 2.09, $p < 0.05$).

Next, semi-partial correlations (Nunnally, 1967) were calculated by partialing Metacognitive skillfulness from the correlation between Intellectual ability and the Learning measure (i.e., semi-partIntel) and partialing Intellectual ability from the correlation between Metacognitive skillfulness and the Learning measure (i.e., semi-partMeta). These semi-partial correlations (see Table 2.4) are needed to calculate the unique, independent contribution of Metacognitive skillfulness and Intellectual ability to the Learning measures.

Table 2.4 Semi-partial correlations

	Semi-partIntel	Semi-partMeta
Learning measureHis	.23	.53**
Learning measureMath	.39**	.33**

**$p < 0.01$

Using regression-analytic techniques (Pedhazur, 1982; Veenman, 1993; Veenman & Verheij, 2003; Veenman & Spaans, 2005) the unique and shared proportions of variance in the Learning measures were distributed to Metacognitive skillfulness and Intellectual ability (see Table 2.5). The math data could be taken as an example. The squared multiple correlation of Intellectual ability and Metacognitive skillfulness for predicting Learning measure in math was calculated from the correlations presented in Table 2.3 and 2.4 (R^2 = the squared correlation between Intellectual ability and Learning measure + the squared semi-partial correlation between Metacognitive skillfulness and Learning measure with Intellectual ability partialled out = $.75^2 + .33^2 = .671$). The unique contribution of Intellectual ability to Learning measure was determined by calculating the squared semi-partial correlation between Intellectual ability and Learning measure with Metacognitive skillfulness partialled from Intellectual ability ($r^2 = .152$). Consequently, it was estimated that Intellectual ability uniquely accounted for 15.2% of the variance in Learning measure for math, Metacognitive skillfulness uniquely accounted for 10.9% of the variance, while both predictors had another 41.0% of variance in common. This procedure was applied to both tasks (see Table 2.5).

Table 2.5 Percentage of variance accounted for in Learning measures

	Intel unique	Meta unique	Shared	Total
History	5.2	28.0	10.8	44.0
Math	15.2	10.9	41.0	67.1

Note: Intel unique means the unique contribution of Intellectual ability to Learning measure; Meta unique means the unique contribution of Metacognitive skillfulness to Learning measure; Shared means the shared contribution of Intellectual ability and Metacognitive skillfulness to Learning measure.

The history results in Table 2.5 show that, despite the variance shared with Intellectual ability, Metacognitive skillfulness substantially added to the prediction of Learning measure in history on top of Intellectual ability. In fact, the unique contribution of Metacognitive skillfulness outweighed the unique contribution of Intellectual ability to Learning measure in history.

2.3.2 Metacognition across domains

A principal component analysis (PCA) with a two-factor solution was performed on the four subscales of metacognitive skillfulness for both tasks (see Table 2.6).

Table 2.6 Unrotated component matrix for metacognitive skillfulness

	Component 1	Component 2
Eigenvalue	3.35	1.71
Variance proportion	.42	.21
metaorientationHis	.41	.21
metaplanningHis	.63	.64
metaevaluationHis	.47	.44
metaelaborationHis	.68	.51
metaorientationMath	.65	-.48
metaplanningMath	.76	-.32
metaevaluationMath	.58	-.67
metaelaborationMath	.87	-.13

The results of the unrotated PCA show that all measures of metacognitive skillfulness substantially load on the first component. This component has an eigenvalue of 3.35 and a variance proportion of .42. Although component loadings are not extremely high, ranging from .41 to .87, this first component may be interpreted as representing general metacognitive skills across the two tasks/domains. On the other hand, we find contrasted loadings in the second component, that is, positive loadings for history and negative ones for math. This points in the direction of a component representing domain-specific metacognitive skills. With an eigenvalue of 1.71 and a variance proportion of .21 this second component cannot be ignored.

2.4 Discussion

This study investigated the relation between intellectual ability and metacognitive skillfulness as predictors of learning performance in young learners. As was expected, results corroborate the mixed model. First, intellectual ability and metacognitive skillfulness are moderately correlated. Moreover, both intellectual ability and metacognitive skillfulness have their own, unique contribution to learning performances on both tasks. These results are similar to results for older age groups obtained in other studies (Veenman, 1993; Veenman & Beishuizen, 2004; Veenman & Verheij, 2003; Veenman et al., 2004). Therefore, the mixed model can be generalized to twelve-year-olds, although the small number of participants may be considered as a possible limitation of this study.

The second research question concerned the generality vs. domain specificity of metacognitive skillfulness. The PCA on the metacognitive data shows a two-component solution: A first component, which can be interpreted as general metacognitive skills, and a second component, which can be interpreted as domain-specific metacognitive skills. Results support our expectation that metacognitive skills of 12 year old students represent a general as well as a domain-specific component. This may indicate that these students are in a transitory phase of metacognitive-skill development. Veenman and Spaans (2005) assumed that metacognitive skills initially develop on separate islands of tasks and domains. Beyond the age of 12, these skills will gradually merge into a more general repertoire that is applicable and transferable across tasks and domains. Among 12-year olds a phase of transition is characterized by applying recently acquired general metacognitive skills, along with a remainder of domain-specific metacognitive skills.

From a developmental perspective, it is interesting to know more about the development of metacognitive skillfulness. On the one hand, the development of metacognitive skills in relation to intellectual ability as predictors of learning performance. On the other hand, the development of the nature of metacognitive skills (general vs. domain-specific). A longitudinal study will offer the opportunity to investigate these aspects of metacognitive development. The present study is the first part of a longitudinal project, where the same students will be followed for three consecutive years.

Chapter 3

Development of metacognitive skillfulness: A longitudinal study

Abstract

This study shows the results of a two-year longitudinal study where the same participants were followed for two consecutive years as they enter secondary school (aged 12 – 14 years). The main issue was to investigate the development of both the quantity and the quality of metacognitive skills. Another issue was to establish whether the development of metacognitive skillfulness is intelligence-related or relatively intelligence-independent. Finally, the generality vs. domain specificity of developing metacognitive skillfulness was investigated. Thirty-two secondary-school students participated in this study. While thinking aloud they performed two different tasks representing two different domains: A text-studying task for history and a problem-solving task for math. Participants' intellectual ability, metacognitive skillfulness and learning performance were assessed. Results show a quantitative as well as a qualitative growth in metacognitive skillfulness. Furthermore, results of both years show that metacognitive skillfulness contributed to learning performance (partly) independent of intellectual ability. A parallel development of metacognitive and intellectual ability was found. Finally, metacognitive skills predominantly appear to be general. Domain-specific metacognitive skills, however, played a substantial, but minor role as well in both years. Instructional implications are being discussed.

3.1 Introduction

Since Flavell (1979) introduced the concept 'metacognition', many studies have addressed the issue of the influence of metacognition on learning performance. Based on a review of studies, Wang, Haertel, and Walberg (1990) concluded that metacognition is the most important predictor of learning performance. Our study focuses on the development of metacognitive skills: What components develop when? Is the development of metacognitive skills dependent on (or part of) the development of intellectual ability? Are developing metacognitive skills general or domain specific by nature. Answers to these questions could contribute to our understanding of the development of metacognitive skills and the educational consequences.

3.1.1 Metacognitive skillfulness

Metacognitive skills concern the *procedural* knowledge that is required for the actual regulation of, and control over one's learning activities (Brown & DeLoache, 1978; Veenman, Elshout, & Meijer, 1997). Metacognitive skills can be inferred from overt behavior or utterances by the student, i.e., from concrete metacognitive activities. Examples of metacognitive activities are given in Table 3.1.

Several studies (Bowen, Shore, & Cartwright, 1992; Brown, 1980; Christoph, 2006; Markman, 1977, 1979; Mevarech & Fridkin, 2006; Pressley & Afflerbach, 1995; Schoenfeld, 1992; Shore & Lazar, 1996) have focused on the use of metacognitive skills while performing different tasks (e.g., reading comprehension or problem solving). This study, however, includes both problem-solving and text-studying tasks focusing on both the quantity (frequency of applying metacognitive skills) and the quality of these skills (the depth, e.g., drawing a conclusion in one's own words is considered as a deeper elaboration than summarizing almost literally). In line with Veenman, Wilhelm, and Beishuizen (2004), we expect metacognitive skills to increase in frequency as well as in quality over the years (hypothesis 1).

A related research issue is whether the development of metacognitive skills is intelligence-related or relatively intelligence-independent. Several researchers (Alexander, Carr, & Schwanenflugel, 1995; Borkowski & Peck 1986; Schneider & Pressley, 1997; Veenman & Spaans, 2005; Veenman, et al., 2004) investigated metacognitive skills in relation to intellectual ability.

3.1.2 Relation between intellectual ability, metacognitive skills, and learning performance from a developmental perspective

Veenman (Veenman & Beishuizen, 2004; Veenman et al., 1997) described three models concerning the relation between intellectual ability and metacognitive skillfulness as predictors of learning performance. Over the last decades, support has been found for each of these models (for an overview, see Veenman & Spaans, 2005; Veenman et al., 2004). The evidence found so far seems to be highly in favor of the *mixed model*. In this model intellectual ability and metacognitive skillfulness are correlated, but metacognitive skillfulness has its own, unique contribution to the prediction of learning performance, on top of intellectual ability. Because many studies concerned the metacognitive skillfulness of older students, it remains to be ascertained more thoroughly whether the mixed model can be generalized to younger students with initially developing metacognitive skills. Furthermore, the role of intellectual ability in the *development* of metacognitive skills will be addressed in this study. Alexander et al. (1995) formulated three developmental hypotheses with regard to the relation between intelligence and the development of metacognition. The *monotonic development hypothesis* assumes that both intelligence and metacognition show a monotonic growth over age. Finding such a parallel development would support the monotonic development hypothesis. We hypothesize that metacognitive skillfulness develops alongside, but not fully dependent on intellectual ability, regardless of tasks and domains. Therefore, we expect to find a parallel development of metacognitive skillfulness and intellectual ability *as predictors* of learning performance in line with the mixed model and the monotonic development hypothesis (hypothesis 2).

3.1.3 Metacognitive skillfulness across domains

Another objective of this study was to establish whether metacognitive skillfulness is general, or domain specific. From a developmental and an instructional perspective, it is relevant to know how metacognitive skills develop: Whether they develop from being general into becoming domain specific or the other way around? Earlier studies yielded contradictory results (Schraw, Dunkle, Bendixen, & Roedel, 1995; Schraw & Nietfeld, 1998; Veenman & Beishuizen 2004; Veenman & Verheij 2003; Veenman et al., 1997, 2004; De Jong, 1992; Glaser, Schauble, Raghavan, & Zeitz, 1992).

Based on earlier studies, the onset of metacognitive *skill* development for academic tasks is not to be expected before the age of 8-10 years (Alexander et al., 1995; Berk, 2006; Kuhn, 1999; Siegler, 1998). The academic metacognitive skills of 12-year olds are still premature and developing, which may explain why these skills may diverge on notably different tasks (Veenman & Spaans, 2005). Participants in the present study are rather young and inexperienced in applying academic metacognitive skills. Therefore, we expect their metacognitive skills to be in a transitory phase of development. We hypothesize that the participants will initially use general as well as domain-specific metacognitive skills. We also hypothesize that the initially acquired domain-specific metacognitive skills tend to generalize during further development. Therefore, we expect older students to resort less to domain-specific metacognitive skills than younger students (hypothesis 3).

3.2 Method

3.2.1 Participants

In the first year of this longitudinal study, 32 first-year secondary school students (12 boys, 20 girls; average age 12 years and 8 months) participated. They were selected on their intellectual ability from 85 students of a school in the Netherlands (section 3.2.3). This school is known because of its large diversity of children, thus representing a broad educational level of the students, a broad range of social economic status of parents, and various ethnic backgrounds. We have chosen not to work with more than one school in order to avoid confounding variables, such as differences in teachers, pedagogical/didactic philosophy, schoolbooks, etc. Students with learning or conduct disorders (e.g., dyslexia or ADHD) were excluded from the study. In the second year we lost four students due to changing residence. The remaining 28 students (10 boys, 18 girls; average age 13 years and 8 months) participated in the second year.

3.2.2 Metacognitive skillfulness

Thinking-aloud protocols were analyzed according to the procedure of Veenman (Prins, Veenman, & Elshout, 2006; Van der Stel & Veenman, 2008; Veenman & Beishuizen, 2004;). Metacognitive skillfulness was divided into four subscales: Orientation (O), Planning and Systematic orderliness (P), Evaluation (Ev), and Elaboration (El). In Table 3.1 general metacognitive activities across both tasks and domains and more specific metacognitive activities for text studying and problem solving are described (Meijer, Veenman, & Van Hout-Wolters, 2006; Pressley, 2000; Pressley & Afflerbach, 1995).

Table 3.1 Examples of domain-specific and general metacognitive activities

	History-specific	Math-specific	General
Orientation			
a.			Activating prior knowledge
b.			Goal setting
c.	Predicting the content of the text	Estimating the answer	
d.	Reading titles of paragraphs prior to reading the entire text	Making a sketch of the problem in order to represent the problem	
Planning & Systematic orderliness			
a.			Subgoaling
b.			Time management
c.	Designing a reading plan and deciding upon which text parts to pay attention to	Designing a step-by-step action plan, instead of working by trial-and-error	
d.	Note taking (self-instruction for doing so)	Writing down calculations step by step	
Evaluation			
a.			Expressing non-understanding
b.			Comment on own activities
c.	Monitoring text comprehension during reading	Monitoring action plan	
d.	Self-correction after rereading (parts of) the text	Checking an answer by recalculating	
Elaboration			
a.			Recapitulating and drawing conclusions
b.			Relating the answer to the question or problem
c.	Paraphrasing (parts of) the text	Paraphrasing the problem	
d.	Summarizing (self-instruction for doing so); Making inferences during reading	Drawing conclusions while referring to the problem statement	

The scoring method consisted of two steps. First, an utterance was coded in the margin if belonging to one of the subscales (O, P, Ev or El). This resulted in a quantitative score obtained by counting the frequency of metacognitive activities on each subscale. Secondly, a score for the quality of metacognitive skillfulness was judged from the protocols. To obtain a reliable score for the quality of metacognitive skillfulness, scoring criteria were formulated. A five-point scale (ranging from 0 to 4)[4] was used to score the quality of each subscale.

In both years, 6 protocols of each task were rated by two judges separately. Since the inter-rater reliability[5] was high, the remaining protocols were analyzed and rated by one judge.

3.2.3 Intellectual ability

In both years, intellectual ability was assessed. Three subtests from the Groninger Intelligence test for Secondary Education (GIVO, standardized Dutch intelligence test; Van Dijk & Tellegen, 1994) were selected: Number Series, Verbal Analogies and Unfolding Figures. A fourth test (Names & Professions, requiring the memorization of word pairs; Veenman & Beishuizen, 2004) was added to assess memory abilities. In both years, the intellectual ability score was obtained by transforming the scores on each test into z-scores and then calculating the mean z-score for each participant.

3.2.4 Tasks

To ensure the novelty of tasks, each year participants were given *new* tasks with task demands adapted to their age. All tasks were piloted beforehand. In order to allow domain-specific metacognitive activities, the differences in tasks and domains were maximized.

3.2.4.1 History task

In an individual session of 50 minutes, participants were asked to study a history text in the same way as they usually do when preparing for a test. They were also asked to read and think aloud. Participants were allowed to study the text for 30 minutes. In the remaining 20 minutes the post-test was administered (section 3.2.5). In both years, three activating questions or assignments were embedded in the text. These were not meant for testing the students' knowledge, but to elicit (more) metacognitive activities. From a

[4] Results of a CatPCA show that it is permitted to treat the scores for metacognitive skills as interval variables.

[5] The mean inter-rater reliability score for math and history for both years was .90.

pilot-study (Meijer, Veenman, & Van Hout-Wolters, 2006) we learned that if a text does not contain such activating questions, many participants just tend to read linearly.

3.2.4.2 Mathematics task

In another thinking-aloud session of 50 minutes, participants practiced to solve mathematical word problems in 20 minutes. Together with the assignments, participants received a sheet containing the answers and a brief stepwise explanation of how to solve the problems. Participants were free to consult this sheet whenever and as much as they liked. The first 20 minutes were considered as a learning-by-doing phase. Next, the participants handed in all materials and received another series of parallel problems, which had to be solved without any help in the remaining 30 minutes. This second part is considered as a post-test assessment of learning performance (section 3.2.5).

3.2.5 Learning performance

Both post-tests for history consisted of five multiple-choice questions (facts and dates) and six essay questions (text comprehension). A total score was calculated and used as a measure of learning performance in history (Cronbach's alpha was .58, 1^{st} year and .51, 2^{nd} year).

For math, post-tests with five (1^{st} year) and six (2^{nd} year) math word problems were administered (Cronbach's alpha = .58, 1^{st} year and .69, 2^{nd} year). A total score was calculated and used as a measure of learning performance in math. In both years, the post-test items were parallel to the items in the learning tasks, that is, the surface structure of the post-test items differed from the one of the learning-task items, but the deep structure was the same.

3.3 Results

3.3.1 Development of metacognitive and intellectual abilities

MANOVAs were performed on the intellectual ability and metacognition scores with age as a within factor. The multivariate within-subjects effect on the intellectual ability scores was [$F(4,24) = 11.74$, $p < .001$, $\eta^2 = .66$]. 14-year-olds had a higher intelligence score than 13-year-olds. Anova on the quality of metacognitive skillfulness also revealed a significant age effect [$F(8,20) = 6.77$, $p < .001$, $\eta^2 = .73$]. The same tests were performed on the quantitative scores of metacognitive skillfulness. Again a significant age effect was found [$F(8,20) = 5.28$, $p < .001$, $\eta^2 = .68$][6]. 14-year-olds exhibited more and better metacognitive activities than 13-year-olds.

Separate univariate tests on the metacognitive and intellectual ability data show which subscale scores increased significantly between the first and the second year (Table 3.2). No effect was found for gender and/or ethnic background.

Table 3.2 Tests of Within-Subjects Contrasts (13 vs. 14 yrs.)

	F	Sig.
Verbal analogies	22.96	.000
Unfolding figures	16.21	.000
Memory	6.45	.017
MetaqlMathP	7.56	.011
MetaqlHistEv	9.71	.004
MetaqnMathO	25.86	.000
MetaqnMathP	14.18	.001
MetaqnMathEv	8.32	.008
MetaqnMathEl	22.38	.000
MetaqnMathTot	32.00	.000
MetaqnHistEv	9.15	.005

Note: MetaqlMathP means the score on the quality of planning activities for math; MetaqlHistEv means the score on the quality of evaluation activities for history; MetaqnMathO means the score on the quantity of orientation activities for math; MetaqnMathP means the score on the quantity of planning activities for math; MetaqnMathEv means the score on the quantity of evaluation activities for math; MetaqnMathEl means the score on the quantity of elaboration activities for math; MetaqnMathTot means the total score on the quantity of metacognition for math; MetaqnHistEv means the score on the quantity of evaluation activities for history.

3.3.2 The monotonic development hypothesis

To determine whether developmental processes affect the relation between intellectual ability (IA) and metacognition (Meta) as predictors of learning performance (LP), the results of both years were compared (Table 3.3).

[6] Because the quantitative metacognitive scores were positively skewed, loglinear and square root transformations on the data were performed. This did not alter the results.

Table 3.3 Correlations and semi-partial correlations

	IA	Meta	Semi-PartIA	Semi-PartMeta
Quality				
LP Math13	.79**	.74**	.39*	.33*
Meta Math13	.65**			
LP Math14	.57**	.74**	.22	.52**
Meta Math14	.51**			
LP History13	.42*	.66**	.23	.53**
Meta Hist13	.27			
LP History14	.25	.36	.17	.33*
Meta Hist14	.32			
Quantity				
LP Math13		.76**	.37*	.30*
Meta Math13	.69**			
LP Math14		.42*	.47**	.28*
Meta Math14	.27			
LP History13		.57**	.31*	.50**
Meta Hist13	.20			
LP History14		.24	.24	.22
Meta Hist14	.21			

Note: LP means Learning performance * $p < .05$, ** $p < .01$

As far as the math task concerned intellectual ability correlated significantly with both the quality of metacognitive skillfulness and the learning measure in both years. The same applies for the correlation between the quality and the quantity of metacognitive skillfulness on the one hand, and the learning performance for math on the other. Intellectual ability and the quantity of metacognition in math correlated significantly among 13-year-olds only. The results on the history task differ partly from the results on the math task. Only in the first year a significant correlation was found between intellectual ability and the learning performance. The same applies for the correlation between the quantity of metacognitive skillfulness and the learning performance. The correlation between the metacognitive quality and the learning performance was significant in both years.

In order to test the mixed model the semi-partial correlations (Nunnally, 1967) were calculated (Table 3.3) by partialling Metacognitive skillfulness from the correlation between Intellectual ability and the Learning performance (i.e., semi-partIA) and partialling Intellectual ability from the correlation between Metacognitive skillfulness and the Learning performance (i.e., semi-partMeta). Next, the unique, independent contribution of Metacognitive skillfulness and Intellectual ability to the Learning performance was calculated. Using regression-analytic techniques (Pedhazur, 1982; Veenman & Spaans, 2005) the unique and shared proportions of variance in the learning performance were distributed to metacognitive skillfulness and intellectual ability (Table 3.4).

Table 3.4 Percentage of variance accounted for in Learning performance

	Intel unique		Meta unique		Shared		Total	
	QL	**QN**	**QL**	**QN**	**QL**	**QN**	**QL**	**QN**
History 13	5.2	9.7	28.0	24.6	10.8	7.9	44.0	42.2
History 14	2.9	5.5	11.3	5.0	5.3	1.0	19.5	11.3
Math 13	15.2	13.5	10.9	8.8	41.0	48.9	67.1	71.2
Math 14	5.1	22.2	27.3	7.9	27.2	10.1	59.6	40.2

Note: Intel unique means the unique contribution of Intellectual ability to Learning performance; Meta unique means the unique contribution of Metacognitive skillfulness to Learning performance; Shared means the shared contribution of Intellectual ability and Metacognitive skillfulness to Learning performance. Total means the total contribution of Intellectual ability and Metacognitive skillfulness to Learning performance. QL = qualitative metacognition scores; QN = quantitative metacognition scores.

Results in Table 3.4 show that, despite the variance shared with Intellectual ability, both qualitative and quantitative Metacognitive skillfulness, added to the prediction of Learning performance on top of Intellectual ability.

3.3.3 Metacognitive skillfulness across domains

The generality vs. domain specificity of metacognitive skillfulness was investigated by performing a principal component analysis (PCA) on the metacognitive scores. For each year separately, a PCA with a two-factor solution was performed on the four subscales of metacognitive skillfulness (Table 3.5).

Table 3.5 Unrotated component matrix for the quality of metacognitive skillfulness

	Component 1 13 yrs	Component 2 13 yrs	Component 1 14 yrs	Component 2 14 yrs
Eigenvalue	3.53	1.78	3.28	1.40
Variance proportion	.44	.22	.41	.17
MetaorientationHis	.50	.49	.51	-.45
MetaplanningHis	.72	.48	.49	-.46
MetaevaluationHis	.48	.52	.77	-.42
MetaelaborationHis	.72	.37	.89	-.14
MetaorientationMath	.61	-.57	.40	.23
MetaplanningMath	.78	-.31	.58	.61
MetaevaluationMath	.55	-.67	.69	.13
MetaelaborationMath	.86	-.16	.63	.59

The unrotated solutions of the PCAs show that all measures of the quality of metacognitive skillfulness substantially load on the first component (Table 3.5). Although not all component loadings are extremely high, these first components may be interpreted as representing general metacognitive skills across the two domains. On the other hand, we found contrasted loadings on both second components. This points in the direction of a component representing domain-specific metacognitive skills. The same analyses were performed on the quantitative scores. These results were in line with the results of the qualitative data.

3.4 Discussion

This study investigated the development of metacognitive skillfulness. Results show an overall growth of the quantity and quality of metacognitive skillfulness indeed. Looking closer into the subscales, we see an increase in the quality of planning in math. This means that 14-year-olds performed more and better planning activities. For history, the frequency of evaluating increased significantly. 14-year-olds not only evaluated more, they also evaluated on a higher level. This means that 14-year-olds not only monitored their own text comprehension more frequently than 13-year-olds, but they also did so on a higher, more effective level. In conclusion, the first hypothesis was confirmed.

From an instructional point of view, it would be interesting to know more about the sequence in which metacognitive skills develop over an extended period of time (Veenman, Van Hout-Wolters, & Afflerbach, 2006).

The second hypothesis concerned the relation between metacognitive skillfulness and intellectual ability as predictors of learning performance over age groups. Results were in line with the mixed model, similar to results of older students in earlier studies (Veenman & Beishuizen, 2004; Veenman & Verheij, 2003; Veenman et al., 2004). The unique contribution of Metacognitive skillfulness outweighed the unique contribution of Intellectual ability to Learning performance in history in both years. The math results show a changing role of Intellectual ability over the years: In the first year the unique contribution of Intellectual ability outweighed the unique contribution of Metacognitive skillfulness to Learning performance. In the second year, on the other hand, the results are developing in line with the history results. This difference in contribution of intellectual ability could be explained by a difference in the novelty of tasks, as experienced by participants. Compared to solving math word problems, the history task may have been less familiar to them, i.e., less in line with their usual schoolwork. In everyday school life students are not used to read lengthy history texts as used in this study. Moreover, they also were unfamiliar with the topic. Solving math problems was a more familiar task format to them. A high task novelty suppresses the impact of intellectual ability on learning performance (Elshout, 1987; Raaheim, 1988; Prins et al., 2006, Veenman & Elshout , 1999; Veenman, Prins, & Elshout, 2002).

We found a parallel development of metacognitive skillfulness and intellectual ability as predictors of learning performance in line with the monotonic development hypothesis. Earlier, Alexander et al. (1995) found that the developmental pattern was not consistent over different constituents of metacognition. They obtained evidence in favor of a monotonic development of metacognitive knowledge, but their results were inconclusive regarding metacognitive skills. Our results point in the direction of a monotonic development in metacognitive *skills* as well: A continuous growth of metacognitive skills with age, alongside intellectual growth (Veenman et al., 2004), thus corroborating hypothesis 2.

The third research question concerned the generality vs. domain specificity of metacognitive skillfulness. In both years, the solutions of the PCAs are very similar : A first component, which can be interpreted as general metacognitive skills, and a second component, which can be interpreted as domain-specific metacognitive skills. Results support our expectation that metacognitive skills of rather young and inexperienced students represent a general as well as a domain-specific component. Veenman and

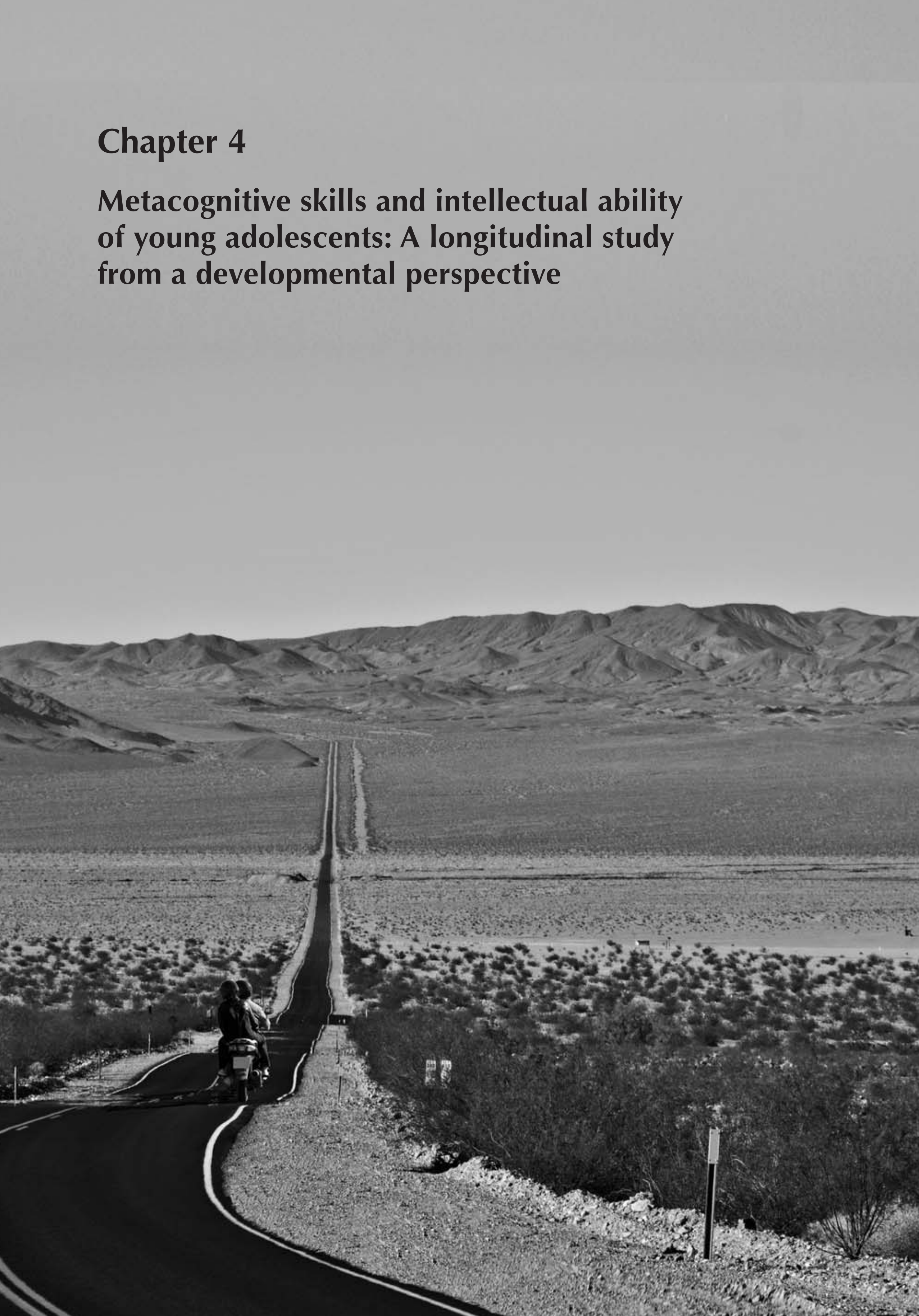
Spaans (2005) assumed that metacognitive skills initially develop on separate islands of tasks and domains. Beyond the age of 12 years, these skills will merge into a more general repertoire that is applicable and transferable across tasks and domains. Among young students a phase of transition could be characterized by applying recently acquired general metacognitive skills, along with a remainder of domain-specific metacognitive skills. We expected that the initially acquired domain-specific metacognitive skills would tend to generalize during development. The present results, however, do not support this part of hypothesis 3 as yet. Next to drawing on a repertoire of general metacognitive skills students seem to continue applying domain-specific metacognitive skills as well. This may indicate that these students are still in a transitory phase of metacognitive-skill development. Being so, the general component would gain weight in the forthcoming years of development. On the other hand, it may indicate that metacognitive skills are only partly general by nature.

Despite finding significant results, there might be some limitations of the study. The small sample may be considered as a limitation to the generalizability. The time-consuming method of protocol analysis of individual sessions did not allow for larger samples. About 220 hours a year were spent on the individual sessions, transcribing protocols, analyzing protocols and tests. The fact that all participants came from the same school might be a limitation too. The same applies for the dissimilarity in tasks. In order to measure the learning performance after studying a *new* task, it was not possible to administer the same tasks over the years. By piloting the tasks and consulting teachers we tried to make the relative difficulty level of the tasks for each year as comparable as possible. Furthermore, the period covering the development of metacognitve skills was rather short.

This study shows that metacognitive skills cannot be ignored as an important predictor of learning performance. These skills develop during an important phase in education. It would be interesting to replicate (parts of) this study over a longer period of time with more participants coming from various schools. Such an extended study could contribute to a better understanding of the development of particular metacognitive skills, and of how appropriate skills can be taught at the right time.

Chapter 4

Metacognitive skills and intellectual ability of young adolescents: A longitudinal study from a developmental perspective



Abstract

This study shows the final results of a longitudinal project where the same participants were followed for three consecutive years as they enter secondary school (aged 12 to 15 years). The first objective of this study was to investigate the development of both quantity and quality of metacognitive skills. The second objective was to establish whether the development of metacognitive skills is intelligence-related or relatively intelligence-independent. Finally, the generality vs. domain-specificity of developing metacognitive skills was investigated. In the first year 32 first-year secondary-school students participated in this study. In the second and third year, respectively 28 and 25 students participated. While thinking aloud, the participants performed two different tasks representing two different domains: A text-studying task for history and a problem-solving task for mathematics. Each year participants were given new tasks, suitable for their age. Participants' intellectual ability was assessed, as well as their metacognitive skills and learning performance for both domains separately. Results of the first two years show a significant growth of both the quantity and the quality of metacognitive skills. In the third year this growth did not continue. Furthermore, results show that metacognitve skills contributed to learning performance partly independent of intellectual ability. Results also show that metacognitive skills appear to be predominantly general by nature over the years. A smaller domain-specific component was found as well in the first two years, while this component disintegrated in the third year. In conclusion, the age around 15 years appears to be a relevant point in time during the developmental trajectory of metacognitive skills. At this age the growth of metacognitive skills is put on hold, while the nature of these skills becomes fully general.

4.1 Introduction

Since Flavell (1979) introduced the concept 'metacognition', many studies have addressed the issue of the influence of metacognition on learning performance. Based on a meta-review of studies, Wang, Haertel, and Walberg (1990) concluded that metacognition is the most important predictor of learning performance. The present study focuses on the development of metacognitive skills in relation to intellectual ability. Another important issue concerns the generality vs. the domain specificity of metacognitive skills.

4.1.1 Metacognitive skills

A generally accepted distinction is the one between metacognitive knowledge and metacognitive skills. Metacognitive knowledge refers to the *declarative* knowledge one has about the interplay between personal characteristics, task characteristics, and available strategies in a learning situation (Flavell, 1979). Having metacognitive knowledge at one's disposal, however, appears to be no guarantee for using this knowledge whenever it is needed. Alexander, Carr and Schwanenflugel (1995) found a discrepancy between childrens' knowledge about monitoring and applying monitoring skills during task performance. In the same vein, Winne (1996) stated that knowledge has no effect on behavior until it is actually being used. Students who are aware of effective strategies still do not always use them (Barnett, 2000; Pressley, Yokoi, Van Meter, Van Etten, & Freebern, 1997). Metacognitive skills concern the *procedural* knowledge that is required for the actual regulation of, and control over one's learning activities (Brown & DeLoache, 1978; Veenman, Elshout, & Meijer, 1997; Veenman, 2011). Task analysis, goal setting, planning, monitoring, checking, and recapitulation are manifestations of such skills. Metacognitive skills can be inferred from overt behavior or utterances by the student, that is, from concrete metacognitive activities (Veenman, Van Hout-Wolters, & Afflerbach, 2006). These activities can be divided in behavior that occurs at the onset of task performance (orientation), during task performance (planning, monitoring, evaluation) and after task performance (reflection and elaboration). Examples of metacognitive activities are given in Table 4.1. Note that some of the behavior in Table 4.1 may be considered as cognitive, but the purposeful application of such cognitive behavior at the appropriate moment results from metacognitive skillfulness. It reflects the intention to attain control over the cognitive task. Several researchers (Bowen, Shore, & Cartwright, 1992; Brown, 1980; Christoph, 2006; Markman, 1977, 1979; Mevarech & Fridkin, 2006; Pressley & Afflerbach, 1995; Schoenfeld, 1992; Shore & Lazar, 1996) have investigated the use of metacognitive skills while performing different tasks (e.g., reading comprehension or problem solving) often focusing on a separate component of metacognitive skills (e.g., planning or monitoring activities). The present study, however, includes a broad range of metacognitive skills referring to orientation, planning, monitoring, as well as elaboration skills in both problem-solving and text-studying tasks. While assessing metacognitive skills over a developmental trajectory two different perspectives can be taken: The quantity and the quality of metacognitive skills. The quantity concerns the frequency of these skills being applied, whereas the quality concerns the depth or the extent to which they are applied. An example of the latter is that making a sketch of the problem in order to represent the problem is considered as a deeper orientation than just reading (a part of) the problem statement. Using metacognitive skills more frequently does not automatically imply that these metacognitive skills have a higher level of quality. Therefore, this study focuses on the development of both the quantity and the quality of metacognitive skillfulness.

4.1.2 Metacognitive skills from a developmental perspective

The first objective of this study was to investigate the development of metacognitive skills. Flavell (1992) related the concept of metacognition to Piaget's developmental stage of formal-operational thinking (Inhelder & Piaget, 1958). At this stage children are capable of hypothetico-deductive reasoning, which requires metacognitive control. Flavell indicated that Piaget would not expect metacognition to show up before the stage of formal-operational thinking has been reached. More recent studies, however, showed that, alongside with the "theory of mind" (ToM), that is, the understanding of one's own and other people's state of mind, (Wellman, 1990), young preschoolers already start to develop some metacognitive awareness (Blöte, Van Otterloo, Stevenson, & Veenman, 2004; Demitriou & Efklides, 1990; Kuhn, 1999). Larkin (2006) found a relation between ToM, metacognitive knowledge and strategy use in two 5- to 6-year-olds. A further metacognitive development in later childhood concerns not only the metacognitive knowledge, but also the onset of the development of metacognitive skills. Although Whitebread et al. (2009) found some planning and monitoring activities in playful situations with youngsters as young as 5 years old, it is generally assumed that the development of metacognitive skills in educational contexts commences around the age of 8-10 years (Berk, 2006; Kuhn, 1999; Siegler, 1998; Veenman et al., 2006; Veenman, Wilhelm, & Beishuizen, 2004). In a cross-sectional study concerning the frequency of metacogntive skills, Veenman et al. (2004) found a linear growth in metacognitive skills between the age of 9 and 22 yrs. In another study (Veenman & Spaans, 2005) a significant growth of the quality of students' metacognitive skills (12

– 15 years) was found. A growth in both frequency and quality of metacognitive skills was found in two studies with participants aged between 13 and 15 yrs. and 12 and 14 yrs. respectively (Van der Stel, Veenman, Deelen, & Haenen, 2010; Van der Stel & Veenman, 2010). In line with these results, metacognitive skills are expected to increase in quantity (frequency) as well as in quality (depth) over the years (hypothesis 1).

4.1.3 Relation between intellectual ability, metacognitive skills, and learning performance from a developmental perspective

A related research issue is whether the development of metacognitive skills is intelligence-related or relatively intelligence-independent. Several researchers (Alexander et al., 1995; Borkowski & Peck, 1986; Schneider & Pressley, 1997; Van der Stel & Veenman, 2008; Van der Stel, et al., 2010; Veenman et al., 2004; Veenman & Spaans 2005) investigated metacognitive ability in relation to intellectual ability.

An interesting question is whether metacognitive skills are part of intelligence, that is, "whether metacognition can be reduced to cognition" (Slife, Weiss, & Bell, 1985). Veenman (1993; Veenman & Beishuizen, 2004; Veenman & Verheij, 2003; Veenman et al., 1997) described three, mutually exclusive models concerning the relation between intellectual ability and metacognitive skills as predictors of learning performance. The *intelligence* model regards metacognitive skills as an integral part of intellectual ability. According to this model, metacognitive skills do not have a predictive value for learning performance independent of intellectual ability. Sternberg (1990), for instance, advocates such an inclusive position of 'metacomponents' in his triarchic theory of intelligence. The second, contrasting model is the *independency* model, in which intellectual ability and metacognitive skills are regarded as entirely independent predictors of learning performance. Finally, in the *mixed* model intellectual ability and metacognitive skills are correlated, but metacognitive skills has a surplus value on top of intellectual ability for the prediction of learning performance.

Over the last decades, support has been found for each of these models (for an overview, see Veenman & Spaans, 2005; Veenman et al., 2004). Many studies, however, are difficult to compare, due to dissimilarities in assessing metacognitive skills (thinking aloud, observation, questionnaires), in participants (age, educational background), and in tasks and domains. Moreover, the focus of some studies is restricted to the relation between intellectual ability and metacognitive skills, thereby excluding the relation of both predictors with learning performance. The evidence found so far seems to be in favor of the mixed model, albeit many of those studies concerned the metacognitive skills of older secondary-school or university students in cross-sectional designs. From the perspective of the development of metacognitive skills, it remains to be ascertained more thoroughly in a longitudinal design whether the mixed model can be generalized to younger students with initially developing metacognitive skills, performing different tasks in different domains (see Veenman & Spaans, 2005; Veenman et al., 2004). More specifically, the role of intellectual ability in the *development* of metacognitive skills will be addressed in this study. Alexander et al. (1995) formulated three developmental hypotheses with regard to the relation between intelligence and the development of metacognition. According to the *ceiling* hypothesis, initial effects of intelligence on the development of metacognition diminish over time. The *acceleration* hypothesis, on the other hand, assumes that the impact of intelligence on the development of metacognition increases with age. The *monotonic development* hypothesis, finally, assumes that both intelligence and metacognition show a monotonic growth over age independent of each other. In their literature overview, Alexander et al. (1995) found support for the monotonic development of metacognitive knowledge. Gifted children showed a general superiority in their declarative metacognitive knowledge, relative to non-gifted children at all ages. Giftedness effects were persistent throughout childhood with gifted children from early elementary school to junior high school showing a similar superiority in this knowledge. With regard to metacognitive skills, however, results were inconclusive. Young gifted children were not more spontaneously strategic than non-gifted children. However, a giftedness advantage showed up in the middle school and high school years for both spontaneous and complex strategy use. In a cross-sectional study, Veenman and Spaans (2005) obtained evidence in favor of a monotonic development of metacognitive skills. They obtained support for a monotonic maturation effect of both intellectual ability and metacognitive skills in students of 13 and 15 years performing a problem-solving task and an inductive-learning task.

In the present study, it is hypothesized that metacognitive skills develop alongside, but not fully dependent on intellectual ability, regardless of tasks and domains. A monotonic development of both metacognitive skillfulness and intellectual ability as predictors of learning performance is expected, in line with the mixed model and the monotonic development hypothesis (hypothesis 2).

4.1.4 Metacognitive skills across domains

Another objective of this study was to establish whether metacognitive skills are general or domain specific. From a developmental as well as from an instructional perspective it is relevant to know not only whether metacognitive skills develop, but also how they develop: Whether they develop from being general into becoming domain specific or the other way around? Earlier studies concerning this issue yielded contradictory results. Despite differences in assessment, age groups, tasks and domains, some researchers found evidence for general metacognitive skills (Schraw, Dunkle, Bendixen, & Roedel, 1995; Schraw & Nietfeld, 1998; Veenman & Beishuizen 2004; Veenman & Verheij 2003; Veenman et al., 1997, 2004). On the other hand, De Jong (1992) found that the quality and quantity of metacognitive activities of secondary-school students varied substantially across tasks. Glaser, Schauble, Raghavan, and Zeitz (1992) showed that metacognitive activities of university students varied across different discovery-learning tasks, although improvement between subsequent tasks did not rule out the existence of general strategies. Kelemen, Frost, and Weaver (2000) concluded that individual differences in meta-memory accuracy were not stable across consecutive sessions and tasks, which they interpreted as evidence against a general metacognitive ability.

Veenman et al. (2004) found support for the generality of metacognitive skills among young novices (aged 9 to 22 yrs.) performing discovery-learning tasks in different domains. This support for young students' general metacognitive skills could not be corroborated by a study of Veenman and Spaans (2005). In their study 13- and 15-year olds performed two tasks in different domains (math word-problem solving and an inductive-learning task for biology). Metacognitive skills of the younger students appeared to be rather domain specific, whereas those of the older ones turned out to be general by nature.

Based on earlier studies, the onset of metacognitive *skill* development for academic tasks is not to be expected before the age of 8 – 10 years (Alexander et al., 1995; Berk, 2006; Kuhn, 1999; Siegler, 1998). The academic metacognitive skills of 12-year olds are still premature and developing, which may explain why these skills may diverge on notably different tasks. Veenman and Spaans (2005) assumed that metacognitive skills might be initially acquired within separate tasks and domains, and then progressively become a generalized repertoire across tasks and domains.

Participants in the present study are rather young adolescents and inexperienced in applying academic metacognitive skills. Spear (2000) characterized adolescence as a transitional developmental period. "Adolescence is the gradual period from childhood to adulthood……adolescence is a period of transitions rather than a moment of attainment" (p.417). Therefore, metacognitive skills of young adolescents are expected to be in a transitory phase of development, which implies that both general and domain-specific metacognitive skills will be used. It is hypothesized that the participants will initially use general as well as domain-specific metacognitive skills. It is also hypothesized that the initially acquired domain-specific metacognitive skills tend to generalize during further development. Therefore, older students are expected to resort less to domain-specific metacognitive skills than younger students do (hypothesis 3).

4.2 Method

4.2.1 Participants

In the first year of this three-year-longitudinal project, 32 first-year secondary-school students participated. They were recruited from 85 students of three different tracks (pre-university education, higher general education and pre-vocational education) of an urban school in the Netherlands. This school is known because of its large diversity of children, thus representing a broad educational level of the students, a broad range of social economic status of parents, and various ethnic backgrounds. It was chosen not to work with more than one school in order to avoid confounding variables, such as differences in teachers, pedagogical/didactic philosophy, schoolbooks, etc. Students with learning or conduct disorders (e.g., dyslexia or ADHD) were excluded from the study. Participants were distributed equally over the three tracks. Participants were selected on their intellectual ability (see section 4.2.3). Consent was requested from and given by the participants' parents. In the second year, four students withdrew as participants due to changing residence or school. In the third year, another three students withdrew for the same reason. In the third year, 25 students (8 boys, 17 girls; average age 14 years and 7 months) participated in the third part of this study[7]. The data in the present study refer to the 25 students that participated in all three years. After completing the tasks, participants received a small financial reward.

4.2.2 Metacognitive skills

All transcribed thinking-aloud protocols were analyzed on metacognitive skills according to the procedure of Veenman (Prins, Veenman, & Elshout, 2006; Van der Stel & Veenman, 2008, 2010; Veenman & Beishuizen, 2004; Veenman, Kerseboom, & Imthorn, 2000). Metacognitive skillfulness was divided into four subscales: Orientation (O), Planning and Systematic orderliness (P), Evaluation (Ev), and Elaboration (El). In Table 4.1 general metacognitive activities across both tasks and domains as well as more specific metacognitive activities for text-studying and problem-solving tasks are

[7] Effects of selective loss of participants over the years were checked for and not found. The same applies for effect of gender.

described for each subscale of metacognitive skillfulness (Meijer, Veenman, & Van Hout-Wolters, 2006; Pressley, 2000; Pressley & Afflerbach, 1995).

Table 4.1 Examples of domain-specific and general metacognitive activities

	History-specific	Math-specific	General
Orientation			
a.			Activating prior knowledge
b.			Goal setting
c.	Predicting the content of the text	Estimating the answer	
d.	Reading titles of paragraphs prior to reading the entire text	Making a sketch of the problem in order to represent the problem	
Planning & Systematic orderliness			
a.			Subgoaling
b.			Time management
c.	Designing a reading plan and deciding upon which text parts to pay attention to	Designing a step-by-step action plan, instead of working by trial-and-error	
d.	Note taking (self-instruction for doing so)	Writing down calculations step by step	
Evaluation			
a.			Expressing non-understanding
b.			Comment on own activities
c.	Monitoring text comprehension during reading	Monitoring action plan	
d.	Self-correction after rereading (parts of) the text	Checking an answer by recalculating	
Elaboration			
a.			Recapitulating and drawing conclusions
b.			Relating the answer to the question or problem
c.	Paraphrasing (parts of) the text	Paraphrasing the problem	
d.	Summarizing (self-instruction for doing so); Making inferences during reading	Drawing conclusions while referring to the problem statement	

The scoring method consisted of two steps for each protocol. First, an utterance was coded in the margin if belonging to one of the four subscales (O, P, Ev or El). This resulted in a quantitative score obtained by counting the frequency of metacognitive activities on each subscale (e.g., if a student evaluated five times, the quantitative Evaluation score was five). Secondly, a score for the quality of metacognitive skills was judged from the protocols. To obtain a reliable score for the quality of metacognitive skills, scoring criteria were formulated for each subscale. This resulted in a method, which allowed for assessing general as well as domain-specific metacognitive activities. A five-point scale (ranging from 0 to 4) was used for each subscale. For example, a participant received a higher score for 'deeper' Elaboration (e.g., drawing a conclusion in one's own words) than for a superficial one (e.g., summarizing a paragraph almost literally). It is important to emphasize that the judges intentionally avoided the confounding of metacognition scores with the correctness or incorrectness of the content matter. So, an incorrect, but highly elaborated conclusion could equally generate a high score for 'Elaboration' as long as it was in line with the participant's own reasoning.

Each year, 6 protocols of each task were rated by two judges separately. The interrater reliability was computed on the summed scores over the four subscales of metacognition. Since the interrater reliability was high, the remaining protocols were analyzed and rated by one judge. Cronbach's alpha interrater reliability ranged from .77 to .93 for the quantitative scores and from .89 to .97 for the qualitative scores.

4.2.3 Intellectual ability

Each year, students' intellectual ability was assessed by a series of ability tests. Three subtests from the Groninger Intelligence test for Secondary Education (GIVO, standardized Dutch intelligence test; Van Dijk & Tellegen, 1994) were selected: Number Series, Verbal Analogies and Unfolding Figures. With these three subtests a number of the primary intelligence factors (Carroll, 1993) is assessed: Both verbal and numerical inductive and deductive reasoning abilities and visuospatial ability. The GIVO, however, lacks a test for assessing memory abilities, another primary factor in Carroll's (1993) model highly relevant to the prediction of school performance (Crone et al., 2006). Therefore, a fourth test (Names & Professions, requiring the memorization of word pairs; see Veenman & Beishuizen, 2004) was added. In order to determine the growth in intellectual ability, the raw scores of the aforementioned four subtests were compared. Furthermore, raw scores were transformed into z-scores and for each participant a mean z-score was calculated over the four subtests for each year. This resulted in a total

score of the participant's intellectual ability for each year. These scores were used in the correlational analyses.
To guarantee sufficient variance in intellectual ability, the median of the intellectual ability scores was calculated and participants were denominated as high (1st quartile), average (2nd and 3rd quartile) or low (4th quartile) in intelligence. Participants were selected at random from each quartile, so as to attain an equal distribution over the quartiles.

4.2.4 Tasks

To ensure the novelty of tasks, each year participants were given *new* tasks with task demands adapted to their age. All tasks were piloted beforehand. In order to answer the question whether metacognitive skills are general or domain specific, students were asked to perform two different tasks representing two different domains. One task was a text-studying task in the domain of history and the other one was a problem-solving task in the domain of mathematics. In order to allow domain-specific metacognitive activities, the differences in tasks and domains were maximized.

4.2.4.1 History task

In an individual session of 50 minutes, participants were asked to study a history text in the same way as they usually do when preparing for a test. They were also asked to read aloud and to think aloud while reading the text and answering the questions or assignments embedded in the text. Participants were allowed to study the text for 30 minutes and in the remaining 20 minutes a post-test was administered (see section 4.2.5).

The history texts were composed of texts parts from two of the most frequently used Dutch schoolbooks for history: "MeMo" (Van Boxtel & Schrover, 1998) and "Sprekend verleden" (Buskop, Dalhuisen, & Geest, 1998). To avoid prior knowledge of the topic on the one hand, and to appeal to the zone of tolerable difficulty (Vygotsky, 1978) on the other hand, the text was based on a subject of the curriculum that was one year ahead (e.g., the first-year text was based on a subject of the second-year curriculum, instead of the first-year curriculum). In all texts, three activating questions or assignments were embedded. These were not meant for testing the students' knowledge, but to elicit text-studying activities (e.g., 'There are several reasons why the north and the south were at war with each other. Describe in your own words at least two of these reasons'). From a pilot-study (Meijer, Veenman, & Van Hout-Wolters, 2006) it appeared that if a text did not contain such activating questions and assignments, many participants just tended to read linearly. In the first year, a text about slavery and the civil war in the United States of America was used. In the second year, a text about the First World War was used. Finally, in the third year, a text about politics and economics in the United States of America in the Thirties of the last century was presented.

4.2.4.2 Mathematics task

In another individual session of 50 minutes, participants practiced to solve mathematical word problems for 20 minutes. Five problems were presented in the first year, six in the second year, and five in the third year. Several categories of problems were presented. In the first year, the categories of problems were distance, fraction, percentage, and surface area of rectangles. In the next year, the categories of problems were content, surface area of a triangle, fraction, percentage, and algebra. In the last year, the categories were calculation of probability, quadratic equation, Pythagoras' theorem, statistics, and formula with a square root. The tasks for each year were composed of adaptations of math problems from one of the most frequently used Dutch schoolbooks for math ("Getal en Ruimte"; Vuijk et al., 2003).

Together with the assignments, participants received a sheet containing the answers and a brief stepwise explanation of problem solutions. Participants were free to consult this sheet whenever and as much as they liked. The first 20 minutes were considered as a learning-by-doing phase. Next, the participants handed in all materials and received another series of parallel problems, which had to be solved in the remaining 30 minutes, without the option to consult an answer sheet. This second part is considered as a post-test assessment of learning performance (see section 4.2.5). All problems had to be solved while thinking aloud.

4.2.5 Learning performance

After the learning phase of both tasks, learning performance was assessed by a post-test, as was explained to the participants in advance. Each year the post-test for history consisted of five multiple-choice questions and six essay questions. The multiple-choice questions assessed reproductive knowledge (facts and dates, e.g., 'What was the name of the Austrian-Hungarian Crown prince?'). The essay questions were meant to assess overall text comprehension (e.g., 'Describe why things went wrong in agriculture and explain what Roosevelt did to restore agriculture economically').

Participants were not allowed to consult the text or their notes while answering the questions. According to a rating system, points were given for the correctness of answers to each question. Multiple-choice questions could render one point, while essay questions could render a maximum of four points. A total score was calculated and used as a measure of learning performance in history (Cronbach's alpha was .58, 1st year; .51, 2nd year; .80 3rd year). For each test the maximum obtainable score was 20 points.

After the learning-by-doing phase for math, learning performance was assessed by the post-test. In each post-test, items were parallel to the items in the learning phase, that is, the surface structure of the post-test items differed from the one of the learning-task items, but the deep structure was the same. Post-tests with five (1st year and 3rd year) and six (2nd year) math word problems were administered. In the first year two points per item could be earned if both the procedure and the answer was correct; one point if either one of them was correct; and zero points if neither of them was correct (Cronbach's alpha = .58). Due to an increase of the complexity of the problems, another scoring system was chosen in the second and third year: For the first five math problems in the second year, an equal amount of 10 points could be earned. Problem 6 consisted of three sub-problems that were independent of each other and, therefore, was valued with a maximum of 30 points. So, the maximum obtainable score in the second year was 80 points. A total score was calculated and used as a measure of learning performance in mathematics (Cronbach's alpha = .69). In the third year, five points per (sub)problem could be earned with a maximum obtainable score of 45 points (Cronbach's alpha = .77). Because of the differences in the number of obtainable scores per item over the years, the mean proportion of right answers (p-value) was calculated for all questions in each year as well as the mean p-value per year[8]. The p-values were very similar over the years.

4.2.6 Procedure

Each year, the intellectual-ability tests were administered during a group session. The individual, thinking-aloud sessions took place during school time. The experiment had a counterbalanced design with respect to task order, meaning that half of the participants started with history and the other half with mathematics. Participants could make use of a pen, pencil, text highlighter, ruler, calculator, and blank sheets of paper for making notes. In order to compare the results of the three years, only the data of the participants that performed all tasks over the years (N = 25) were used in the statistical analyses.

All participants were instructed to think aloud while working on the individual tasks. The experimenter refrained from helping students in any way. Whenever a student

[8] Mean p-values for History over the years were .51, .54 and .56 respectively. Mean p-values for Math over the years were .44, .69 and .66 respectively. ANOVA and post-hoc test (Bonferroni) were performed on the math data. No significant difference was found.

fell silent, the experimenter used standard prompts (e.g., 'please, keep on thinking aloud') in order to encourage students to think aloud. All utterances of participants were audio-taped, transcribed, and analyzed on metacognitive skills.

4.3 Results

4.3.1 Development of metacognitive skills and intellectual ability

In order to analyze growth in intellectual ability and metacognitive skills, results of the three consecutive years were compared. First, ANOVA was performed on the raw subscale scores of intellectual ability with age as within-subjects factor. A significant effect of age was found [$F(7,18) = 7.40$, $p < .001$, $\eta^2 = .78$]. Pairwise comparisons (comparing the first to the second year, and the second to the third year) showed an incremental change in intellectual ability over the years (see Table 4.2).

Table 4.2 Means (and standard deviations) of intellectual ability

Intellectual ability *N* = 25	**13 years**	**14 years**	**15 years**
Number series	18.32 (4.03)	19.20 (4.23)	21.04 (3.61)
Verbal analogies	13.88 (3.27)	16.40 (3.61)	17.64 (3.14)
Unfolding figures	10.48 (4.67)	12.72 (4.95)	14.48 (4.62)
Memory	7.76 (2.22)	9.22 (2.59)	9.30 (3.11)
Total	12.61 (2.80)	14.38 (2.83)	15.68 (2.73)

Furthermore, separate ANOVAs with repeated measures were performed on the quantitative and the qualitative subscale scores of metacognition of both tasks with age as within-subjects factor. A significant age effect was found for the frequency of metacognitive skills in math [$F(8,17) = 4.32$, $p < .01$, $\eta^2 = .67$], whereas for history no significant age effect was found [$F(8,17) = 2.14$, $p > .05$, $\eta^2 = .50$]. ANOVAs on the quality of metacognitive skills revealed a significant age effect for both tasks [$F(8,17) = 2.90$, $p < .05$, $\eta^2 = .58$, math] and [$F(8,17) = 3.28$, $p < .02$, $\eta^2 = .61$, history]. Means and standard deviations are shown below in Tables 4.3 (quality) and 4.4 (frequency).

Table 4.3 Means (and standard deviations) of quality of metacognition

Quality of metacognition *N* = 25	13 years	14 years	15 years
Orientation Math	1.52 (.65)	1.80 (.82)	1.60 (.71)
Planning Math	1.84 (1.54)	2.36 (1.10)	2.48 (.92)
Evaluation Math	1.12 (1.10)	1.40 (.76)	1.36 (.99)
Elaboration Math	1.36 (.99)	1.48 (.92)	1.08 (.81)
Total Math	5.96 (3.33)	7.04 (2.61)	6.52 (2.50)
Orientation History	.56 (.58)	.92 (.76)	1.04 (.79)
Planning History	2.00 (1.50)	1.64 (.91)	1.96 (1.27)
Evaluation History	.80 (1.00)	1.44 (1.35)	.72 (.98)
Elaboration History	1.84 (1.55)	1.96 (1.02)	2.00 (1.22)
Total History	5.24 (3.77)	5.88 (3.20)	5.72 (3.30)

Table 4.4 Means (and standard deviations) of quantity (frequency) of metacognition

Quantity of metacognition	13 years	14 years	15 years
Orientation Math	6.84 (1.95)	9.44 (3.13)	6.52 (1.80)
Planning Math	8.40 (4.11)	12.16 (4.30)	10.88 (2.74)
Evaluation Math	2.72 (2.50)	5.04 (4.83)	2.84 (2.35)
Elaboration Math	3.24 (2.63)	5.88 (4.00)	3.68 (2.54)
Total Math	21.20 (8.44)	32.52 (10.90)	23.88 (6.58)
Orientation History	.24 (.66)	.56 (.87)	.80 (1.04)
Planning History	7.36 (6.73)	9.00 (7.70)	8.60 (6.77)
Evaluation History	1.44 (1.98)	3.56 (3.93)	1.60 (2.23)
Elaboration History	9.32 (9.44)	7.40 (4.55)	8.92 (5.89)
Total History	18.36 (13.83)	20.52 (12.83)	19.52 (13.38)

Pairwise comparisons were performed in order to look closer into changes on subscale level over the years. These tests revealed different developmental patterns at subscale level (see Figures 4.1 and 4.2).

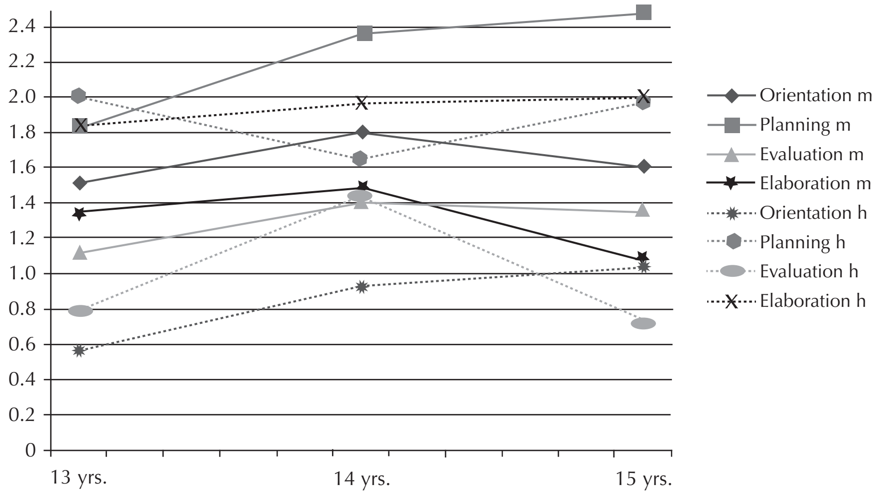


Figure 4.1 Qualitative metacognition scores across age (m = math; h = history)

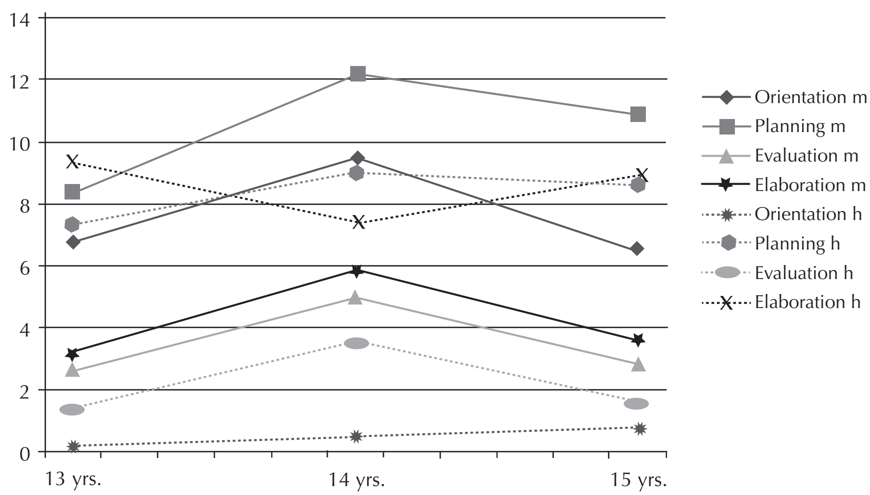


Figure 4.2 Quantitative metacognition scores across age (m = math; h = history)

The majority of the metacognitive scores did not increase continuously over the years. Two main patterns can be observed: (1) Growth between the first and the second year, followed by stabilization in scores between the second and the third year, and (2) Growth between the first and the second year followed by regression between the second and third year.

4.3.2 Testing the mixed model

To determine whether developmental processes affect the relation between intellectual ability and metacognition as predictors of learning performance, the correlations between these three variables over the three consecutive years were compared (see Table 4.5).

Table 4.5 Correlations and Semi-partial correlations

	IA	Meta	Semi-PartIA	Semi-PartMeta
Quality				
LP Math13	.77**	.70**	.43**	.30*
Meta Math13	.61**			
LP Math14	.54**	.74**	.20	.55**
Meta Math14	.49*			
LP Math15	.79**	.59**	.52**	.13
Meta Math15	.66**			
LP History13	.46*	.68**	.28*	.58**
Meta Hist13	.28			
LP History14	.24	.35	.16	.30*
Meta Hist14	.26			
LP History15	.25	.60**	.00	.55**
Meta Hist15	.41*			
Quantity				
LP Math 13		.73**	.40**	.30*
Meta Math13	.64**			
LP Math14		.40	.46**	.27
Meta Math14	.24			
LP Math15		.34	.70**	.08
Meta Math15	.42*			
LP History13		.61**	.32*	.51**
Meta Hist13	.26			
LP History14		.23	.21	.20
Meta Hist14	.15			
LP History15		.43*	.15	.38*
Meta Hist15	.23			

Note: LP means Learning performance * $p < .05$, ** $p < .01$

As far as the math task was concerned, intellectual ability correlated significantly with both quality of metacognitive skills and learning performance in the three consecutive years. The same applies for the correlation between quality of metacognitive skills and learning performance. The correlation between frequency of metacognitive skills for math and learning performance was significant only in the first year. The correlation between intellectual ability and frequency of metacognitive skills was significant, except for the second year.

Results on the history task differ partly from results on the math task. Only in the first year a significant correlation was found between intellectual ability and learning performance. The correlation between intellectual ability and quality of metacognitive skills was significant in the third year only. The correlation between quality of metacognitive skills and learning performance was significant in the first and the third year. The same applies for frequency of metacognitive skills and learning performance. No significant correlations were found between intellectual ability and frequency of metacognitive skills for history.

To test the mixed model, semi-partial correlations for each age group (Nunnally, 1967) were calculated by partialling metacognitive skill from the correlation between intellectual ability and learning performance (i.e., Semi-PartIA) and partialling intellectual ability from the correlation between metacognitive skills and learning performance (i.e., Semi-PartMeta). These semi-partial correlations (see Table 4.5) are needed to calculate the unique, independent contribution of metacognitive skills and intellectual ability to learning performance. Using regression-analytic techniques (Pedhazur, 1982; Van der Stel & Veenman, 2008, 2010; Veenman & Spaans, 2005) the unique and shared proportions of variance in learning performance were distributed to metacognitive skills and intellectual ability (see Table 4.6).

History results in Table 4.6 show that, despite the variance shared with intellectual ability, both frequency (QN) and quality (QL) of metacognitive skills, substantially added to the prediction of learning performance on top of intellectual ability. Between 13 and 14 years the unique contribution of metacognition decreased in order to increase again between 14 and 15 years. The unique contribution of intellectual ability to learning performance in history faded out over the years. Math results show an increasing contribution of metacognitive skillfulness to the prediction of learning performance on top of intellectual ability between 13 and 14 years. With 15 years, however, this unique contribution practically disappeared. The unique contribution of intellectual ability to the learning performance on top of the quality of metacognitive skills decreased substantially between 13 and 14 years, however, to reappear with 15 years. In order to check whether the contribution of metacognitive skills differed significantly over the years, Fisher-z ratios were calculated for pairs of correlations (Guilford, 1965). All Fisher-z ratios were smaller than 1.46, meaning that none of the correlations differed significantly.

Table 4.6 Percentage of variance accounted for in Learning performance

	Intel unique		Meta unique		Shared		Total	
	QL	QN	QL	QN	QL	QN	QL	QN
History 13	7.9	9.9	33.0	25.9	13.3	11.1	54.2	46.9
History 14	2.5	4.5	9.0	3.8	3.5	1.4	15.0	9.7
History 15	0.0	2.3	30.1	14.3	6.1	3.8	36.2	20.4
Math 13	18.8	15.8	8.8	9.2	40.6	43.7	68.2	68.7
Math 14	4.2	21.0	29.7	7.5	25.0	8.3	59.0	36.8
Math 15	26.6	51.8	1.6	0.0	38.0	12.8	66.2	64.6

Note: Intel unique means the unique contribution of Intellectual ability to Learning performance; Meta unique means the unique contribution of Metacognitive skills to Learning performance; Shared means the shared contribution of Intellectual ability and Metacognitive skills to Learning performance. Total means the total contribution of Intellectual ability and Metacognitive skills to Learning performance. QL = qualitative metacognition scores; QN = quantitative metacognition scores.

4.3.3 Metacognitive skills across domains

The generality vs. domain specificity of metacognitive skills was investigated by performing a principal component analysis (PCA) on the metacognition scores. For each year separately, a principal component analysis with a two-factor solution was performed on the four subscales of metacognitive skills for both tasks (see Table 4.7).

The unrotated solutions of the PCAs show that all measures of quality of metacognitive skills substantially load on the first component (see Table 4.4). This component has eigenvalues of 3.53 (13 yrs.), 3.28 (14 yrs.), and 3.87 (15 yrs.), with variance proportions of .44; .41 and .48 respectively. Moreover, in the first two years a second component contrasting the two domains was extracted with eigenvalues of 1.78 (13 yrs.), and 1.40 (14 yrs.), and with variance proportions of .22, .17 respectively. Loadings on a second component of the third year with an eigenvalue of 1.11 (15 yrs.), and a variance proportion of .14 did not contrast the two domains (see Table 4.7). The same analysis was performed on quantitative scores of metacognitive skills. Results were in line with those of the qualitative data.

Table 4.7 Unrotated component matrix for the quality of metacognitive skillfulness

	Com-ponent1 13 yrs	Com-ponent2 13 yrs	Com-ponent1 14 yrs	Com-ponent2 14 yrs	Com-ponent1 15 yrs	Com-ponent2 15 yrs
Eigenvalue	3.53	1.78	3.28	1.40	3.87	1.11
Variance proportion	.44	.22	.41	.17	.48	.14
Metaorientation Hist	.50	.49	.51	-.45	.21	.86
Metaplanning Hist	.72	.48	.49	-.46	.86	.19
Metaevaluation Hist	.48	.52	.77	-.42	.71	-.44
Metaelaboration Hist	.72	.37	.89	-.14	.87	.04
Metaorientation Math	.61	-.57	.40	.23	.46	-.27
Metaplanning Math	.78	-.31	.58	.61	.73	.04
Metaevaluation Math	.55	-.67	.69	.13	.68	-.17
Metaelaboration Math	.86	-.16	.63	.59	.79	.17

4.3.4 Exploratory analysis

After the individual math sessions of the third year were completed, the experimenter had the impression that the frequency of using the step-wise explanation sheet during the math task had changed over the years. Together with the assignments, participants received this sheet containing the answers and a brief stepwise explanation of problem solutions. Participants were free to consult this sheet whenever and as much as they liked. The impression was that older participants made more use of the sheet to check their own solutions, that is, older participants would consult the sheet more *after* solving a math problem, relative to younger participants. Change in the frequency of using the sheets *prior* to attempts to solve a problem was not suspected. A change in using the sheet could have caused the unexpected low unique contribution of metacognition to learning performance for math in the 3rd year. In order to test this assumption, the sheet use prior and after problem solving was coded in all math protocols. Because the number of math assignments was not the same each year, the sheet-use scores were recoded in a relative frequency of sheet usage. ANOVA with repeated measures on consulting the explanation sheets *after* problem solving with age as within-subjects factor revealed a significant effect of age [$F(2,23) = 6.82$, $p<.005$, $\eta^2 = .37$]. Fourteen-year-olds consulted the sheets more than 13-year-olds, and 15-year-olds more than 14-year-olds. The mean percentage of assignments for which 13-year-olds consulted the sheet after problem solving was 10 (*SD* = 23.9); 14-year-olds (*M* = 24, *SD* = 28.7);

15-year-olds (M = 41, SD = 33.2). ANOVA on the scores *prior* to problem solving did not reveal a significant age effect [$F(2,23) = .04$, $p > .05$, $\eta^2 = .00$]. Each year, the mean percentage of assignments for which the sheet was consulted prior to problem solving was about 30.

4.4 Discussion

This longitudinal study investigated the development of both the quantity (frequency) and the quality (depth) of metacognitive skills in young adolescents. According to the first hypothesis, metacognitive skills were expected to increase in frequency as well as in depth over the three consecutive years. Results show an overall growth of quantitative and qualitative scores of metacognitive skills over the first two years (between 13 and 14 yrs.). Between the second year and the third year (between 14 and 15 yrs.), this growth did not continue. So, the first hypothesis is partly corroborated: Metacognitive skills do grow in frequency and in depth, but growth was not continuous over the three consecutive years. In prior research (Veenman & Spaans, 2005; Veenman et al., 2004) a continuous growth of metacognitive skillfulness was found. It should be mentioned, however, that these studies were concerned with larger intervals between measurements, and did not focus on the development between 14 and 15 years in particular. Moreover, these studies had a cross-sectional design and the same tasks were used over the years. Therefore, it is presumed that growth is arrested only temporarily between 14 and 15 yrs. According to dynamic-systems theories (Siegler, DeLoache, & Eisenberg, 2010), a class of theories that focus on how change occurs over time in complex systems, individual children acquire skills at different ages and in different ways. Their development entails regressions as well as progress. Development of metacogitive skills seems to be in line with the notion of dynamic-systems theories: During development both progress and regression occur, and not all components of metacognitive skillfulness develop at the same pace.

The second hypothesis concerned the relation between metacognitive skills and intellectual ability as predictors of learning performance over age groups. Results were expected to be in line with the mixed model and the monotonic development hypothesis. In the present study, a unique contribution of metacognitive skills to learning performance and a shared contribution of metacognitive skills with intellectual ability to learning performance was found in all three consecutive years, with the exception of the frequency of metacognitive skills in math in the 3rd year. The unique contribution of the quality of metacognitive skills in math in the 3rd year was rather small (1.6%). In a cross-sectional study with the same tasks and the same age groups, however, a much higher unique contribution of metacognitive skills (42.8%) in 15-year-olds was found (Van der Stel, et al., 2010). The small unique contribution in the present study could be the result of the more frequent use of the explanation sheets in the 3rd year. Consulting the sheet after problem solving, that is, comparing the solution given on the sheet with one's own solution, could be acquired behavior promoted by the teachers of this particular group. It goes without doubt that this is useful learning behavior, but this acquired behavior probably suppressed the unique contribution of spontaneous metacognitive skills during problem solving. In conclusion, the mixed model was found over the years for both history and math, albeit less convincing than expected for math in the 3rd year.

Another part of hypothesis 2 was the expected monotonic development of metacognitive skills and intellectual ability as predictors of learning performance in line with Alexander's monotonic development hypothesis. Results of the first two years of the present study point in the direction of a monotonic development of metacognitive skills: A continuous growth of metacognitive skills with age was found, alongside intellectual growth. Results of the 3rd year, however, show a continued growth in intellectual ability, but no further growth in metacognitive skills. Despite the (temporary) stabilization in metacognitive growth, results predominantly agree with the monotonic development hypothesis. Here it is hypothesized that intellectual development does not direct metacognitive development, as is the case in both the ceiling and the acceleration hypotheses (see section 4.1.3). Moreover, the mixed model was found each year, confirming an independent contribution of metacognition to learning performance (except for the quantity of metacognition in 3rd year math). Thus, intellectual development does not direct metacognitive development. Therefore, the current results are considered to agree most with the monotonic development hypothesis, which is relevant to the training of metacognitive skills in education. Metacognitive skills can be trained successfully at different ages and in various tasks and domains (cf. Campione, Brown & Ferrara, 1982; Chinnappan & Lawson, 1996; Kramarski & Mevarech, 2003; Masui & De Corte, 1999; Pressley & Gaskins, 2006).

The third and last research question concerned the generality vs. domain specificity of metacognitive skills. In the first two years, the solutions of the principal component analysis (PCA) on the metacognitive data show a highly similar two-component solution: A first component with rather high component loadings, which may be interpreted as representing general metacognitive skills across domains, and a second, weaker component with contrasted component loadings, which may be interpreted as representing domain-specific metacognitive skills. In the third year, however, the solution of the PCA changed: The first component still can be interpreted as representing general metacognitive skills, but the structure of the second component has become much more scattered. It no longer can be interpreted as a domain-specific component. Results support our expectation that metacognitive skills of rather young and inexperienced adolescents represent a general as well as a domain-specific component. Veenman and Spaans (2005) assumed that metacognitive skills initially develop on separate islands of tasks and domains. They also assumed that beyond the age of 12 years, these skills merge into a more general repertoire that is applicable and transferable across tasks and domains. Among young adolescents, a phase of transition could be characterized by applying recently acquired general metacognitive skills, along with a remainder of domain-specific metacognitive skills. In line with hypothesis 3, it was expected that the initially acquired domain-specific metacognitive skills would tend to generalize during development. Although the present results corroborate hypothesis 3, the generalization process was less gradual than expected. Next to drawing on a repertoire of general metacognitive skills, students continue to apply domain-specific metacognitive skills between the age of 12 and 14 years. This may indicate that these students are still in a transitory phase of metacognitive-skill development. The use of both general and domain-specific metacognitive skills for a longer period of time could be explained by the overlapping-waves model (Siegler, 1998). According to this model, children initially use multiple strategies, and with age and experience they will selectively rely on more advanced strategies.

From an instructional perspective, it would be advisable to extend the training of domain-specific metacognitive skills in a particular learning context to more general, domain-surpassing ones (Veenman et al., 2004). Students will profit from an explicit training in metacognitive skills more effectively if that training surpasses a particular learning context. Metacognitive skills, acquired in separate domains, may gradually be generalized across domains (Schneider & Pressley, 1997). This process can be considered as high road transfer (Salomon & Perkins, 1989). Teachers should initially encourage students to develop their domain-specific metacognitive skills. As a next step, teachers should pay attention to the generalized applicability of the students' repertoire of metacognitive skills across domains. If teachers from various disciplines attune their instructions regarding metacognitive skills, transfer of metacognitive skills could be facilitated, thus providing students with tools for performing new tasks in new domains. It should be acknowledged that there are some limitations to the present study. A first limitation concerns the generalizability due to the small sample size. The time-consuming method of protocol analysis of individual sessions did not allow for larger samples. A second limitation could be the dissimilarity in tasks over the years. Repeatedly measuring learning performance in a longitudinal design, however, makes it inevitable to use *new* tasks each year. By piloting the tasks and consulting teachers, efforts were made to balance the relative difficulty level of the tasks for each age group.

During the last decade, neurocognitive developmental research showed that changes in the adolescent brain are non-linear, non-synchronous and with large individual differences (Casey, Getz & Galvan, 2008; Steinberg, 2005; Toga, Thompson & Sowell, 2006). The prefrontal cortex matures until late adolescence (Toga et al., 2006). Veenman et al. (2004) found that a continued growth also applies to metacognitive skills, they continue to develop till at least the age of 22 yrs. The current study show that different components of metacognitive skillfulness develop neither at the same pace, nor continuously. Knowledge about the developmental trajectory of the various components of metacognitive skillfulness will enable teachers to teach the right things at the right time. For future research it would be a challenge to look for opportunities to combine research that describes developmental changes based on behavioral experiments with research based on new methods like functional imaging. Such studies would make it possible to focus on *processes* of change rather than focusing on steady states at different ages.

4.5 Conclusions

Results show that the age of 15 years is a significant point in time during the developmental trajectory of metacognitive skills. It seems that the development of metacognitive skills of students between 12 and 14 years is dominated by growth, resulting in an increase in both frequency and quality of metacognitive skills. Once this growth of metacognitive skills has developed up to a certain level, development of metacognitive skills is not longer dominated by growth, but by the generalized application of these skills. Students around the age of 15 yrs. will increasingly be able to transfer the metacognitive skills that were acquired in certain tasks and domains to new tasks and domains. The present study shows that the age of 15 yrs. is a significant landmark in the development of metacognitive skillfulness on the way to adulthood.

Chapter 5

The increasing role of metacognitive skills in math: A cross-sectional study from a developmental perspective

Abstract

Both intelligence and metacognitive skillfulness have been regarded as important predictors of math performance. The role that metacognitive skills play in math, however, seems to be subjected to change over the early years of secondary education. Metacognitive skills seem to become more general (i.e., less domain-specific) by nature (Veenman & Spaans, 2005). Moreover, according to the monotonic development hypothesis (Alexander, Carr, & Schwanenflugel, 1995), metacognitive skills increase with age independent of intellectual development. This hypothesis was tested in a study with 29 second-year students (13 – 14 years) and 30 third-year students (14 – 15 years) in secondary education. A standardized intelligence test was administered to all students. Participants solved math word problems with a difficulty level adapted to their age group. Thinking-aloud protocols were collected and analyzed on the frequency and quality of metacognitive activities. Another series of math word problems served as post-test. Results show that the frequency of metacognitive activity, especially those of planning and evaluation, increased with age. Intelligence was a strong predictor of math performance in 13- to 14 year-olds, but it was less prominent in 14- to 15 year-olds. Although the quality of metacognitive skills appeared to predict math performance in both age groups, its predictive power was stronger in 14- to 15 year-olds, even on top of intelligence. It bears relevance to math education, as it shows the increasing relevance of metacognitive skills to math learning with age.

5.1 Introduction

Flavell (1976, 1979) considered metacognition as a very powerful predictor of learning performance. Based on a meta-review of studies, Wang, Haertel, and Walberg (1990) concluded that metacognition is the most important predictor of learning performance in general. At the initial stage of mathematical problem solving, metacognitive skills of orientation and planning play an important role in preventing students from a trial-and-error approach and allow students to use prior knowledge in a strategic way by determining what information is given and what is asked for (Desoete & Veenman, 2006). Metacognitive skills of monitoring and evaluation facilitate students to avoid or repair errors during the math problem-solving process, detect progression being made and compare the answer given against the problem statement (Veenman, Kok, & Blöte, 2005). In fact, metacognition is omnipresent in mathematical problem solving.

This cross-sectional study focuses on the development of metacognitive skillfulness during math problem solving. The following issues will be investigated: To what extent do metacognitive skills develop between the age of 13 and 15 years? Is there a difference in development between various components of metacognitive skillfulness? How do metacognitive skills relate to intellectual ability (IA) as predictors of math performance and, more importantly, how does this relationship develop? Answers to these questions could help us to understand when and how metacognitive skills develop and its educational consequences for math.

5.1.1 Metacognitive skillfulness

The distinction between metacognitive knowledge and metacognitive skills has been generally accepted. Metacognitive knowledge refers to the declarative knowledge one has about the interplay between personal characteristics, task characteristics, and available strategies in a learning performance (Flavell, 1979). This knowledge, however, is not always applied when necessary, even when people do have it at their disposal. Alexander, Carr, and Schwanenflugel (1995) found a discrepancy between children's knowledge about monitoring and applying monitoring skills during task performance. Winne (1996) stated that knowledge has no effect on behavior until it is actually needed. So, it is quite possible that children may have knowledge of a certain strategy at their disposal, but still do not spontaneously produce those strategies (Barnett, 2000; Focant, Grégoire, & Desoete, 2006; Pressley, Yokoi, Van Meter, Van Etten, & Freebern, 1997).

Metacognitive skills, on the other hand, refer to the procedural knowledge that is required for the actual regulation of, and control over, one's learning performance

(Brown & DeLoache, 1978; Veenman, Elshout, & Meijer, 1997). Metacognitive skills can be inferred from students' overt behavior or utterances, i.e., from concrete metacognitive activities (see Table 5.1). Some of these activities occur at the onset of task performance (orientation), during task performance (planning, monitoring, evaluation), and at the end of task performance (reflection and elaboration).

Table 5.1 Examples of math-specific and general metacognitive activities

	Math-specific	General
Orientation		
a.		Activating prior knowledge
b.		Goal setting
c.	Estimating the answer	
d.	Making a sketch of the problem in order to represent the problem	
Planning		
a.		Subgoaling
b.		Time management
c.	Designing a step-by-step action plan, instead of working by trial and error	
d.	Writing down calculations step by step	
Evaluation		
a.		Expressing non-understanding
b.		Comment on own activities
c.	Monitoring action plan	
d.	Checking an answer by recalculating	
Elaboration		
a.		Recapitulating and drawing conclusions
b.		Relating the answer to the question or problem
c.	Paraphrasing the problem	
d.	Drawing conclusions while referring to the problem statement	

Metacognitive skills appear to be highly interdependent, also for math tasks (Veenman & Spaans, 2005). When orienting thoroughly on a task, a student probably will build a deeper representation of the problem. Consequently, the student will be able to work according to a detailed plan, which enables him/her to monitor and control the learning process. Finally, such a clear trace of problem-solving activities, including repairs of errors made, provides an opportunity for learning through reflection in future occasions. Over the last few decades, several studies have focused on the use of metacognitive skills in general, while performing different tasks, for instance, reading comprehension (Markman, 1977, 1979; Pressley & Afflerbach, 1995; Veenman & Beishuizen, 2004) or problem solving (Carr & Jessup, 1995; Christoph, 2006; Mevarech & Fridkin, 2006; Schoenfeld, 1992; Veenman & Spaans, 2005; Veenman, Wilhelm, & Beishuizen, 2004). Others focused on one or more separate components of metacognitive skills, such as planning (Shore & Lazar, 1996; Focant et al., 2006) or monitoring skills (Mengelkamp & Bannert, 2008).

This study, however, focused on all metacognitive skills prior to, during and after task performance in math. Hence, orientation, planning, monitoring as well as reflection skills have been included in this study.

5.1.2 Development of metacognitive skills

The first objective of this study was to investigate the development of metacognitive skillfulness during math performance in particular. Flavell (1992) related the concept of metacognition to Piaget's developmental stage of formal-operational thinking (Inhelder & Piaget, 1958). At this stage, children are capable of hypothetico-deductive reasoning, which requires metacognitive control. Flavell indicated that Piaget did not expect metacognition to show up before the stage of formal-operational thinking had been reached. More recent studies, however, show that, alongside with the "theory of mind", i.e., understanding of one's own and other people's state of mind, (Wellman, 1990), young preschoolers already start to develop a metacognitive awareness (Blöte, Van Otterloo, Stevenson, & Veenman, 2004; Demitriou & Efklides, 1990; Kuhn, 1999). In later childhood, not only metacognitive knowledge, but also metacognitive skills develop. Although Whitebread et al. (2009) found some planning and monitoring activities in playful situations with youngsters as young as 5 years old, it is generally assumed that the development of metacognitive skills in educational contexts commences around the age of 8-10 years (Berk, 2006; Kuhn, 1999; Siegler, 1998; Veenman, Van Hout-Wolters, & Afflerbach, 2006).

From a developmental perspective, it is interesting to investigate the development of the aforementioned four components of metacognitive skillfulness in relation to each other. To be able to offer students an appropriate metacognitive instruction in math, it would be useful to understand more about the development of these specific skills, in particular, about the sequence in which they develop over the years. Focant et al. (2006)

found positive and significant relations between planning and control activities, on the one hand, and school achievement, on the other. They also found that most children are able to correctly specify the goals of an arithmetical problem at the end of elementary school. On the other hand, they found that most children, although possessing sufficient content knowledge, did not succeed in detecting their errors. Apparently, monitoring and evaluation are more abstract metacognitive skills that arise later in the developmental trajectory (Veenman et al., 2006).

Studying the developmental trajectory of metacognitive skillfulness in math, two different measurement perspectives can be taken: The quantity and the quality of metacognitive skills. Quantity concerns the frequency of applying those skills, whereas quality concerns their level of adequate utilization. Using metacognitive skills more frequently does not automatically mean that the metacognitive skills have a higher level of quality. More is not always better. In a cross-sectional study concerning the quantity of metacognitive skills, Veenman et al., (2004) found a linear growth in the quantity of metacognitive skills between the age of 9 and young adults when performing a discovery-learning task. In another study (Veenman & Spaans, 2005), a significant growth of the quality of students' metacognitive skills (12 – 15 years) was found for both discovery-learning task and a problem-solving task. In a pilot study, Veenman (2006) found a similar growth in metacognitive quality for math between 12 and 15 years. In line with these results we expect metacognitive skills in mathematics to increase in frequency as well as in quality over the years.

The second objective of this study was to investigate the relation between metacognitive skills, intellectual ability, and learning performance in math from a developmental perspective. Several researchers (Alexander et al., 1995; Borkowski & Peck, 1986; Cheng, 1993; Hannah & Shore, 1995; Schneider & Pressley, 1997; Span & Overtoom-Corsmit, 1986; Veenman, 2006; Veenman & Spaans, 2005; Veenman et al., 2004; Zimmerman & Martinez-Pons, 1990) investigated metacognitive ability in relation to intellectual ability. In the next section, this relation will be discussed.

5.1.3 Relation between metacognitive ability, intellectual ability, and learning performance in math from a developmental perspective

Veenman (Veenman et al., 1997, 2004; Veenman & Spaans, 2005) described three mutually exclusive models concerning the relation between intellectual ability and metacognitive skillfulness as predictors of learning performance. The *intelligence* model regards metacognitive skillfulness as an integral part of intellectual ability. In this model, metacognitive skillfulness does not contribute to learning performance independent of intellectual ability. According to this model, metacognitive skills cannot have a predictive value for learning performance independent of intellectual ability. Sternberg (1990), for instance, advocates such an inclusive position of 'metacomponents' in his triarchic theory of intelligence. The second, contrasting model is the *independency* model, in which intellectual ability and metacognitive skillfulness are regarded as entirely independent predictors of learning performance. Finally, in the *mixed* model, intellectual ability and metacognitive skillfulness are correlated to a certain extent, but metacognition has its own, unique contribution to the prediction of learning performance, on top of intellectual ability.

Over the last decades, support has been found for each of these models by various researchers (for an overview, see Veenman & Spaans, 2005; Veenman et al., 2004). However, it is difficult to compare many studies, due to dissimilarities in the assessment method of metacognitive skillfulness (thinking aloud observations vs. questionnaires), in participants (age, educational background), and in tasks and domains. Moreover, the focus of some studies is restricted to the relation between intellectual ability and metacognitive skillfulness, thereby excluding the relation of both predictors with learning performance (Alexander et al., 1995; Berger & Reid, 1989; Span & Overtoom-Corsmit, 1986; Shore & Dover, 1987; Stankov, 2000). The evidence found so far seems to be highly in favor of the mixed model. Many studies, however, deal with the metacognitive skillfulness of older secondary-school or university students. From the perspective of the development of metacognitive skills, it remains to be ascertained more thoroughly whether the mixed model can be generalized to younger students at the crucial point of developing initial metacognitive skills. Therefore, in the present study, the participants are young secondary-school students (aged 13 – 15 years) who are engaged in performing math school tasks.

From a developmental perspective, a relevant research question is whether the development of metacognitive skills is intelligence related or relatively intelligence independent according to the mixed model. Alexander et al. (1995) formulated three developmental hypotheses with regard to the relation between intellectual ability and the development of metacognition, though excluding the relation of both predictors with learning performance. The ceiling hypothesis assumes that the effects of intelligence on the development of metacognition diminish over time. The acceleration hypothesis, on the other hand, predicts that the impact of intelligence on the development of metacognition increases with age. The monotonic development hypothesis, finally, assumes that both intelligence and metacognition show a monotonic growth over age. When taking the relations of both predictors with learning performance into account, the last hypothesis would be in line with the mixed model, as both intellectual ability and metacognition would have a substantial independent contribution to learning outcomes. Support for the intelligence model, on the other hand, would support the acceleration hypothesis as the influence of intellectual ability on metacognition would increase with age. Finally, the ceiling hypothesis predicts that the intelligence model will fit less with age. The independency model fits none of Alexander's hypotheses, since it predicts there is no relation between intelligence and metacognition at all. In their literature overview, Alexander et al. (1995) found support for the monotonic development of metacognitive knowledge. Gifted children showed a general superiority in their declarative metacognitive knowledge. Giftedness effects were persistent throughout childhood, with gifted early elementary school children showing a similar superiority in this knowledge as did junior high school students. With regard to metacognitive skills, however, the results were inconclusive. In a cross-sectional study, Veenman (2006) and Veenman and Spaans (2005) obtained evidence in favor of a monotonic development of metacognitive skills. They obtained support for a monotonic maturation effect of both intellectual ability and metacognitive skillfulness in students of 12 and 15 years performing various problem-solving tasks. We hypothesize that metacognitive skillfulness develops alongside, but is not fully dependent on intellectual ability. Therefore, we expect to find a parallel development of metacognitive skillfulness and intellectual ability as predictors of math learning performance in line with the mixed model and the monotonic development model.

5.1.4 Research questions and hypotheses

The first research question is whether metacognitive skills in math do develop over age. We expect these metacognitive skills to increase in frequency as well as in quality over the years. The second research question relates to the development of the relation between metacognitive skills, intellectual ability, and math performance. We expect to find a parallel development of metacognitive skills and intellectual ability as predictors of math performance in line with the monotonic development hypothesis and the mixed model.

5.2 Method

5.2.1 Participants

Twenty-nine second-year students (13 – 14 years; 11 boys and 18 girls) and 30 third-year students (14 – 15 years; 12 boys and 18 girls) in secondary education participated in this study. They were recruited from three different tracks (pre-university education, higher general education and pre-vocational education) of two suburban schools in the Netherlands. Both schools are well known because of their large diversity of children, thus representing a broad educational level of the students, a broad range of social economic status of parents, and various ethnic backgrounds. Participants were distributed equally over the three tracks. Students with learning or conduct disorders (e.g., dyslexia or ADHD) were excluded from the study. Parental consent was requested and given for all participants.

5.2.2 Metacognitive skillfulness

Thinking-aloud protocols were analyzed on spontaneous use of metacognitive skills according to the procedure of Veenman (Prins, Veenman, & Elshout, 2006; Van der Stel & Veenman, 2008; Veenman & Spaans, 2005; Veenman et al., 2004). Metacognitive skillfulness was divided into four subscales: orientation (O), planning and systematical orderliness (P), evaluation (Ev), and elaboration (El). In Table 5.1, examples of such activities are given for each subscale of metacognitive skillfulness. These activities are partly characteristic of metacognitive skillfulness, in general (Brown, 1978; Sternberg, 1990; Veenman et al., 1997), and partly domain-specific for math (de Corte & Verschaffel, 1980; Gagné, Yekovich, & Yekovich, 1993; Schoenfeld, 1983). For example, goal setting is an activity independent of tasks and domains. Writing down calculations step-by-step, on the other hand, is related to a math task, whereas in a text-studying task, summarizing the text after each paragraph is considered as a planning activity. Note that some of the behavior in Table 5.1 may be considered as cognitive, but the purposeful application of such cognitive behavior at the appropriate moment results from metacognitive skillfulness. It reflects the intention to get control over and regulate the cognitive task. For example, the recalculation of the answer itself is cognitive by nature, but it is the decision to check one's outcomes at a particular point in time that constitutes the metacognitive nature of the activity.

The scoring method consisted of two steps for each protocol. First, an utterance was coded in the margin if belonging to one of the four subscales (O, P, Ev, or El). This resulted in a quantitative score obtained by counting the frequency of metacognitive activities on each subscale (e.g., if a student checked the calculations five times, the quantitative score for evaluation was five). Secondly, for each subscale, the criteria that should be met to obtain a certain rate for the quality of metacognitive skillfulness were described. So, each subscale received a qualitative score according to the formulated criteria on a five-point scale (ranging from 0 to 4). For example, a participant received a higher score for a 'deeper' orientation (e.g., making a sketch of the problem to represent the problem) than for a superficial one (e.g., only partly reading the problem statement). It is important to emphasize that the judges intentionally avoided confounding metacognition scores with the correctness or incorrectness of the content matter. A properly argued, yet incorrect, conclusion would yield a similar score for elaboration as a correct conclusion would.

Two judges independently rated six protocols of both years. This resulted in an interrater reliability of 0.95 (second year) and 0.98 (third year) for the qualitative scores, and 0.94 (second year) and 0.86 (third year) for the quantitative scores. These correlations were computed on the summed scores over the four subscales of metacognition.

5.2.3 Intellectual ability

In two group sessions, the intellectual ability of 59 students (29 second and 30 third year) was assessed by a series of ability tests. Three subtests of the Groninger Intelligence test for Secondary Education (GIVO, standardized Dutch intelligence test; Van Dijk & Tellegen, 1994) were selected: Number Series, Verbal Analogies and Unfolding Figures. With these subtests three primary factors of intelligence (Carroll, 1993) were assessed: Inductive and deductive reasoning abilities, both verbal and numerical, and visuospatial ability. The GIVO, however, lacks a test for assessing memory abilities, another primary factor in Carroll's (1993) model. Therefore, a fourth test (Names & Professions, requiring the memorization of word pairs; see Veenman & Beishuizen, 2004) was administered. A total score for intellectual ability was calculated by transforming the individual test score into *z* scores and then calculating an unweighted mean score for each participant.

5.2.4 Tasks

For each year, participants were administered math tasks with task demands suitable for their age. The tasks were piloted with appropriate age groups beforehand and teachers were consulted about the suitability of the tasks.

In an individual session of 50 minutes, the participants learned to solve mathematical word problems in 20 minutes. Six problems were presented in the second year and five in the third. Several categories of problems were presented. In the second year, the categories of the problems were content, surface area of a triangle, fraction, percentage, algebra. For instance, an algebraic problem was 'In a village are two camping sites. At the first one you pay for the rent of a caravan 20 euros cleaning costs plus 5 euros a day. At the second one you pay 40 euros cleaning costs and two euros a day. Which site would you choose if you wanted to stay eight days? Show your calculations'. In the third year, the categories of the problems were calculation of probability, quadratic equation, Pythagoras' theorem, statistics, and formula with a square root. For instance, a problem was 'In the center of a city the air pollution on one day is given by the formula $V = -0.2t^2 + 3.1t + 1.7$, where V = air pollution in grams per m^3 and t = point in time in hours. A) Calculate V for 8.15 a.m. B) Calculate the percentage of difference in pollution between 7 and 11 a.m.' Both tasks for second- and third-year students were composed of adaptations of math problems from one of the most frequently used Dutch schoolbooks for math ("Getal en Ruimte"; Vuijk et al., 2003).

Together with the assignments, participants received a sheet containing the answers and a brief stepwise explanation of how to solve the problems. Participants were free to consult this sheet whenever and as much as they liked. The first 20 min of the session was considered as a learning-by-doing phase. Next, the participants handed in all materials and received another series of parallel problems, which had to be solved without any help in the remaining 30 min. This second part was considered as a post-test assessment of learning performance (see Sect. 5.2.5). All problems had to be solved while thinking aloud.

5.2.5 Learning performance

After the learning-by-doing phase, the learning performance was assessed by the post-tests, as was explained to the participants in advance. In both years, the post-test items were parallel to the items in the learning phase, i.e., the surface structure of the post-test items differed from the one in the learning task items, but the deep structure was the same.

In the second year, the post-test consisted of six math word problems. For each problem, an equal amount of ten points could be earned. According to a rating system, points were given for the steps that had to be made to come to a correct solution. So, the maximum obtainable score was 60 points. A total score was calculated and used as a measure of learning performance. Cronbach's α was 0.66. In the third year, the post-test consisted of five math word problems. The items were rated in the same way as in the 2^{nd} year. The maximum obtainable score was 50 points. Cronbach's α was 0.67.

5.2.6 Procedure

The intellectual ability test was administered during a group session of 100 min. The math tasks were presented in an individual thinking-aloud session of 50 min. Participants could make use of a pen, pencil, text highlighter, ruler, calculator, and blank sheets of paper for making notes and/or calculations.

All participants were instructed to think aloud during the individual session. The experimenter was not allowed to help the students in any way. To encourage the student to keep on thinking aloud, the experimenter used standard prompts (e.g., 'please, keep on thinking aloud') whenever the student fell silent. All the utterances of the participants were audio-taped, transcribed, and analyzed in relation to metacognitive skillfulness.

5.3 Results

5.3.1 Development of metacognitive and intellectual abilities

In order to establish a continuous growth in both metacognitive and intellectual abilities, the results of both age groups (second- and third-year students) were compared. First, MANOVAs were performed on the metacognition and intellectual ability scores with age as between-groups factor. Next, univariate tests were performed. Results of the MANOVA on the raw scores of intellectual ability revealed a significant age effect [$F(4,54) = 3.93$, $p < 0.01$, $\eta^2 = 0.23$]. Third-year students had a higher intellectual ability score than second-year students. Results of the MANOVAs on both the quantitative [$F(4,54) = 13.84$, $p < 0.001$, $\eta^2 = 0.51$] and the qualitative [$F(4,54) = 4.90$, $p < 0.005$, $\eta^2 = 0.27$] scores of metacognitive skills revealed a significant age effect as well. So, third-year students had higher metacognition scores than second-year students. Thus, both intellectual and metacognitive abilities show an increase between the second and third year in secondary education.

Results of the subsequent univariate tests on the subscales of intellectual ability and metacognition scores show a significant growth over the years (see Table 5.2). With the exception of the quantity of orientation activities, results of the univariate tests show an increase in all the components of intellectual and metacognitive abilities.

Table 5.2 Comparison of the results second and third year

	2nd year (*N*=29) *M* (SD)	3rd year (*N*=30) *M* (SD)	*F*	*p*	η^2
Quality of meta skills					
Orientation	1.69 (.76)	1.93 (.94)	1.19	n.s.	0.02
Planning	1.83 (.80)	2.73 (1.11)	12.77	<0.005	0.18
Evaluation	1.14 (.88)	1.93 (1.14)	8.97	<0.005	0.14
Elaboration	0.83 (.85)	0.90 (1.19)	0.07	n.s.	0.00
Quantity of meta skills					
Orientation	7.90 (1.54)	5.13 (3.20)	17.62	<0.001	0.24
Planning	5.31 (2.42)	8.83 (3.98)	16.76	<0.001	0.23
Evaluation	2.62 (2.47)	7.07 (4.30)	23.53	<0.001	0.29
Elaboration	0.83 (.90)	1.80 (2.19)	4.94	<0.05	0.08
Intellectual ability					
Number series	17.28(4.42)	21.07(3.71)	12.77	<0.005	0.18
Verbal analogies	13.79(3.92)	16.07(3.45)	6.56	<0.05	0.10
Unfolding figures	13.79(3.92)	16.37(3.94)	6.31	<0.05	0.10
Memory	17.24(5.52)	19.17(6.12)	2.45	n.s.	0.04

Note: Because the total scores for Intellectual ability were transformed into *z* scores, the means and standard deviations for Intellectual ability are the scores for the subtests of the intelligence test and the memory test.

5.3.2 Development of the relation between intellectual and metacognitive abilities as predictors of math performance: Testing the mixed model and the monotonic development hypothesis

To be able to answer the question whether developmental processes affect the relation between intellectual ability, metacognitive skillfulness, and math performance, correlations between these three variables were calculated for both groups separately (see Table 5.3). In the correlational analyses, the subtest scores for intellectual ability were transformed into one total score. This IA score was obtained by transforming the raw scores on all subtests into *z* scores and then calculating the mean *z* score for second- and third-year students separately (see Sect. 5.2.3). The total score of the quantity of metacognitive skillfulness was obtained by adding the quantitative subscale scores of metacognition. The same procedure was repeated for the quality of metacognitive skillfulness.

Table 5.3 Correlations between intellectual ability, metacognition, and math performance for both age groups separately

	SECOND YEAR			THIRD YEAR		
	Intellectual ability	**MetaQL**	**MetaQN**	**Intellectual ability**	**MetaQL**	**MetaQN**
Math performance	0.79**	0.53**	0.29	0.46*	0.78**	0.40*
MetaQL	0.46**			0.37*		
MetaQN	0.39*	0.73**		0.16	0.74**	

MetaQL the total score on the quality of metacognition, MetaQN the total score on the quantity of metacognition * $p < 0.05$ ** $p < 0.01$

Results show that nearly all correlations between intellectual ability, quantity and quality of metacognitive skillfulness, and math performance were significant. The only exceptions were the correlation between the quantity of metacognitive skillfulness and math performance (second year) and the correlation between intellectual ability and the quantity of metacognitive skillfulness (third year).

To test the mixed model, the semi-partial correlations for both groups (Nunnally, 1967) were calculated by partialling metacognitive skillfulness from the correlations between intellectual ability and math performance (i.e., semi-part Intel) and partialling intellectual ability from the correlation between metacognitive skillfulness and math performance (i.e., semi-part Meta). These semi-partial correlations (see Table 5.4) are needed to calculate the unique contribution of metacognitive and intellectual abilities to math performance.

Table 5.4 Semi-partial correlations

	Semi-part Intel second year		Semi-part Meta second year		Semi-part Intel third year		Semi-part Meta third year	
	QL	**QN**	**QL**	**QN**	**QL**	**QN**	**QL**	**QN**
Math performance second year	0.58**	0.70**	0.21	0.00				
Math performance third year					0.19	0.41**	0.65**	0.33*

QL qualitative metascores; QN quantitative metascores * $p < 0.05$ ** $p < 0.01$

Using regression-analytic techniques (Pedhazur, 1982; Van der Stel & Veenman, 2008; Veenman & Spaans, 2005; Veenman et al., 2004), the unique and shared variances in the math performance were distributed to metacognitive skillfulness and intellectual ability (see Table 5.5). The math data of the second-year students could be taken as an example. The squared multiple correlation of intellectual ability and metacognitive skillfulness for predicting the math performance was calculated from the correlations presented in Tables 5.3 and 5.4 (R^2 = the squared correlation between intellectual ability and math performance + the squared semi-partial correlation between metacognitive skillfulness and math performance with intellectual ability partialled out = $0.79^2 + 0.21^2 = 0.67$). The unique contribution of intellectual ability to math performance was determined by calculating the squared semi-partial correlation between intellectual ability and math performance with metacognition partialled out from intellectual ability ($r^2 = 0.336$). Consequently, it was estimated that intellectual ability uniquely accounted for 33.6% of the variance in math performance, metacognitive skillfulness accounted for 4.3% of the variance, while both predictors had another 23.9% of variance in common. This procedure was applied for both age groups (see Table 5.5).

Table 5.5 Percentage of variance accounted for in math performance

	Intel unique		Meta unique		Shared		Total	
	QL	QN	QL	QN	QL	QN	QL	QN
Math performance second year	33.6	49.1	4.3	0	23.9	8.4	61.8	57.8
Math performance third year	3.5	16.5	42.8	10.6	17.9	4.9	62.4	32.0

Intel unique the unique contribution of intellectual ability to math performance; *Meta unique* the unique contribution of metacognitive skillfulness to math performance; *Shared* the shared contribution of intellectual ability and metacognitive skillfulness to math performance. *Total* the total contribution of intellectual ability and metacognitive skillfulness to math performance. *QL* qualitative metacognition scores, *QN* quantitative metacognition scores

In both age groups, intellectual ability as well as the quality of metacognitive skillfulness have their own, unique contribution to the prediction of math performance. In the youngest group, however, there is no unique contribution of the quantity of metacognitive skillfulness to the prediction of math performance. Comparison of the unique contribution of the quality of metacognitive skillfulness in relation to the contribution of intellectual ability over the years shows that the roles have been turned around. In the youngest group, intellectual ability is the most important predictor of math performance, whereas in the oldest group the contribution of the quality of metacognition outweighs the unique contribution of intellectual ability.

5.4 Discussion

This study investigated the development of both the quantity and the quality of metacognitive skillfulness in math. According to the first hypothesis, we expected a growth in metacognitive skills in math, both in frequency and in quality over the years. Results show an overall growth of quantitative and qualitative metacognitive skillfulness, indeed. Looking closer into the various components of metacognitive skillfulness (orientation, planning, evaluation, and elaboration), results show a significant growth of both the quantity and the quality of planning and evaluation activities. It seems that not only the quantity of these activities increased significantly between 13 and 15 years, but that also the quality of these activities developed in a positive way. The quantity of orientation activities, on the other hand, decreased significantly, which decrease was not reflected in the quality of orientation activities. Possibly, students become more selective in their orientation activities over the years, resulting in fewer, but perhaps better, orientation activities. Also, Mevarech and Amrany (2008) report about students who did not report to have attempted to comprehend a problem prior to solving it. Finally, the elaboration activities show a significant growth in frequency, but not in quality. Although students increased the number of their elaboration activities between 13 and 15 years, they seem to experience a problem in abstracting knowledge as a result of these activities. In conclusion, the first hypothesis that the metacognitive skills in math would increase in frequency as well as in quality over the years is generally corroborated. However, results also show that the various components of metacognitive skillfulness differ in their developmental trajectory. "The ages on which strategies are acquired seem to depend largely on the strategy itself" (Focant et al., 2006, p. 61).

It seems that the metacognitive activities that are required during task performance (planning and evaluation) develop in an earlier phase than activities that play a role prior to (orientation) and after (elaboration) task performance. It might be that students experience the activities during task performance as more concrete and, therefore, easier. Maybe teachers pay more attention to overt activities during task performance than to less obvious activities prior to or after task performance.

From an instructional perspective, it would be interesting to learn more about the development of specific components of metacognitive skillfulness and, in particular, the sequence and the pace in which they develop over a longer period of time (Veenman, Van Hout-Wolters, & Afflerbach, 2006). This would require longitudinal research over an extended period of time.

The second hypothesis concerned the relation between metacognitive skillfulness and intellectual ability as predictors of math performance over the years. The results for both age groups were in line with the mixed model as far as it concerned the qualitative scores for metacognition. As we expected, metacognitive skillfulness and intellectual ability were moderately correlated. Moreover, metacognitive skillfulness ability had its own, unique contribution to math performance in both age groups, on top of intellectual ability. These results are similar to those for older age groups performing different tasks (Veenman & Beishuizen, 2004; Veenman & Verheij, 2003; Veenman et al., 2004). Therefore, the mixed model can be generalized to younger students with less developed metacognitive skills performing everyday math school tasks. For the quantity of metacognitive skills, the mixed model could not be corroborated for the youngest group, as no unique contribution of the quantity of metacognition to math performance was obtained, contrary to the older group of students. On comparing both age groups, an interesting shift in the contribution to math performance occurs. The roles of metacognitive skills and intellectual ability as predictors of math performance have been turned around between 13 and 15 years. In the youngest group, intellectual ability is the most important predictor of math performance, whereas in the oldest group, the contribution of the quality of metacognition outweighs the unique contribution of intellectual ability. The correlation between both predictors of math performance, however, remains practically the same for both age groups. Evidently, it is the growth of metacognitive skills that demand a more prominent role in math performance of older students.

A parallel development of metacognitive skillfulness and intellectual ability as predictors of math performance was found. This parallel growth is in line with the monotonic development hypothesis. Earlier, Alexander et al. (1995) found a different developmental pattern in the metacognition of gifted and non-gifted children. However, developmental patterns were not consistently found over the different components of metacognition. They obtained evidence in favor of a monotonic development of metacognitive knowledge, but their results were inconclusive on metacognitive skills. The results of our study point in the direction of a monotonic development in metacognitive skills as well: A continuous growth of metacognitive skills with age, alongside intellectual growth (Veenman et al., 2004), corroborating the second hypothesis.

This study focused on students with a normal cognitive development, without learning disabilities or conduct disorders. Participants did not receive any explicit training on metacognition prior to the experiments. Therefore, the growth in metacognitive skillfulness can be considered (partly) as a spontaneous development due to maturation. Testing the metacognitive skillfulness of third graders with mathematical learning disabilities, Desoete (2006), however, found evidence against the maturational development. She found that these children had significantly less accurate evaluation skills on number system knowledge and procedural calculation than younger children with comparable mathematical performance scores. Based on these findings, Desoete (2006) stated that we cannot expect metacognition to develop spontaneously as children grow older or as they have more experience with math. Differences in findings can be caused by differences in participants (age, mathematical disabilities) and/or by differences in assessing metacognition (thinking aloud during task performance vs. interviews prior to and after task performance.

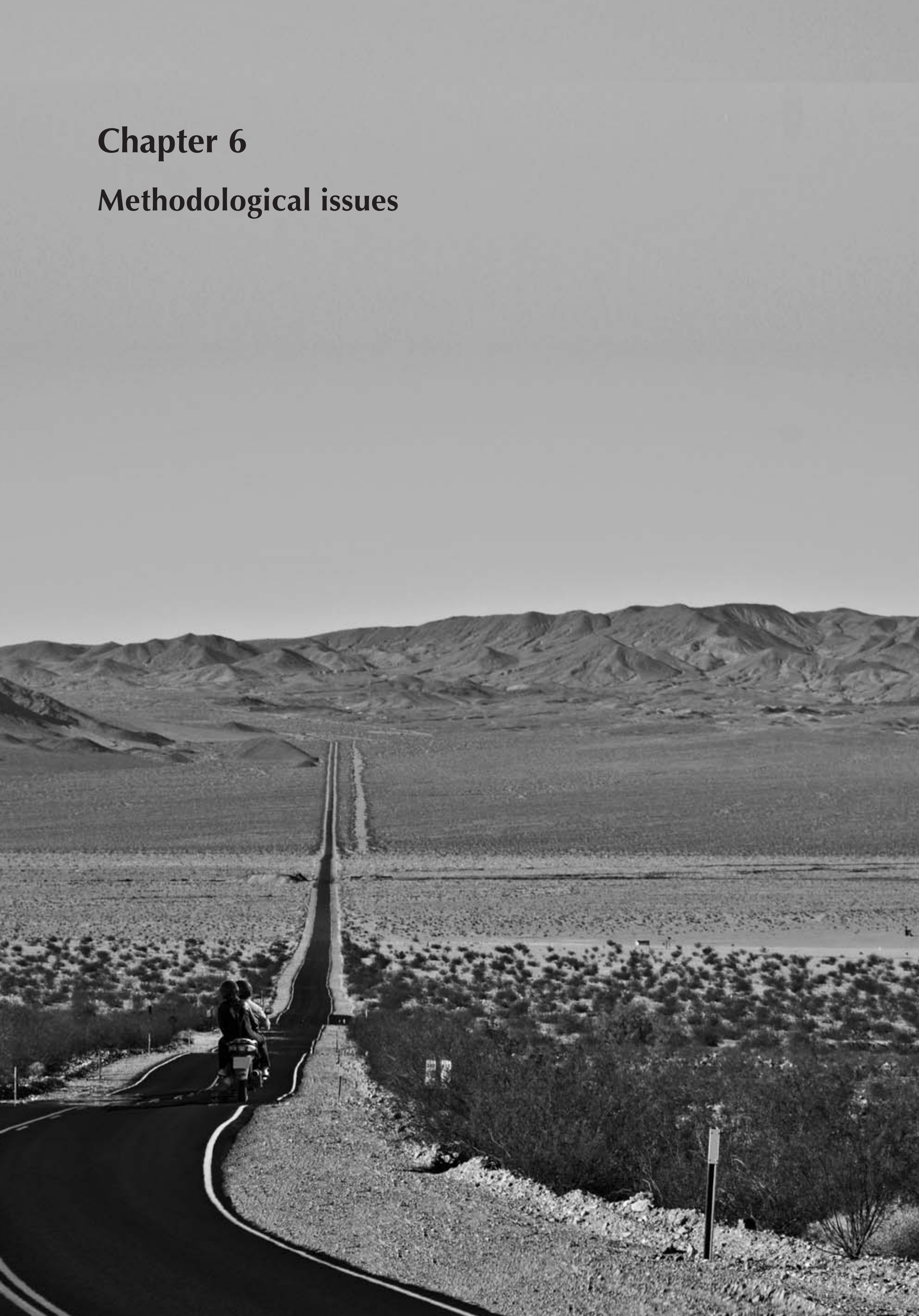
Despite finding significant results, there might be some limitations of the study. The small number of participants in each group may be considered as a limitation of the generalizability of the results. The same applies for the fact that all participants came from only two schools. Although both schools were highly representative of secondary schools in the Netherlands, yet some confirmation of results from a broader population of schools is needed. Furthermore, it would be interesting for future research to replicate this study with more participants in a longitudinal study over a longer period of time. Special attention should be paid to the developmental trajectory of specific components of metacognitive skillfulness, especially their relation with math performance. At present, studies with multi-method designs are scarcely available in the literature on metacognition. Therefore, it would be worthwhile to have more studies with a multi-method design in order to compare off-line and on-line methods of assessment (Van Hout-Wolters, 2000; Veenman, 2005).

Although metacognitive skills in math seem to develop (partly) as a result of maturation, there are substantial individual differences in the level of metacognitive skillfulness during the developmental trajectory. An important issue in the educational context is, therefore, how the development of metacognitive skills in math can be enhanced. In the past, various instructional methods to enhance metacognitive skillfulness in math have been developed and used with success. Mevarech and Kramarski (1997) developed a training program called IMPROVE. With this program, students are taught to use a series of metacognitive questions during math tasks. Veenman (1998) formulated the WWW&H rule for training metacognition, referring to instructions about

What metacognitive activities should be executed When, Why, and How. Van Luit and Naglieri (1999) developed a program (MASTER) for teaching math to children in special education. Results with these training methods show that children, varying substantially in intellectual and metacognitive abilities, can benefit from training their metacognitive competencies in math. Training metacognitive skillfulness in math could be very useful as a supplement to the spontaneous development, especially if the right component is trained at the right moment in the developmental trajectory.

Chapter 6

Methodological issues



Although calls for longitudinal designs in developmental studies are frequently made, the vast part of developmental studies consists of studies with a cross-sectional design. “Although the goal of developmental psychology is to understand change in behavior across the life span, most empirical work provides only a short snapshot view of behavioral change, because most developmental research infers change by comparing *different* people of *different* ages (cross-sectional studies) rather than attempting to follow change within the same people over time (longitudinal studies studying intra-individual changes)” (Bullock & Schneider, 2009, p. 1). One of the most important reasons for this lack of longitudinal studies is a pragmatic one. Longitudinal studies not only require an investment in time and resources, but the researcher also has to deal with the risk (and the possible consequences) of participants dropping out before data collection has been finished. In this chapter some methodological issues related to the longitudinal design of this thesis are discussed.

6.1 Participants

At the start of the data collection in 2005, 32 first-year secondary-school students were included in the study. They were recruited from 85 students (for further details see Chapter 2, sections 2.2.1 and 2.2.2). Unfortunately, the repeated presentation of two tasks each year for three consecutive years and the very time-consuming, and labor-intensive analysis of thinking-aloud protocols of individual student sessions did not allow for a larger sample. All students came from the same school located in one of the largest cities in the Netherlands. This particular school is known because of its large diversity of children, thus representing a broad educational level of students, a broad range of social economic status of parents, and various ethnic backgrounds. The choice for just one school was deliberately made to avoid confounding variables, such as differences in teachers, pedagogical and/or didactic philosophy, schoolbooks, etc.

As stated above, a longitudinal design always risks an early dropout of participants, resulting in an unrepresentative sample. Loss of participants also happened in this study. After the first year, four participants dropped out due to a change of residence or school. From the remaining 28 students in the second year, three students were lost after the second year for the same reasons. This resulted in 25 participants in the third year. As long as there is no selective drop out, the loss of participants will not necessarily affect the results. Therefore, several checks were performed in order to assess any effect that might have resulted from the dropout.

In Table 6.1 descriptives for the first-year participants are shown. Intellectual-ability scores were transformed into z-scores, resulting in a mean of 0 and a standard deviation (*SD*) of 1. Participants, however, were equally distributed over the four quartiles. Unfortunately, boys and girls were not equally represented (12 boys, 20 girls), but no effect of gender was found. The average age was 12 years and 8 months. By calculating the skewness (see Table 6.1) of the independent variables (intellectual ability and metacognitive skills), it was investigated whether the scores on intellectual ability and metacognition were divided symmetrically. Results of correlational analyses and t-tests would be affected by a skewness larger than 1 (De Vocht, 2009).

Table 6.1 Descriptives participants 1st year

1st year *N*=32	Intellectual ability	Meta QLHis	Meta QLMath	Meta QNHis	Meta QNMath	LP Hist	LP Math
Mean (*SD*)	0.00 (1.00)	5.03 (3.40)	6.09 (3.30)	17.34 (12.83)	21.75 (8.60)	8.46 (3.28)	4.43 (2.53)
Skewness	.44	.36	.80	.85	.43		

Note: MetaQLHis means qualitative scores for metacognitive skills in history; MetaQLMath means qualitative scores for metacognitive skills in math. MetaQNHis means quantative scores for metacognitive skills in history; MetaQNMath means quantitative scores for metacognitive skills in math; LP means Learning performance.

Although the skewness of intellectual-ability and metacognition scores was smaller than .85, scores of both variables were further checked by transforming them into square root scores. According to Tabachnick and Fidell (2007), such a transformation would neutralize a skewed distribution. Transformed scores, however, did not alter the results of correlational analyses (see Chapter 2, Tables 2.3 and 2.4).

In order to find cases with exceptional values that would have a strong and undesirable impact on the results, Leverage values and Cook's distance were calculated (De Vocht, 2009). All cases had a Leverage value smaller than 0.5 and a Cook's distance smaller than 1, meaning that no cases had an extreme impact on the results. Therefore, no participants were to be excluded.

The same procedure was applied to the data of the second year and the third year. Again the skewness of both intellectual ability and metacognition was smaller than 1, and all cases had a Leverage value smaller than 0.5 and a Cook's distance smaller than 1. Transformation into square root scores did not lead to other conclusions.

Furthermore, the participants that dropped out after the first year and the second year have been examined more closely. After the first year, two boys (one out of the 4th quartile of intellectual-ability scores and one out of the 3rd quartile) and two girls (both out of the 4th quartile) were lost. None of these dropouts had the highest or lowest scores on intellectual ability, metacognitive skills, or learning performance. It was also investigated whether the results of the dropouts differed significantly from those of the 'stayers'. Therefore, ANOVAs were performed on the scores on intellectual ability, metacognitive skills, and learning performance, contrasting the dropouts with the rest of the participants. No significant differences were found. Because the number of dropouts was only four and their scores were not normally distributed, Mann-Whitney tests were performed too. This test is a non-parametric test without requirements of the sample distribution**.** No significant differences were found either (see Table 6.2).

Table 6.2 Results ANOVA and Mann-Whitney comparing results dropouts and 'stayers' after the first year

***N*=32**	***F***	**Sig**	**Asymp. sig**
Intellectual ability	3.51	.07	.07
MetaQLHis	.23	.63	.71
MetaQNHis	.00	.99	.75
LPHis	.02	.89	1.00
MetaQLMath	.49	.49	.55
MetaQNMath	.30	.58	.77
LPMath	.33	.57	.66

Note: MetaQLHis means qualitative scores for metacognitive skills in history; MetaQLMath means qualitative scores for metacognitive skills in math. MetaQNHis means quantative scores for metacognitive skills in history; MetaQNMath means quantitative scores for metacognitive skills in math; LP means Learning performance.

In conclusion, there was no indication of selective loss of participants after the first year. Both ANOVAs and Mann-Whitney tests did not reveal any significant differences between dropouts and 'stayers'. Moreover, the loss of four participants from the sample resulted in a perfect skewness (0.00) for intellectual-ability scores of the second year. In the second year no effect of gender was found either.

After the second year, another two boys (one out of the 1st quartile of intellectual-ability scores and one out of the 3rd quartile) and one girl (out of the 1st quartile) were lost. Again no effect of gender was found. Tests for significant differences between the dropouts and the rest of the participants were repeated on the data of the second year (see Table 6.3).

Again ANOVA nor Mann-Whitney tests revealed a significant difference between dropouts and 'stayers'. The participants that dropped out after the second year did not have any extreme scores either. These tests lead to the conclusion that participants, who dropped out of the sample after the first year and the second year, did not cause a selective loss and, therefore, did not affect the results of the longitudinal study.

Table 6.3 Results ANOVA and Mann-Whitney comparing results dropouts and 'stayers' after the second year

N=28	*F*	Sig	Asymp. sig
Intellectual ability	.96	.34	.35
MetaQLHis	1.64	.21	.15
MetaQNHis	.69	.41	.33
LPHis	2.11	.16	.12
MetaQLMath	.69	.41	.50
MetaQNMath	.82	.37	.30
LPMath	1.57	.22	.17

Note: MetaQLHis means qualitative scores for metacognitive skills in history; MetaQLMath means qualitative scores for metacognitive skills in math. MetaQNHis means quantative scores for metacognitive skills in history; MetaQNMath means quantitative scores for metacognitive skills in math; LP means Learning performance.

6.2 Intellectual ability and Metacognitive skills

6.2.1 Intellectual ability

Although intellectual ability generally is considered as a rather stable person-related feature at the age of 13, intellectual ability was repeatedly measured each year. In order to be able to answer the research question whether intellectual ability and metacognitive skills develop in line with the monotonic development hypothesis, a measure for *growth* of intellectual ability was needed. Raw scores on the various subtests were used, because norm scores would have ruled out age effects. Although there was a period of one year between two consecutive assessments, it could be argued that a repeated measure of intellectual ability involves a test-retest effect. However, no substantial intra-individual changes in test scores were observed: Over the years 85% of the participants remained in the same quartile or at the boundary between two quartiles. Therefore, it is not likely that the repeated assessments of intellectual ability yielded a test-retest effect that would distort the results of the correlational analyses (see Chapter 2, Tables 2.3 and 2.4, Chapter 3, Table 3.3, Chapter 4, Table 4.2).

To establish whether intellectual-ability scores over the three consecutive years represented the same construct, correlations of intellectual-ability scores over the three years were calculated (see Table 6.4) and a principal component analysis (PCA) was performed on subscale level (see Table 6.5; see Appendix C for correlations on subscale level).

Table 6.4 Correlations of Intellectual ability over the years

N=25	IA13	IA14
IA13		
IA14	.75**	
IA15	.71**	.82**

Note: IA13 means Intellectual ability at 13 yr. ** $p < 0.01$

Table 6.5 PCA on subtests of Intellectual-ability tests over the years

N=25	1st component	2nd component
Eigenvalue	5.59	2.01
Variance proportion	.47	.17
Number series13yrs	.70	-.23
Number series14yrs	.83	-.07
Number series15yrs	.75	.06
Verbal analogies13yrs	.69	-.44
Verbal analogies14yrs	.52	-.69
Verbal analogies15yrs	.57	-.51
Unfolding figures13yrs	.82	-.04
Unfolding figures14yrs	.83	.29
Unfolding figures15yrs	.78	.09
Memory13yrs	.50	.47
Memory14yrs	.46	.64
Memory15 yrs	.59	.55

Correlations in Table 6.4 are rather high varying from .71 to .82. Furthermore, the principal component analysis (PCA) on intellectual-ability subtest scores of all three years resulted in a two-factor solution with eigenvalues of 5.59 of the first component and 2.01 of the second component, with 47% and 17% of variance accounted for respectively (see Table 6.5). The first component could be interpreted as representing general intellectual ability and the second component could be interpreted as representing memory ability contrasted with verbal-analogical reasoning. These results allow for considering intellectual ability as a stable person-related characteristic over the years. The rather high correlations of intellectual-ability scores over the years together with the two-factor solution allow for the conclusion that intellectual ability can be considered as the same construct over the years.

6.2.2 Metacognitive skills

The transcribed thinking-aloud protocols for both tasks were analyzed on spontaneous use of metacognitive skills according to the procedure of Veenman (1993; Veenman & Beishuizen, 2004; Veenman, Kerseboom, & Imthorn, 2000). For a description of the scoring method, see Chapter 2, section 2.2.4 and Appendices A and B). Although method and rater were the same for the three consecutive years, it can be argued that a difference in rating metacognitive skills might have occurred during the study. This would mean that a certain activity was rated differently from one year to another, resulting in metacognitive skillfulness as an unstable construct. Therefore, after the third-year protocols were rated, six protocols of each task and year (36 protocols) were rated again on the same day. In order to check the consistency in rating throughout the years, a paired-samples t-test on prior scores and most recent scores was performed. No significant difference in rating between the two moments of rating was found ($t(35) = .33$, $p = .74$), meaning that quality of metacognitive skills was not rated differentially. The correlation between ratings of the two moments was very high (.99), meaning that participants were rated consistently.

6.2.3 Relation between intellectual ability and metacognitive skills

So far, intellectual ability and metacognitive skills were discussed separately in this chapter. From a developmental perspective, it is relevant to establish whether the correlations of these two independent variables with learning performance are stable over the years. In the graphs below, the correlation of each independent variable with learning performance is shown for math and history (see Figures 6.1 and 6.2).

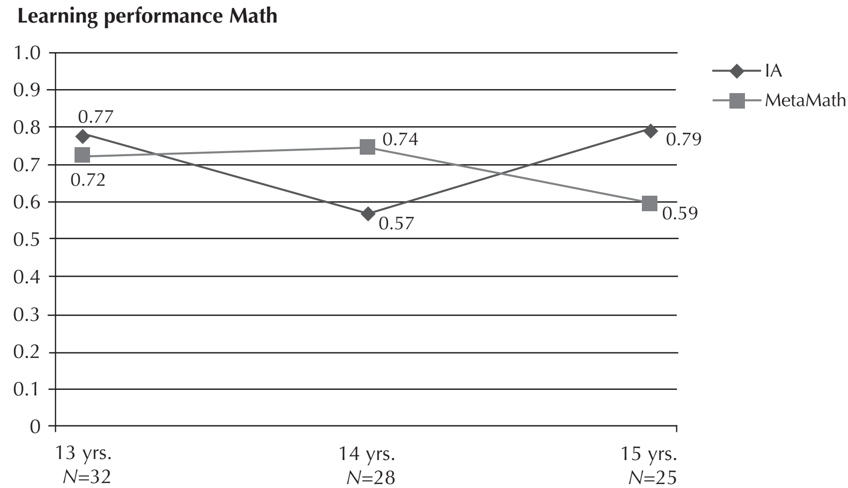


Figure 6.1 Correlations between Intellectual ability (IA), quality of metacognitive skills in math, and Learning performance Math

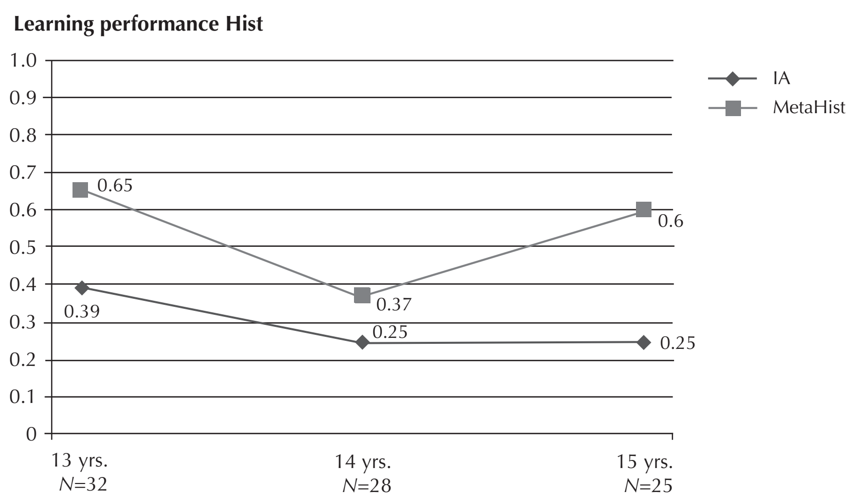


Figure 6.2 Correlations between Intellectual ability (IA), quality of metacognitive skills in history, and Learning performance History

Despite correlations seem to differ at face value over the years, Fisher-*z* ratios (see Table 6.6) show that there is no significant difference between the correlations over the years. All Fisher-z ratios are smaller than 1.96 (Guilford, 1965).

Table 6.6 Fisher-*z* ratios

Math	13yrs(32)	14yrs(28)	Fz	14yrs(28)	15yrs(25)	Fz
IA-LP	.77	.57	1.37	.57	.79	1.45
MS-LP	.72	.74	.16	.74	.59	.93
IA-MS	.62	.51	.60	.51	.66	.79
History	**13yrs(32)**	**14yrs(28)**	**Fz**	**14yrs(28)**	**15yrs(25)**	**Fz**
IA-LP	.39	.25	.57	.25	.25	.00
MS-LP	.65	.37	1.42	.37	.60	1.04
IA-MS	.27	.32	.82	.32	.41	.36

Note: IA means intellectual ability; LP means learning performance; MS means Metacognition (qualitative scores). (32) means *N*=32; (28) means *N*=28; (25) means *N*=25; Fz means Fisher-*z* ratio.

In the graphs below (see Figures 6.3 and 6.4), the unique contribution in percentage of both intellectual ability and metacognitive skills for both tasks separately are shown. The shared variance accounted for by both variables share is shown as well.

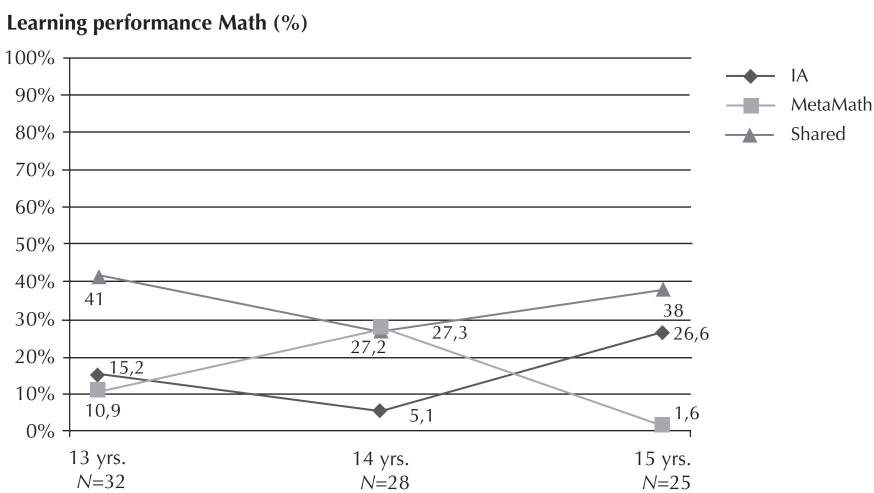


Figure 6.3 Distribution of unique and shared variance accounted for in Learning performance Math

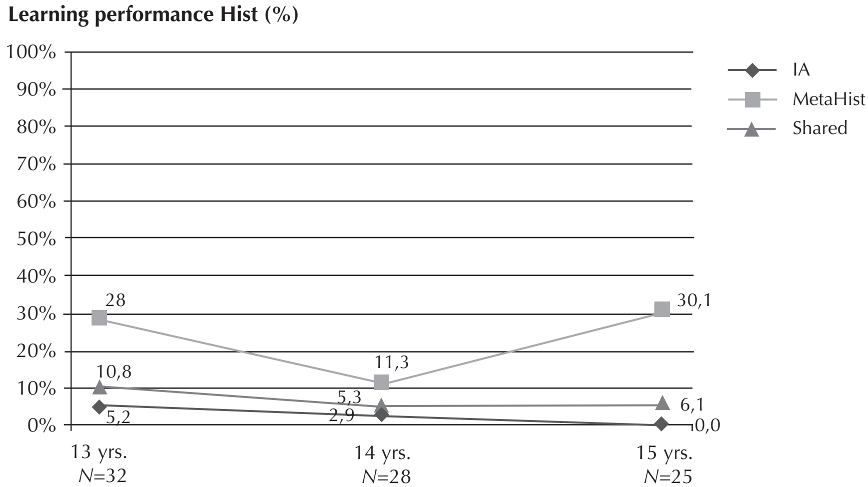


Figure 6.4 Distribution of unique and shared variance accounted for in Learning performance History

To calculate the unique and shared contribution of intellectual ability and metacognitive skills to learning performance, depicted in Figures 6.3 and 6.4, semi-partial correlations are needed. If semi-partial correlations would differ significantly, the stability of these correlations would be at risk. This would cause instability in the unique variance accounted for of either one of the predictors of learning performance. Therefore, Fisher-*z* ratios were calculated for the semi-partial correlations as well (see Table 6.7).

Table 6.7 Fisher-*z* ratios for Semi-partial correlations

Math	**13yrs(32)**	**14yrs(28)**	**F*z***	**14yrs(28)**	**15yrs(25)**	**F*z***
SemIA-LP	.39	.22	.66	.22	.52	1.15
SemMS-LP	.33	.52	.82	.52	.13	1.46
History	**13yrs(32)**	**14yrs(28)**	**F*z***	**14yrs(28)**	**15yrs(25)**	**F*z***
SemIA-LP	.23	.17	.22	.17	.00	.56
SemMS-LP	.53	.33	.87	.33	.55	.90

Note: SemIA means semi-partial correlation intellectual ability; LP means learning performance; SemMS means semi-partial correlation Metacognition (qualitative scores). (32) means *N*=32; (28) means *N*=28; (25) means *N*=25; Fz means Fisher-*z* ratio.

Again all Fisher-*z* ratios were smaller than 1.96. This means, for instance, that it cannot be concluded that the semi-partial correlation of IA and LP at the age of 15 (.52) is higher than the one at the age of 14 (.22). It can be concluded that the correlations and the semi-partial correlations were stable over the years.

6.3 Learning tasks

In this thesis, intellectual ability and metacognitive skills were investigated as predictors of learning performance. In order to investigate the unique contribution of metacognitive skills to learning performance from a developmental perspective, *new* learning tasks and post-tests were required each year. In order to exclude confounding variables as much as possible, only the content of the learning tasks was adapted each year to age and grade, while the format of the learning tasks and post-tests was kept the same for both math and history.

6.3.1 Math

For math the content of assignments in the learning-by-doing phase were adapted to age and grade each year. However, the tasks were made as comparable as possible as far as it concerned the format. Each year, the tasks were ecologically valid, because they were composed of adaptations of math problems from a frequently used schoolbook for math in the Netherlands. The tasks were piloted in the age group of participants.

Although, the content of assignments had to be new each year, items with a comparable content, that is, an ascending level of difficulty within the same area of math, were included in the tasks over the years. For example, in every year a geometry assignment was included. In the first year participants had to calculate the circumference of a meadow, in the second year it concerned the surface area of a triangle, and in the last year they had to apply Pythagoras' theorem in order to calculate the horizontal side of a triangle.

6.3.2 History

To make sure that the texts were suitable for text studying and measuring learning performance afterwards, the content of the texts had to be new to the participants. Participants likely had little or no content knowledge about the topic of the text, because topics were taken from the curriculum that was one year ahead. All learning tasks were piloted as well. No familiarity with the topics was observed.

In order to minimize a possible confounding effect of differences in learning texts, the *format* of the texts was made as comparable as possible. Van Hout-Wolters (1986) described various text characteristics that affect learning processes and/or learning results in text studying: Type of text, structure, difficulty of language used, length, and didactic help. All these variables were taken into account when composing the history learning tasks. All texts were informative, and ecologically valid (derived from the two most frequently used schoolbooks in the Netherlands). Structure, layout, and length of the text were kept almost identical (see Table 6.8). In order to be suitable for text studying, texts need to be of a certain length. Texts that are too short will only be memorized instead of being studied. In each text, the same didactic help was embedded, that is, three activating questions and/or assignments were included in order to elicit (more) metacognitive activities.

Table 6.8 Text characteristics History tasks

Number of	1st year	2nd year	3rd year
Pages	4,5	5	5
Paragraphs	18	19	20
Words	1497	1518	1522
Words per sentence	12	12	12
Concepts	76	95	122

According to Van Hout-Wolters (1986), Veenman and Beishuizen (2004), and Weaver and Bryant (1995), the average number of words per sentence is an important indicator for the difficulty and readability of texts. Each year, the average number of words per sentence was twelve. The other text variables depicted in Table 6.8 remain almost the same as well, except for the number of concepts. It is assumed that the texts are equivalent as far as the format was concerned. The content, on the other hand, can be considered as more abstract and more 'condensed', thus more difficult, because of the growing number of concepts introduced in the texts.

6.4 Post-tests

As explained above, new post-tests were needed each year to measure the learning performance. The content of the post-tests had to be adapted to the learning tasks and had to be suitable for the age group. Like the learning tasks, the post-tests were piloted before they were administered to the participants. Again the format was kept the same. For math, the items in the learning phase were parallel to the items in the post-test, that is, the surface structure of the post-test items differed from the ones of the learning-task, but the deep structure was the same. For history, each post-test consisted of five multiple-choice questions and six essay questions.

6.4.1 Math

Despite the efforts to make the post-tests as comparable as possible in relative level of difficulty, participants could have perceived a difference in level of difficulty, other than just a relative difference. Moreover, the math pilot revealed that for older students more assignments were needed in a 50 minute-session relative to younger students. This resulted in a difference in the number of items and in obtainable scores over the years for math. Therefore, all post-test results were checked on differences in level of difficulty. First, the mean proportion of right answers (*p*-value) was calculated for each task (see Table 6.9).

Table 6.9 Mean P-values post-tests Math (*SD*)

***N*=25**	**1st year**	**2nd year**	**3rd year**
Math	.44 (.23)	.69 (.15)	.66 (.15)

ANOVA was performed on the p-values of all math items. A slightly significant difference was found ($F(2,22) = 3.59$, $p = .048$). Therefore, a post-hoc test (Bonferroni) was performed on the math data. This post-hoc test did not reveal a significant difference between the learning outcomes for math over the three years.
Correlations between learning performance measures over the years vary from .63 to .66 (see Appendix C).

6.4.2 History

In history, correlations between learning performance measures over the years vary from .48 to .74 (see Appendix C). ANOVA was repeated for the *p*-values of the history post-tests (for mean p-values, see Table 6.10).

Table 6.10 Mean P-values post-tests History (*SD*)

N=25	1st year	2nd year	3rd year
History	.51 (.26)	.54 (.29)	.56 (.30)

ANOVA on the p-values of all history items did not reveal a significant difference ($F(2,37) = .11$, $p = .90$). In conclusion, no significant difference in the relative difficulty level of the post-tests for math and history was found.

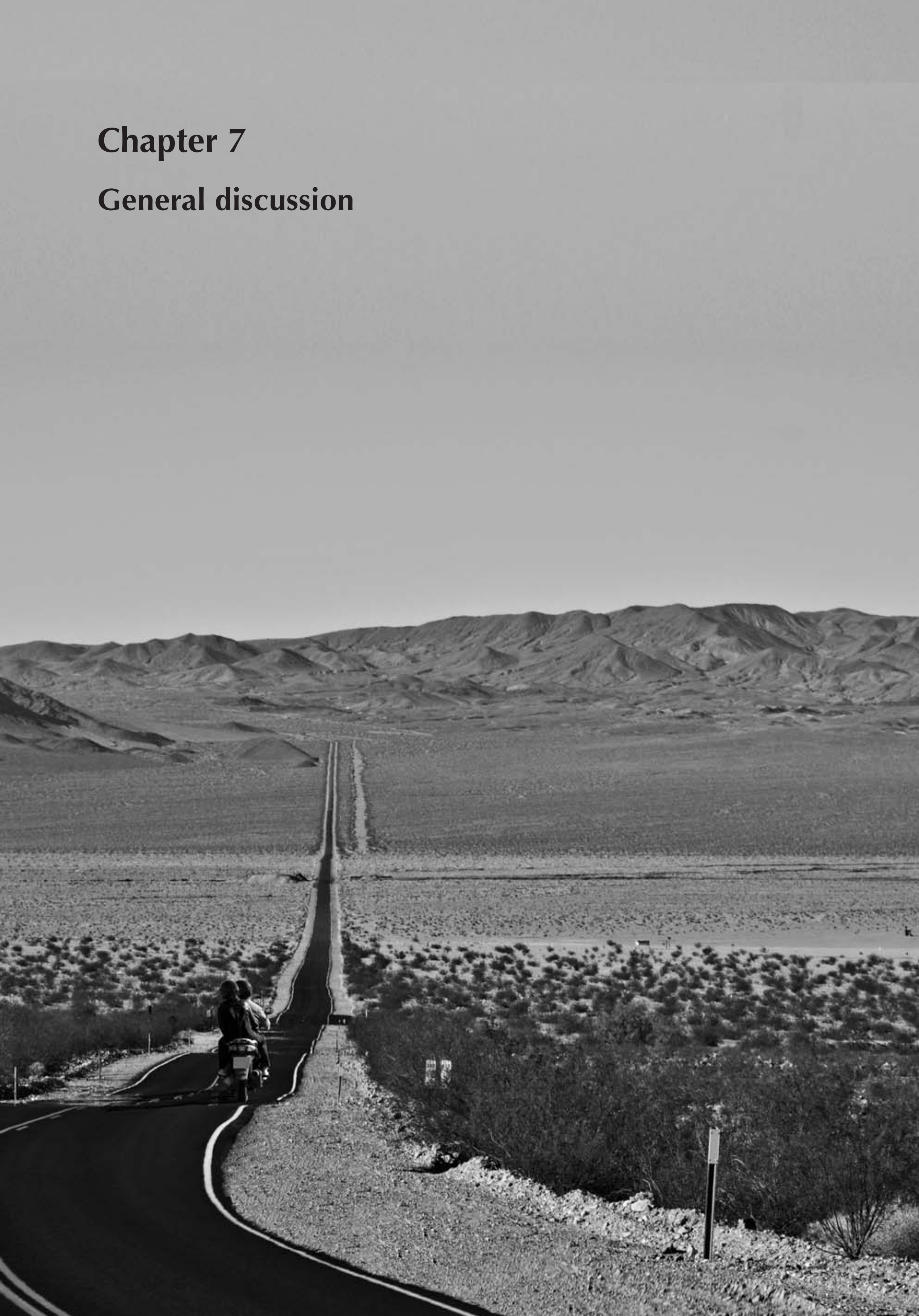
6.5 Testing generality vs. domain specificity of metacognitive skills

To establish whether metacognitive skills are general or domain specific by nature, principal component analysis (PCA) was performed, each year separately. For these analyses unrotated PCAs were used. An unrotated solution is a so-called direct solution, that is, originating directly from correlational matrices, while derivated solutions result from rotation and are obtained from direct solutions. In this thesis, no use was made of any rotation, because a rotation would rotate out the general component. Justification for this decision was found in the literature on factor analysis. If you are looking for separate, contrasting factors and want to avoid a general factor, you need to rotate (e.g., for the purpose of test validation). A rotation, however, should *not* be used if the theoretical expectation suggests that a general factor may occur (Gregory, 1996). Unrotated solutions are frequently applied in exploratory factor analysis, summarizing interrelationships between a number of variables. In this thesis, PCAs were performed to find an answer on one of the research questions, that is, to establish whether metacognitive skills are general or domain specific by nature. Using PCAs as a tool to address this issue was in line with prior studies (Veenman & Beishuizen, 2004; Veenman & Verheij, 2003; Veenman, Wilhelm & Beishuizen, 2004). It certainly would have been interesting to perform confirmatory factor analysis as well (see Veenman, Elshout, & Meijer, 1997). Then the purpose is to confirm that variables fit a certain pattern predicted by a theory. Lisrel and SEM are examples of such model-testing programs. Unfortunately, the sample was too small to do so. Hayduk (1987) stated that goodness of fit can be estimated for small samples, but only in experimental designs (cf. Veenman et al., 1997). The studies in this thesis, however, do not have an experimental design.

In this chapter, several checks were performed in order to rule out confounding effects due to the longitudinal design. In summary, loss of participants did not cause a selective loss of participants, repeated measures of metacognitive skills did not lead a significant difference in rating between the moments of rating, intellectual ability can be considered as the same construct over the years, and no significant difference in the relative difficulty level of the post-tests for math and history was found.

Chapter 7

General discussion



The studies in this thesis addressed developmental changes in metacognitive skillfulness in young adolescents aged 12 to 15 years. The research aimed to gain insight in (a) whether metacognitive skills grow in frequency and/or in quality during young adolescence; (b) how metacognitive skills relate to intellectual ability as predictors of learning performance during this period in life; (c) whether metacognitive skills are general or domain specific by nature in young adolescence. It was expected that metacognitve skills would show a continuous increase both in frequency and in quality (hypothesis 1). Furthermore, it was expected that metacognitve skills would have a unique contribution, on top of intellectual ability, to the prediction of learning performance. Moreover, it was expected that intellectual ability and metacognitive skills would develop in a monotonic way as predictors of learning performance (hypothesis 2). Finally, it was predicted that metacognitve skills would tend to generalize across development (hypothesis 3). In this final chapter, the findings of the longitudinal study (Chapters 2 – 4) and the cross-sectional study (Chapter 5) will be summarized and discussed.

7.1 Summary of the findings

7.1.1 Growth of metacognitive skills

Results from the longitudinal study concerning the growth of metacognitive skills were not quite as expected. Based on prior cross-sectional studies that investigated metacognitive skills from a developmental perspective (Veenman, Wilhelm, & Beishuizen, 2004; Veenman & Spaans, 2005), a continuous increase of metacognitive skills was expected. Between the first and the second year (13 to 14 yrs.) a substantial growth was found, indeed, in both frequency and quality of metacognitive skills. This growth, however, did not continue after the second year (between 14 and 15 yrs.). Only in one of the subscales, metacognition scores increased continuously over the three consecutive years, whereas most of the subscale scores leveled off or regressed in the third year. Results of the cross-sectional study in this thesis, on the other hand, did reveal a growth between 14 and 15 yrs. These contradictory results are rather remarkable, because the same math tasks were used for the same age groups in both the longitudinal study and the cross-sectional study. In conclusion, the findings in the longitudinal study do not allow for fully accepting the first hypothesis of this thesis.

On the level of subscales of metacognitive skills, two general developmental patterns were found: Growth between the first and the second year, followed either by stabilization or by regression. Only one subscale met the expectation of continuous growth over the three years. The quality of planning and evaluation activities in math increased between the first and the second year and then stabilized, whereas these activities increased in the cross-sectional study. The quality of elaboration activities in math was stable over the first two years and then regressed; in the cross-sectional study, no change occurred in elaboration activities. In history, the quality of orientation increased between the first and the second year and then stabilized. The quality of elaboration activities was stable over the years, while the quality of evaluation increased between the first and the second year and then regressed. For the quality of planning in history, it was the other way around. Quality of planning activities decreased between the first and the second year and then increased.

The frequency of metacognitive activities showed another pattern than the quality did. In math, the frequency of metacognitive skills increased in all subscales between the first and the second year in the longitudinal study. Between the second and the third year, however, frequency decreased, while there was an increase in frequency of metacognitive skills in the cross-sectional study (except for the number of orientation activities). In history, the frequency of orientation showed a continuous growth over the years. The number of planning activities increased between the first and the second year and then stabilized. Evaluation activities increased in frequency between the first and the second year and then regressed. For elaboration, it was the other way around; frequency of elaboration decreased between the first and the second year and then increased.

One salient conclusion can be drawn from the results of the longitudinal study: Metacognitive growth is not strictly continuous in young adolescents. In the current longitudinal study, most of the subscales of metacognition show discontinuity in growth between 14 and 15 years.

A relevant issue to discuss concerns the question why in the longitudinal study no continuous growth of metacognitive skills was found, whereas in prior cross-sectional studies (Veenman et al., 2004; Veenman & Spaans, 2005) linear growth was reported. Veenman et al. (2004) assessed metacognitive skills at the age of 9 yrs., 14 yrs., 17 yrs., and 22 yrs. They found a steep linear developmental growth over these four points in time. Veenman and Spaans (2005) found a strong growth in metacognitive skills between 13 and 15 years (first and third year in secondary education). It has to be noticed, however, that the interval between assessments was two years or more. If intervals of assessments are rather extended, growth mistakenly may be characterized as continuous, that is, uninterrupted, whereas growth may in fact not be continuous. In that case, results of the present longitudinal study would not contradict results of prior studies: Metacognitive skills show an overall increase between 13 and 15 years. So, it can be argued that over a more extended time span metacognitive skills will grow continuously, albeit with one or more period(s) of discontinuity within that time span.

A related issue concerns the fact that patterns of growth between 14 and 15 years in the present cross-sectional study (Chapter 5) only partly correspond with the longitudinal study of this thesis. Differences in interpretation of findings between the present longitudinal study on the one hand, and the studies of Veenman and colleagues, and the present cross-sectional study on the other hand, might be due to differences in design. Longitudinal studies might be more sensitive than cross-sectional studies to detect changes, for example discontinuity, in development. Any differences between groups are excluded by a longitudinal design with the same participants, thereby reducing the error of variance.

Methodological issues, like selective loss of participants or lack of consistency in rating throughout the consecutive years that can occur in longitudinal designs, could be responsible for the difference in results as well. Therefore, several checks were performed in order to ensure that methodological issues did not account for the difference in results (see Chapter 6). Despite methodological risks that are inherent to longitudinal designs, in the last decade several researchers in the field of cognitive and neurocognitive developmental studies advocated a more frequent use of longitudinal designs (Bullock & Schneider, 2009; Casey, Tottenham, Liston, & Durston, 2005; Crone et al., 2006). In their opinion, longitudinal designs would be more sensitive to detect and follow changes during development, relative to cross-sectional designs. In general, it does not become clear from cross-sectional studies whether results on developmental trends based on group means are also valid on the individual level. Improvements on the group mean level could be due to some children making enormous progress, whereas others remain stable or even decline. In a 10-year longitudinal study on verbal-memory development (Schneider, Knopf, & Sodian, 2009), it was found that individual children changed their relative position in the sample between two measurements. Therefore, the model that fits the group data does not always adequately describe intra-individual changes. Children showed leaps ("jumpers") and U-shaped curves in memory-strategy development. Thus, the pattern of linear growth indicated by the group mean development obtained from cross-sectional studies sometimes can be misleading.

Looking closer into the data of the present longitudinal study, some intra-individual changes are found too. Between the first and the second year almost half of the participants showed a 'leap'[9] (in problem solving the leap was predominantly forward; in text studying some leaped forwardly, others backwardly) in the use of metacognitive skills. Between the second and the third year about one third of the participants 'leaped', either forwards or backwards for both tasks. These intra-individual changes would have not been revealed in a cross-sectional study. They do not become clear either from group mean data in a longitudinal design that wash out individual differences. For example, it seemed that for some participants not much was happening regarding changes in applying metacognitive skills in text studying, whereas others showed rather big 'leaps'. From (neuro)cognitive developmental studies it is known that there is a large individual variability in brain structure among individuals, especially during development (Casey et al., 2005). Furthermore, in dynamic-systems theories (Siegler, DeLoache, & Eisenberg, 2010), a class of theories that focus on how change occurs over time in complex systems, it is stated that individual children acquire skills at different ages and in different ways, and that their development entails regressions as well as progress. Results of the longitudinal study are in line with this notion of individual variability. Young adolescents not only differ substantially from each other in their use of metacognitive skills, they also differ within themselves from moment to

9 Leap means a change of 50% or more

moment, or from task to task. During development, both progress and regression occur, and not all components of metacognitive skillfulness develop at the same pace. It seems that metacognitive skills are still in an unsettled developmental phase during young adolescence.

7.1.2 Metacognitive skills in relation to intellectual ability

As far as known, in this thesis the mixed model was tested for the first time in a longitudinal design, including both text-studying and problem-solving tasks. Previous studies that found evidence for the mixed model across age groups were studies with a cross-sectional design without text studying (Veenman et al., 2004; Veenman & Spaans, 2005). Further evidence for the mixed model was found in a number of non-developmental studies, including problem-solving or text-studying tasks (Elshout & Veenman, 1992; Veenman & Beishuizen, 2004; Veenman & Elshout, 1991, 1995, 1999; Veenman, Elshout, & Busato, 1994; Veenman, Elshout, & Meijer, 1997; Veenman, Kok, & Blöte, 2005; Veenman & Verheij, 2003).

Results of the present longitudinal study show that metacognitive skills had their own unique contribution, on top of intellectual ability, to the prediction of learning performance in line with the mixed model. In the three consecutive years, metacognitive skills had a unique contribution to the prediction of learning performance, regardless of tasks and domains. These findings are in line with results of the afore-cited studies that investigated the relation between intellectual ability and metacognitive skills as predictors of learning performance.

In the cross-sectional study of this thesis results corroborated the mixed model as well, with the exception of the frequency of metacognitive skills in 14-year-olds. The latter had no contribution to the learning performance at all. Both in the longitudinal and the cross-sectional studies of this thesis, the contributions of intellectual and metacognitive skills vary. Sometimes the contribution of intellectual ability outweighs the contribution of metacognitive skills; sometimes it is the other way around. Fluctuations in unique contributions over the years, however, were not significantly different (see Chapter 6). Therefore, results of this thesis allow for the conclusion that the mixed model is considered to be stable throughout the period of young adolescence.

Another important issue, addressed in the second research question, was to investigate whether the development of metacognitive skills is intelligence-related or relatively intelligence-independent. Alexander, Carr, and Schwanenflugel (1995) compared the metacognition of gifted vs. non-gifted children. They found support for a monotonic growth of metacognitive knowledge and intelligence. However, their results were inconclusive regarding metacognitive skills. In this thesis, the relation between intellectual ability, metacognitive skills, and learning performance was investigated from a developmental perspective. The monotonic development hypothesis is based on two presuppositions: A development of metacognition parallel to intellectual development, and the appropriateness of the mixed model for describing the relation between metacognition and intellectual ability as predictors of learning performance.

Two other developmental hypotheses, the acceleration hypothesis and the ceiling hypothesis (Alexander et al., 1995), do not relate to the mixed model. Instead, these models can be related to the intelligence model (Veenman, 1993) as the influence of intellectual ability on metacognition either increases or diminishes with age. Finally, the independency model (Veenman, 1993) fits none of Alexander's hypotheses, since it predicts that there is no relation between intelligence and metacognition at all. In the first and the second year of the longitudinal study, support was found for a parallel development of intellectual ability and metacognitive skills as predictors of learning performance. In this period, intellectual ability and most of the metacognition subscales increased significantly. After the second year, metacognitive growth was hardly found, apart from a few subscales of metacognition. In the cross-sectional study, however, significant growth between 14 and 15 years occurred in both intellectual ability and metacognitive skills. Apparently, the relation between metacognition and intellectual ability does not develop strictly according to the acceleration hypothesis, nor according to the ceiling hypothesis. Moreover, the relation between metacognition and intellectual ability does not fit better or worse with the intelligence model over age. Therefore, both the acceleration and the ceiling hypothesis can be rejected as a model for describing the relation between metacognition and intellectual ability during development. In the previous paragraph the discontinuity in metacognitive growth was discussed. If development of metacognitive skills is not strictly continuous, it cannot be strictly monotonic either. The monotonic development hypothesis (Alexander et al., 1995), however, is based on two presuppositions. The first one, that is, a development of metacognition parallel to intellectual development, was not found systematically over the years. The second one, that is, the appropriateness of the mixed model for describing the relation between metacognition and intellectual ability, was found systematically. Metacognitive skills keep on having their unique contribution to learning performance on top of intellectual ability, thus supporting the mixed model (Veenman, 1993). Although the various components of intellectual ability (numerical and verbal reasoning, visual-spatial ability, and memory), and metacognitive skills (orientation, planning, evaluation, and elaboration) did not develop all at the same pace, the overall relation between intellectual ability and metacognitive skills as predictors of learning performance was not affected. As stated above, the mixed model can be considered as stable in young adolescence. This means that the present findings corroborate the first part of the second hypothesis. In conclusion, results do not corroborate the second part: Metacognive skills did not always develop parallel to intellectual ability. Although the second hypothesis cannot be fully accepted, it was demonstrated that metacognitve development is not directed by intellectual development. The '*autonomous* development hypothesis' might be a more appropriate name for describing the relation between metacognitive and intellectual development, because metacognitive skills follow their own developmental trajectory in an autonomous way.

7.1.3 Generality vs. domain specificity of metacognitive skills

Results of the first two years of the longitudinal study showed that 13- and 14-year-olds resorted mainly to general metacognitive skills, but also to domain-specific metacognitive skills to a lesser extent. Metacognitive skills of 15-year-olds, on the other hand, appeared to be fully general. Relative to prior studies (Prins, 2002; Schraw et al., 1995; Veenman & Spaans, 2005; Veenman et al., 1997, 2004; Veenman & Verheij, 2003), the opportunity for finding domain specific and general components of metacognitive skillfulness was enhanced in this thesis by maximizing the difference between both tasks and domains at the same time. Problem solving in the domain of math was contrasted with text studying in the domain of history. Moreover, a broad range of metacognitive skills was assessed from thinking-aloud protocols in a longitudinal design, with measurement intervals of one year. By doing so, the conditions for detecting transitions in the domain specificity or generality of metacognitive skills over age were optimized.

Results of prior studies concerning the issue of metacognitive skills being general or domain specific were contradictory (Glaser, Schauble, Raghavan, & Zeitz, 1992; Kelemen, Frost, & Weaver, 2000; Schraw et al., 1995; Veenman & Beishuizen, 2004; Veenman, Elshout, & Meijer, 1997; Veenman & Spaans, 2005; Veenman & Verheij, 2003; Veenman et al., 2004). One of the reasons for contradictory results is dissimilarity between the studies (see Chapter 1, section 1.3). The study that is most comparable to the present study is the study by Veenman and Spaans (2005). In both studies 13- and 15-year-olds had to solve math word problems. In both studies it was concluded that between the age of 13 and 15 years a generalization of metacognitive skills took place, resulting in metacognitive skills being general for 15-year-olds. In Veenman and Spaans, however, metacognitive skills of 13-year-olds appeared to be predominantly domain specific. Apart from drawing a similar conclusion for the 15-year-olds, there were rather important dissimilarities between the two studies. First, tasks and domains differed to a lesser extent. In Veenman and Spaans participants had to perform an inductive learning task in the domain of biology and to solve math word problems. In the present study math word problems were contrasted with text studying in history. Secondly, the number of participants per age group was smaller in Veenman and Spaans (two age groups of 16 participants vs. N=25 in the present study). Furthermore, different methods for assessing metacognitive skills were used. Veenman and Spaans used systematic observation (math tasks) and log-file analysis (inductive-learning tasks). Because not all subscales of metacognitive skills could be assessed with log-file measures, log-file scores were validated by the analysis of a limited number of thinking-aloud protocols. Finally, another dissimilarity concerned the method of statistical analysis for investigating the generality vs. domain specificity of metacognitive skills: A correlational analysis (Veenman & Spaans) vs. a principal component analysis in the present study. So, Veenman and Spaans, and the current study show some crucial methodological differences that might explain the difference in findings concerning the 13-year-olds.

Schraw et al. (1995) suggested a compromise between domain-specific and domain-general hypotheses. They argued that domain-general monitoring skills emerge late in development and that they are preceded by modularized monitoring skills. In the same vein, Veenman and Spaans (2005) assumed that metacognitive skills initially develop on separate islands of tasks and domains and that beyond the age of 12 yrs. these metacognitive skills become increasingly general. Present results support the assumption that metacognitive skills tend to generalize across development, even if differences in tasks and domains were to be maximized. The generalization process, however, was less gradual than expected. Already in the first two years, the general component was much stronger than the domain-specific component and there was hardly any difference between the PCA solutions of the first two years. In the third year, however, the domain-specific component diminished rather abruptly. Therefore, it could be argued that prior to a final generalization, metacognitive skills are predominantly general, complemented with domain-specific skills. In conclusion, based on the present results the third hypothesis can be accepted. A future longitudinal study starting in primary school would more fully test the hypothesis that metacognitive skills start to develop on entirely separate islands and then tend to generalize with increasing age.

7.2 Conclusions

Reflecting on the results of the longitudinal study of this thesis, the overall conclusion is that between the age of 12 and 15 years growth in frequency and quality of metacognitive skills was not continuous. Various components (orientation, planning, evaluation, and elaboration) of metacognitive skillfulness developed in a non-synchronous way, that is, not at the same pace. Several scenarios were found in the development of these components: No growth at all; growth between the first two years followed by stabilization; growth in the first two years followed by regression. While between the age of 14 and 15 years further growth was found in a limited number of components of metacognition, another interesting change in metacognitive skillfulness occurred at the same time: Metacognitive skills of 15-year-olds no longer appeared to be partly domain specific, but became fully general.

From the cross-sectional study of Veenman et al. (2004), it became clear that metacognitive skills continue to develop till at least the age of 22 years. Therefore, it can be argued that in the long term metacognitive skills will continue to develop till late adolescence, but the developmental trajectory will probably know some temporary holds and leaps in growth. During these delays growth might give room to other developmental changes. In this case, growth could have made room for the transition of metacognitive skills from general and partly domain specific in the period between 12 to 14 years to fully general at the age of 15 years. This transition can be considered as a qualitative change that does not come without any effort of the learner. Therefore, this change may not go hand in hand with a further increase in frequency or quality of metacognitive skills, resulting in an intermittent growth at the age of 15 years. Maybe due to cognitive overload, growth and transition cannot develop at the same time, but occur alternately. Metacognitive skills are considered as procedural knowledge (see Chapter 1, section 1.1), that is, a production system of condition-action rules acquired in specific domains for specific tasks (Anderson, 1996; Veenman, 2011; Winne, 2010). The condition part of production rules triggers certain activities (actions) of the learner. When the reach or scope of these condition parts extends, production rules merge and can be applied more generally, initiating the transfer of production rules to other tasks and other domains. The intermittent growth of metacognitive skills could mean a temporary hold on the action part of production rules. They do not expand for a while as alternative actions parts of former individual production rules have to be tuned to the new, generalized conditions. This generalization process of conditions could be considered as a qualitative change for which the growth of action parts temporarily has to give way. Once students are capable of transferring metacognitive skills that were acquired in one context to another, different context, they will continue to increase the frequency and quality of their metacognitive activity.

Salomon and Perkins (1989) distinguished low-road from high-road transfer. Low-road transfer involves spontaneous, automatic transfer of highly practiced skills, with little need for reflective thinking. High-road transfer, on the other hand, involves the explicit conscious formulation of abstractions in one situation that allows for making a connection to another situation. In the same vein, Adams (1989) distinguished direct transfer from mediated transfer. The former involves a direct mapping from one problem-solving situation to another on the basis of superficial similarities between two problem situations, whereas the latter may transcend superficial differences between problem situations. In mediated transfer, students are capable of applying principles and procedures that have been abstracted from previous training problems to new situations. According to Salomon and Perkins (1989), low-road transfer comes as a result of extended practice in behaviors or cognitions. In contrast, high-road transfer results from mindful, controlled processes that decontextualize the elements that are to be transferred. It should be noted that Salomon and Perkins explicitly stated that metacognitive guidance appear to play a major role in high-road transfer. It can be argued that students could not apply high-road transfer -a conscious and metacognitively guided process-, and at the same time enhance the frequency and quality of their metacognitive skills. This could also explain the stabilization in growth at the time metacognitive skills tend to fully generalize. Future research must prove whether this explanation for intermittent growth is sustainable.

In summary, this thesis has shown that (1) Metacognitive skills do increase spontaneously in frequency and quality during young adolescence, albeit not continuously. The various subscales of metacognitive skillfulness do not develop at the same pace; (2) Metacognitive skills have their own contribution to the prediction of learning performance, on top of intellectual ability. The relation between intellectual ability and metacognitive skills as predictors of learning performance is not affected by development between 12 and 15 yrs.; (3) Around the age of 15 yrs. metacognitive skills become fully general.

7.3 Educational implications

In this section educational implications of two of the conclusions of this thesis are discussed. First, results obtained in this thesis show that metacognitive skills grow between the age of 12 to 15 years. It should be noticed, however, that this growth is not continuous, and that there are substantial differences in individual growth on the overall level, as well as on the various subscales of metacognitive skillfulness. Although spontaneous growth in metacognitive skills takes place, that is, growth without interventions that explicitly aim at training metacognitive skills, the developmental trajectory of metacognitive skills is a lengthy and 'bumpy' trajectory with alternating periods of progress, stabilization, and regression. Pressley (1986, p. 154): "Developing good strategy use is a formidable educational challenge, one that probably requires many years. Considered in this light, it is not surprising that few and small general effects follow from classroom interventions that span a semester…" A firmly-rooted use of metacognitive skills will neither develop totally spontaneously, nor can it be attained by short-term interventions. At the same time, however, in modern (secondary) education a lot is demanded from students in terms of taking responsibility for their own learning process by regulating, controlling, and reflecting (on) it. In other words, students need well developed metacognitive skills in order to be successful in secondary education. In many studies it was found that metacognitive skills in both problem solving and math (Cardelle-Elawar, 1995; Chinnappan & Lawson, 1996; Kramarski & Mevarech, 2003; Masui & De Corte, 1999; Veenman et al., 1994; Veenman et al., 2005) as well as in reading and text studying (Boulware-Gooden, Carreker, Thornhill, & Joshi, 2007; Houtveen & Van de Grift, 2007; Pressley & Gaskins, 2006; Souvignier & Mokhlesgerami, 2006) can be trained successfully. The interventions in the afore-cited studies were performed in widely varying age groups, school levels, and levels of intellectual ability. So, educators could foster the development of metacognitive skills by teaching them explicitly. There are three conditions for training programs of metacognitive skillfulness formulated in the literature (Veenman et al., 2006). In order to be successful, (1) training must be offered over an extended period of time, (2) students have to be convinced of the usefulness of trained skills (informed training), and (3) the skills to be acquired have to be trained in the context of a domain. Based on results of the current study, a fourth condition could be added, that is, metacognitive-skill components should be trained for which the time is right in terms of the developmental trajectory. The training of certain skills should be attuned to the spontaneous development of the same skills. For example, if young students of a particular age hardly reflect spontaneously, then, probably training reflection as metacognitive activity will not be very effective at that time. If, on the other hand, spontaneous reflection starts to develop, training will be more effective. Not only teachers, but also authors of methods for teaching should consider which component(s) of metacognitive skills has to be offered when. For example, in recent methods for teaching text comprehension in primary school much more attention is paid to metacognitive skills relative to older methods. Some of the recent methods are so-called concentric methods. In these methods, in every grade the same metacognitive skills are trained, albeit at different levels. It might be more effective to make a selection of skills, resulting in metacognitive-skill training that is more attuned to the developmental trajectory of that particular skill. For example, evaluation activities in history increased between 13 and 14 years. This could be an appropriate moment to foster this development as a teacher. By doing so and by stressing the importance of this particular skill in a critical period, the regression that followed the increase might be prevented.

Secondly, results in this thesis not only show a spontaneous growth in metacognitive skills, at least between 13 and 14 yrs., but also a spontaneous transformation of metacognitive skills to fully general skills. Nickerson, Perkins, and Smith (1985) noted that one especially prominent point in the teaching of metacognition is its relationship to transfer. According to them, there is the possibility of treating transfer itself as a metacognitive skill and attempting to train it directly. By doing so, generalization and transfer are no longer considered as "hoped-for-by-products" (p. 301) of teaching. Instead, students have to be made aware of the importance of transfer by giving them explicit instructions with respect to how to attain transfer. Brown (1978) argued that, as part of the training procedure, students should be informed that the skill they are acquiring can be useful in a variety of contexts. Next, they should be challenged in learning to recognize those situations for which a particular skill is appropriate. In other words, transfer itself should be taught as a metacognitive skill. So, educators are challenged not only to implement metacognitive-skill training within the scope of their own field, but also to generalize this instruction, to teach expectations for transfer, and to expect transfer beyond the boundaries of their field. Teachers of different disciplines should do so concurrently, while referring to one another during their classes (Veenman et al., 2004). Such coordinated teaching requires commitment of both the individual teachers and the school organization (Pressley & Gaskins, 2006).

Despite the proven usefulness of teaching and training metacognitive skills, teachers seem to have problems incorporating such training in their daily practice. Knowledge about the concept of metacognition often is lacking. In many cases metacognition is regarded as equivalent for 'learning to learn' or 'independent learning', without knowing how metacognitive-skill training should be implemented (Veenman, Kok, & Kuilenburg, 2001).

Waeytens, Lens, and Vandenberghe (2002) interviewed 53 secondary-school teachers about their subjective interpretations and the way they implement 'learning to learn'. The majority of teachers has a narrow sense of 'learning to learn'. In the opinion of these teachers, 'learning to learn' is limited to giving tips and general advice, mostly to younger and less able students.

Zohar (1999) found that teachers' intuitive (i.e., pre-instructional) knowledge of how to teach metacognitive skills is unsatisfactory for the purpose of teaching higher-order thinking in science classrooms. Moreover, most teachers are inclined to think that the teaching of strategy use and higher-order thinking skills is predominantly suited for students with high IQs (Zohar, Vaaknin, & Degani, 2001). Dignath and Büttner (2008) performed a meta-analysis on self-regulated learning interventions that were integrated in normal teaching contexts in primary and secondary schools. It was inferred from this meta-analysis that training programs performed by researchers (researcher-directed interventions) had better results than training programs performed by teachers (teacher-directed interventions), which may be the consequence of inadequate or insufficient teacher training. In order to take up their role as promoter of metacognitive skills in students, teachers should be thoroughly educated in the teaching and training of those skills.

7.4 Limitations and directions for further research

Due to the method chosen for assessing metacognitive skills (analyzing thinking-aloud protocols), it was not possible within the frame of this thesis to follow a large number of participants for more than three consecutive years. As a result, some limitations should be considered. One of the limitations is the rather small number of participants. Due to the labor intensiveness of analyzing thinking-aloud protocols of individual student sessions, it was not feasible to work with a larger sample. Another limitation is the fact that all participants came from the same school. Both limitations could have affected the generalizability of the results. Furthermore, the period of data collection, three consecutive years, was rather short relative to the entire period of adolescence. The period between 12 and 15 years offers an interesting, though limited window on adolescence. Finally, the current study relied on one particular on-line method for assessing metacognitive skills, that is, the analysis of thinking-aloud protocols. Thinking-aloud protocols depend on verbalization of executed skills with the risk of missing out highly automated skills that are not verbalized. Perhaps, thinking-aloud measures did not capture all metacognitive activities.

Knowing that brain maturation goes on till the early twenties at least, it would be very interesting to follow students for an extended period of time across development. A longitudinal design, starting in primary school (around the age of 8 years) and ending in late adolescence (around the age of 25 years), should be considered for future research. A more realistic, that is, pragmatic alternative might be an overlapping roof-tile construction of cross-sectional and longitudinal research combined in one study. In such a design, one group of participants will be followed for a number of consecutive years (e.g., at the age of 8, 9, and 10 yrs.), and another group of participants will be followed at different, partly overlapping ages (e.g., at the age of 10, 11, and 12 years). A third group from 12 – 14 yrs., and so on. This way a lengthy period can be covered by a relatively short period of data collection. To monitor development closely, intervals between assessments should be no longer than one year. In such a roof-tile design, the focus will be on processes of change instead of describing steady states at different ages as is the case in cross-sectional studies.

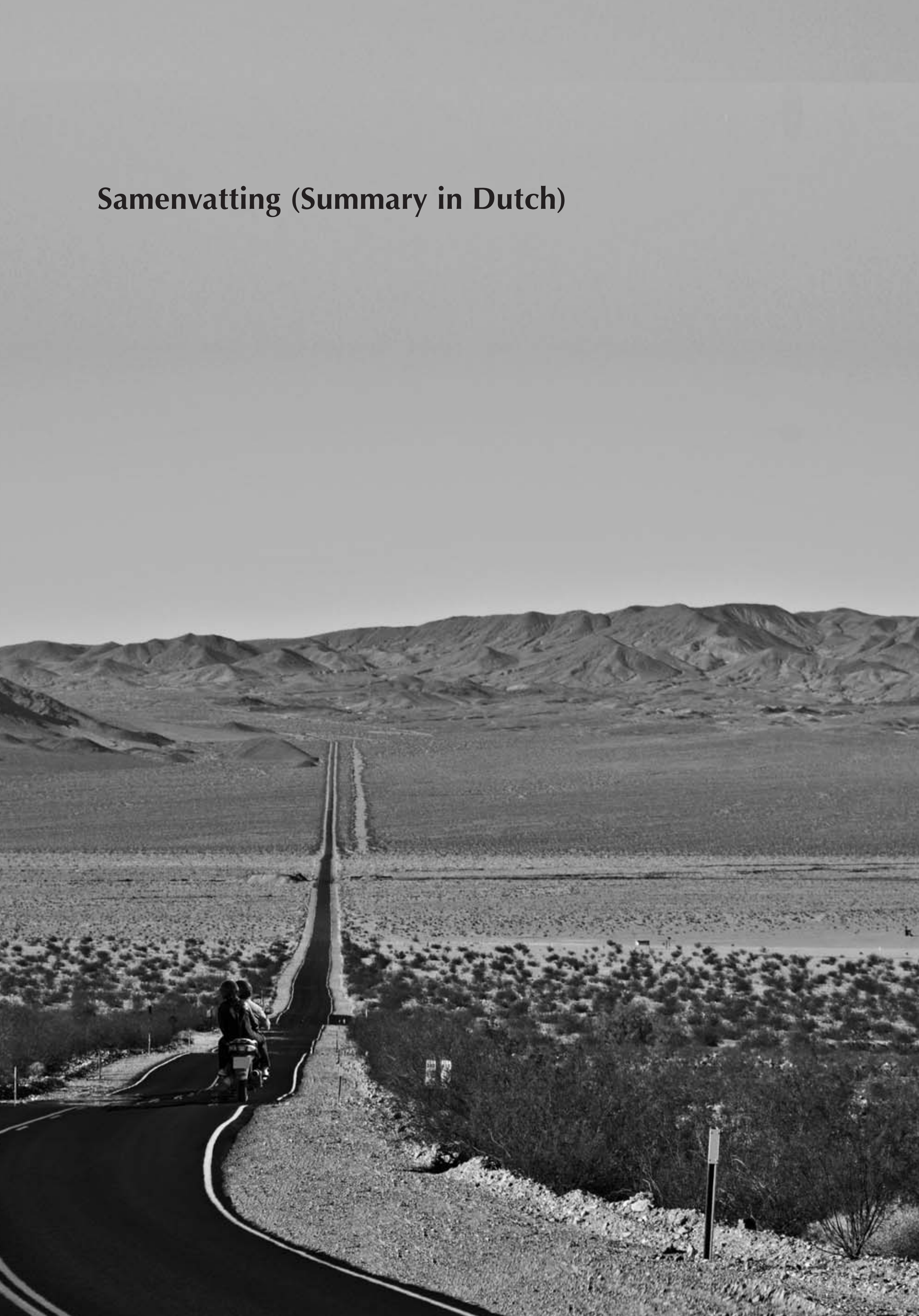
Apart from the analysis of thinking-aloud protocols, there are several other methods to assess metacognitive skills, either on-line or off-line (see Chapter 1, section 1.6). Using more than one method in future research will make it possible to cross-validate and complement a particular method with another one (Veenman, in press). A multi-method design will enable the assessment of metacognitive skills in a more fine-grained way. For example in text studying, eye tracking could be added to thinking aloud (Kinnunen & Vauras, 1995). This way, navigating through the text can be registered as a monitoring activity without verbalizations of the student.

In the present study, stabilization in growth took place in the same period that metacognitive skills became fully general. These two changes in development were considered and interpreted as related developmental processes. This study could not establish whether the concurrence of the two changes was coincidental or crucial for 14-15 yr. olds. Future research with more participants performing widely varying tasks over a longer period of time could give more insight whether the two concurrent developments found at the age of 15 yrs. can be replicated as a stable pattern, or whether the concurrence was coincidental. Moreover, following students over a period from the age of 8 till 25 years could establish whether more periods of intermittent growth concur with a transformation process of generalizing metacognitive skills. If metacognitive skills indeed initially set out on separate islands (Veenman & Spaans, 2005) and become fully general during development, there should be at least one period prior to the age of 12 yrs. where intermittent growth and generalization concur. Especially for the educational field, it would be relevant if future research would address this issue again.

7.5 Final remark

In Chapter 2 (section 2.1.2), the question was asked whether metacognition could be reduced to cognition (Slife et al., 1985). This thesis has shown that the answer must be in the negative. Metacognition has its own contribution to learning performance and its own developmental trajectory. Because not all components of metacognitive skillfulness develop at the same time or at the same pace, it is important that teachers foster the right components at the right time during development. By doing so, educators can have a valuable contribution to make the developmental trajectory of students' metacognitive skillfulness a less bumpy one.

Samenvatting (Summary in Dutch)



In de laatste decennia wordt van jonge adolescenten reeds bij aanvang van het voortgezet onderwijs in toenemende mate verwacht dat zij zich gedragen als actieve, zelfstandige leerders. Zij worden daarmee voor een groot deel verantwoordelijk gesteld voor hun eigen leerproces en studieresultaat. Om hierin succesvol te zijn, dienen leerlingen zich zorgvuldig te oriënteren op hun leertaak. Vervolgens dienen zij hun leeractiviteiten te plannen en uit te voeren op een systematische en ordelijke manier, hun eigen leren te monitoren en te evalueren en ten slotte te reflecteren op de uitvoering en de uitkomst. Kortom, zij dienen te beschikken over metacognitieve vaardigheden. Uit verschillende overzichtsstudies blijkt dat metacognitieve vaardigheden een sterke voorspeller van leerresultaat zijn (Veenman, 2008; Wang e.a., 1990).

Het onderzoek beschreven in dit proefschrift is gericht op de *ontwikkeling* van metacognitieve vaardigheden bij jonge adolescenten (12 – 15 jaar). Metacognitieve vaardigheden zijn vaardigheden die leerlingen aanwenden om hun cognitieve processen te sturen, te reguleren en te controleren. Bij metacognitieve vaardigheden worden activiteiten onderscheiden die vóór (oriëntatie), tijdens (plannen; evaluatie) of na (elaboratie) de taakuitvoering plaatsvinden. De frequentie en de kwaliteit van deze activiteiten worden in dit onderzoek gemeten met behulp van de hardop-denkmethode (Veenman, 1993). De ontwikkeling van metacognitieve vaardigheden wordt onderzocht in relatie tot intelligentie, waarbij de focus ligt op de bijdrage van beide variabelen aan de voorspelling van leerresultaat. Het gaat hierbij nadrukkelijk om het spontane gebruik van metacognitieve vaardigheden bij ecologisch valide schooltaken, dus niet voorafgegaan door enige expliciete training. Tevens is de aard van metacognitieve vaardigheden onderwerp van onderzoek. De vraag of metacognitieve vaardigheden algemeen of domeinspecifiek van aard zijn, staat daarbij centaal.

Piaget veronderstelde dat kinderen jonger dan 11 – 12 jaar niet in staat zijn hun eigen denken als object in beschouwing te nemen (Flavell, 1992). Pas met het bereiken van het formeel-operationele stadium zouden kinderen, volgens Piaget, zich bewust worden van hun eigen denken en denkprocessen. Uit recenter onderzoek blijkt dat kinderen reeds in de kleutertijd beschikken over elementaire vormen van metacognitieve vaardigheden (Blöte e.a., 2004; Whitebread e.a., 2009). Echter, met betrekking tot metacognitieve vaardigheden in een schoolse context wordt algemeen aangenomen dat deze zich beginnen te ontwikkelen tussen het achtste en tiende jaar (Berk, 2006; Kuhn, 1999; Siegler, 1998; Veenman e.a., 2006).

Veenman (1993) beschrijft drie modellen voor de relatie tussen metacognitieve vaardigheden en intelligentie als voorspellers van leerresultaat. In het *intelligentie-model* worden metacognitieve vaardigheden beschouwd als een onderdeel van intelligentie. In dit model hebben metacognitieve vaardigheden geen zelfstandige voorspellende waarde voor leerresultaat. In het *onafhankelijkheidsmodel*, daarentegen, zijn metacognitieve vaardigheden en intelligentie onafhankelijke voorspellers van leerresultaat. In het *gemengde model*, ten slotte, zijn metacognitieve vaardigheden en intelligentie gecorreleerd, maar hebben metacognitieve vaardigheden ook een eigen, unieke bijdrage aan de voorspelling van leerresultaat. In de studies beschreven in de hoofdstukken 2, 3, 4 en 5 van dit proefschrift worden deze modellen getoetst bij jonge adolescenten.

Alexander e.a., (1995) formuleerden drie hypothesen met betrekking tot de relatie tussen intelligentie en de ontwikkeling van metacognitie. Hierbij werd de relatie met leerresultaat buiten beschouwing gelaten. De *'ceiling'* en de *'accelaration'* hypothesen veronderstellen een afnemend, respectievelijk toenemend effect van intelligentie op de ontwikkeling van metacognitie met de jaren. De *'monotonic development'* hypothese veronderstelt een monotone groei van zowel intelligentie als metacognitie over de jaren. Alexander e.a., (1995) vonden een monotone ontwikkeling van zowel intelligentie als van metacognitieve kennis. Dit betekent dat de ontwikkeling van metacognitieve kennis niet wordt gedirigeerd door intelligentie. Met betrekking tot metacognitieve vaardigheden waren de resultaten echter niet duidelijk. In de onderzoeken beschreven in de hoofdstukken 3, 4 en 5 van dit proefschrift worden de hypothesen van Alexander e.a. getoetst met betrekking tot metacognitieve vaardigheden.

De vraag of metacognitieve vaardigheden algemeen of domeinspecifiek van aard zijn, is in de afgelopen decennia regelmatig onderwerp van onderzoek geweest. Resultaten leverden geen eensluidende conclusie op. Voor zowel een algemene als een domeinspecifieke aard werd evidentie gevonden. Doordat studies op tal van punten verschilden (leeftijd en onderwijsniveau van de participanten, taken, meetmethoden van metacognitie) is het moeilijk de uitkomsten van de verschillende studies met elkaar te vergelijken. In de huidige studie is getracht het verschil in taken en domeinen te maximaliseren ten opzichte van eerdere studies. Hierdoor is de kans op het vinden van een domeinspecifieke component geoptimaliseerd. In de hoofdstukken 2, 3 en 4 is de aard van metacognitieve vaardigheden onderzocht vanuit een ontwikkelingsperspectief. Hierbij is de focus gericht op de vraag *of* en *hoe* de aard van metacognitieve vaardigheden verandert tijdens de ontwikkeling van jonge adolescenten. Schraw e.a., (1995) veronderstellen dat de algemene aard van metacognitie pas laat in de ontwikkeling ontstaat en dat de algemene aard wordt voorafgegaan door domeinspecifieke vaardigheden. In dezelfde lijn, veronderstellen Veenman en Spaans (2005) dat metacognitieve vaardigheden zich aanvankelijk ontwikkelen op aparte 'eilandjes' van taken en domeinen. In de loop van de ontwikkeling, vanaf ongeveer twaalfjarige leeftijd, zouden de metacognitieve vaardigheden vervolgens steeds algemener van aard worden.

De studies beschreven in de hoofdstukken 2, 3 en 4 vormen samen een longitudinaal onderzoek. Dezelfde leerlingen zijn gedurende drie opeenvolgende jaren gevolgd. Elk jaar voerden zij hardop denkend een tekstbestuderingstaak voor het vak geschiedenis en een probleemoplostaak voor het vak wiskunde uit. De taken werden jaarlijks aangepast aan het leeftijdsniveau. Aan de hand van de verkregen hardop-denk protocollen werd aan iedere participant een score toegekend voor de kwantiteit (frequentie) en de kwaliteit van zijn/haar metacognitieve vaardigheden. De metacognitieve activiteiten werden gecodeerd als behorend bij één van de vier subschalen (oriëntatie, planning, evaluatie of elaboratie). De individuele totaalscore voor metacognitieve vaardigheden werd gevormd door de som van de score op de vier subschalen. De kwantitatieve score werd vastgesteld aan de hand van het aantal keren dat de activiteiten optraden; de kwalitatieve score werd vastgesteld aan de hand van een vooraf opgesteld scoringsmodel. Daarnaast werd elk jaar een intelligentietest en een natoets voor beide taken afgenomen.

De studie beschreven in hoofdstuk 5 is een cross-sectionele studie. Hierin werden twee groepen leerlingen van verschillende leeftijden vergeleken. Zij voerden hardop denkend een wiskunde taak uit. Ook bij deze leerlingen werd een intelligentietest en een natoets afgenomen.

In *hoofdstuk 2* wordt het eerste jaar van de longitudinale studie beschreven. Tweeëndertig eerstejaars leerlingen uit het voortgezet onderwijs (VWO, HAVO en VMBO-T) namen deel aan het onderzoek. Dit onderzoek richtte zich op de relatie tussen intelligentie en metacognitieve vaardigheden als voorspellers van leerresultaat. Daarnaast werd de algemene vs. domeinspecifieke aard van metacognitieve vaardigheden onderzocht.

In een individuele sessie werd de leerlingen gevraagd hardop denkend een tekst te bestuderen over de Amerikaanse Burgeroorlog. De daarop volgende natoets bestond uit meerkeuze vragen en open vragen. In een andere individuele sessie kregen de leerlingen als probleemoplostaak opgaven voor het vak wiskunde voorgelegd. De daarbij behorende natoets bestond uit parallelle opgaven. De scores op de natoetsen resulteerden in de leermaten voor beide taken.

De eerste onderzoeksvraag betrof de bijdrage van enerzijds intelligentie en anderzijds metacognitieve vaardigheden aan het leerresultaat. De resultaten van dit eerste onderzoek ondersteunen het *gemengde* model. Volgens dit model correleren intelligentie en metacognitieve vaardigheden met elkaar, maar draagt metacognitie ook zelfstandig bij aan de voorspelling van het leerresultaat, bovenop de bijdrage van intelligentie.

De tweede onderzoeksvraag betrof de algemeenheid versus domeinspecificiteit van metacognitieve vaardigheden. Een principale componenten analyse (PCA) op de metacognitie data resulteerde in een twee-componenten oplossing. De eerste, sterke component kan worden geïnterpreteerd als representant van algemene metacognitieve vaardigheden, terwijl de tweede, zwakkere component domeinspecifieke metacognitieve vaardigheden representeert. Hieruit kan de conclusie worden getrokken dat metacognitieve vaardigheden van brugklassers zowel algemeen als (nog) domeinspecifiek van aard zijn.

In *hoofdstuk 3* worden de resultaten van het tweede jaar van de longitudinale studie beschreven en vergeleken met die van het eerste jaar. Wegens verhuizing of verandering van school zijn vier participanten afgevallen, zodat de beschreven resultaten betrekking hebben op de overgebleven 28 participanten.

De taken bestonden in het tweede jaar uit een tekstbestuderingstaak over de Eerste Wereldoorlog en een aantal probleemoplostaken voor wiskunde. De taken en natoetsen zijn qua formaat gelijk gehouden aan het eerste jaar, maar de inhoud is qua moeilijkheidsgraad aangepast aan de leeftijdsgroep.

Resultaten laten zien dat tussen het eerste en tweede jaar van het voortgezet onderwijs metacognitieve vaardigheden toenemen. Dit geldt zowel voor de kwantiteit (frequentie) als voor de kwaliteit van metacognitieve vaardigheden.

Evenals in het eerste jaar, ondersteunen de resultaten ook in het tweede jaar het *gemengde* model. Dit betekent dat ook in het tweede jaar metacognitieve vaardigheden deels onafhankelijk van intelligentie bijdragen aan de voorspelling van leerresultaat. Resultaten zijn niet alleen in lijn met het gemengde model (Veenman, 1993), maar ook met de monotone ontwikkelingshypothese (Alexander e.a., 1995). Metacognitie en intelligentie ontwikkelen beide monotoon.

Tussen het eerste en tweede jaar is nagenoeg niets veranderd met betrekking tot de aard van metacognitieve vaardigheden. In het tweede jaar is vrijwel dezelfde PCA-oplossing gevonden als in het eerste jaar. Ook de metacognitieve vaardigheden van tweedeklassers zijn zowel algemeen als (nog) domeinspecifiek van aard.

In *hoofdstuk 4* worden de resultaten van het derde en tevens laatste jaar van de longitudinale studie beschreven. Het doel van dit onderzoek was de resultaten van derdeklassers te vergelijken met die van eerste- en tweedeklassers. Ten opzichte van het tweede jaar namen drie leerlingen minder deel aan het onderzoek. Ook deze drie leerlingen vielen uit wegens verhuizing of verandering van school. De beschreven resultaten in hoofdstuk vier hebben dan ook alleen betrekking op de overgebleven 25 participanten.

De taken bestonden in het derde jaar uit een tekstbestuderingstaak over de economische depressie van de jaren dertig in de Verenigde Staten van Amerika en een aantal probleemoplostaken voor wiskunde. De taken en natoetsen zijn qua formaat gelijk gehouden aan voorgaande jaren, maar de inhoud is qua moeilijkheidsgraad aangepast aan de leeftijdsgroep.

Resultaten laten zien dat de gevonden groei van metacognitieve vaardigheden tussen het eerste en het tweede jaar zich niet voortzet tussen het tweede en het derde jaar. Er is dus geen sprake van een continue groei over de gehele periode tussen 12- en 15-jarige leeftijd. Dit geldt zowel voor de kwantiteit (frequentie) als voor de kwaliteit van metacognitieve vaardigheden.

Het *gemengde* model blijft stabiel over de drie jaar. Ook in het derde jaar dragen metacognitieve vaardigheden deels onafhankelijk van intelligentie bij aan de voorspelling van leerresultaat. In tegenstelling tot metacognitieve vaardigheden, laat intelligentie wel een continue groei zien over de gehele periode. Dit betekent dat resultaten van het derde jaar de monotone ontwikkelingshypothese niet bevestigen.

In het derde jaar verandert de aard van metacognitieve vaardigheden. De principale componenten analyse (PCA) laat nog steeds een eerste sterke, algemene component zien, terwijl de tweede, zwakkere component niet langer als domeinspecifiek kan worden geïnterpreteerd. Rond de leeftijd van vijftien jaar lijkt zich een belangrijke ontwikkeling met betrekking tot metacognitieve vaardigheden te voltrekken: de groei stagneert, terwijl de aard verandert naar louter domeinoverstijgende vaardigheden.

In *hoofdstuk 5* worden de resultaten van een cross-sectionele studie beschreven. In deze studie is opnieuw onderzocht of kwantiteit (frequentie) en kwaliteit van metacognitieve vaardigheden toenemen met leeftijd. Tevens is de relatie van metacognitieve vaardigheden met intelligentie als voorspellers van leerresultaat onderzocht. Participanten waren 29 tweedeklassers en 30 derdeklassers van het voortgezet onderwijs (VWO, HAVO en VMBO-T). Zij voerden dezelfde probleemoplostaken en natoetsen voor wiskunde uit (behorend bij hun leeftijdsgroep) als de participanten van de longitudinale studie. Intelligentie werd gemeten met behulp van een gestandaardiseerde intelligentietest. Maten voor metacognitieve vaardigheden zijn wederom verkregen uit de analyse van hardop-denkprotocollen.

Resultaten tonen een groei in kwantitatieve en kwalitatieve scores voor metacognitieve vaardigheden. De kwantitatieve scores op de subschalen ‘planning’ en ‘evaluatie’ maakten de sterkste groei door. In relatie met intelligentie werd evenals in de longitudinale studie het *gemengde* model gevonden. Hoewel dit model in beide leeftijdsgroepen werd gevonden, was de voorspellende waarde van metacognitieve vaardigheden voor het leerresultaat, bovenop die van intelligentie, sterker bij de oudere groep. Resultaten ondersteunen de monotone ontwikkelingshypothese (Alexander e.a., 1995): een monotone groei van metacognitie en intelligentie over de jaren.

In *hoofdstuk 6* worden enkele methodologische kwesties besproken met betrekking tot de longitudinale studie. Het betreft hier een aantal controles dat is uitgevoerd met behulp van statistische toetsen met als doel mogelijk verstorende effecten als gevolg van de longitudinale opzet uit te sluiten. De belangrijkste conclusies van deze controles waren dat de uitval van participanten niet heeft geleid tot selectieve uitval, dat er geen significant verschil is gevonden wat betreft het relatieve moeilijkheidsniveau van de natoetsen over de drie jaren, en dat het herhaald meten van metacognitieve vaardigheden met telkens een onderbreking van een jaar niet heeft geleid tot een significant verschil in het toekennen van kwalitatieve scores.

In *hoofdstuk 7* worden de resultaten van de studies samengevat en besproken. De eerste conclusie die getrokken kan worden uit de resultaten van het longitudinale onderzoek is dat zich discontinuïteit voordoet in de ontwikkeling van metacognitieve vaardigheden van jonge adolescenten. Na een aanvankelijke toename van zowel de frequentie als de kwaliteit van deze vaardigheden tussen het eerste en tweede jaar van het voortgezet onderwijs, trad in het daarop volgende jaar stabilisatie of zelfs regressie op. Op basis van eerdere cross-sectionele studies van Veenman e.a. (2004) en Veenman en Spaans (2005) werd een continue groei verwacht. In deze studies waren de intervallen tussen meetmomenten echter groter, minimaal twee jaar. Het zou kunnen dat over een langere periode een continue toename zich voordoet, maar dat binnen die periode één of meer periode(n) van discontinuïteit bestaan. Bij grotere intervallen worden kortdurende, tijdelijke veranderingen niet gezien. Resultaten van de cross-sectionele studie gepresenteerd in hoofdstuk 5, komen slechts gedeeltelijk overeen met die van de longitudinale studie. In de cross-sectionele studie was wel sprake van een toename van metacognitie tussen tweede en derde jaar van het voortgezet onderwijs. Het is mogelijk dat het verschil in resultaten tussen enerzijds een longitudinale studie en anderzijds cross-sectionele studies mede veroorzaakt wordt door het verschil in onderzoeksopzet. Longitudinale studies zijn mogelijk gevoeliger voor het vinden van veranderingen tijdens de ontwikkeling. Alle mogelijke, andere verschillen tussen groepen zijn immers uitgesloten. In recente ontwikkelingsliteratuur wordt dan ook regelmatig gepleit voor longitudinaal onderzoek (Bullock & Schneider, 2009; Casey e.a., 2005; Crone e.a., 2006).

De tweede conclusie luidt dat het *gemengde* model door de data van elk jaar in het longitudinale onderzoek en de data van het cross-sectionele onderzoek werd ondersteund. De relatie van intelligentie en metacognitie als voorspellers van leerresultaat is daarmee stabiel gedurende de jonge adolescentie. Resultaten zijn in lijn met eerdere studies waarbij ook oudere adolescenten waren betrokken (Veenman, 1993; Veenman & Beishuizen, 2004; Veenman e.a., 2004; Veenman & Verheij, 2003).

De derde conclusie betreft de aard van metacognitieve vaardigheden. Verondersteld werd dat deze vaardigheden zich aanvankelijk ontwikkelen binnen de context van taken en domeinen en dat gedurende de ontwikkeling deze vaardigheden algemeen van aard worden. De metacognitieve vaardigheden van eerste- en tweedeklassers bleken inderdaad zowel domeinspecifiek als algemeen van aard te zijn, terwijl die van derdeklassers nog uitsluitend algemeen van aard bleken te zijn.

Rond het vijftiende jaar deden zich dus tegelijkertijd twee interessante veranderingen op het ontwikkelingstraject van metacognitieve vaardigheden voor: de groei stagneert, terwijl de aard verandert. Uit onderzoek van Veenman e.a. (2004) is bekend dat metacognitieve vaardigheden toenemen tot ten minste de leeftijd van 22 jaar. Aangenomen kan daarom worden dat de toenamestop slechts een tijdelijke onderbreking is. Tijdens deze stop vindt een verandering in de aard van de vaardigheden plaats. Een ingrijpende verandering die waarschijnlijk niet hand in hand kan gaan met een continue toename van metacognitie. Het tegelijkertijd voorkomen van toename én verandering van aard zou cognitieve overbelasting tot gevolg kunnen hebben. Metacognitieve vaardigheden worden beschouwd als procedurele kennis (zie hoofdstuk 1, paragraaf 1.1), dat wil zeggen, als een productiesysteem van conditie-actieregels verworven binnen een specifiek domein voor specifieke taken (Anderson, 1996; Veenman, 2011; Winne, 2010). Het conditiegedeelte van de productieregels zet bepaalde activiteiten (acties) van de leerder in gang. Als de reikwijdte van het conditiegedeelte toeneemt, kunnen productieregels voor specifieke taken en domeinen samensmelten en veralgemeniseren. Vervolgens kunnen zij worden toegepast op andere taken en domeinen dan waarvoor ze oorspronkelijk zijn verworven. Een onderbroken groei in metacognitieve vaardigheden zou een tijdelijke stop op de uitbreiding van het actiegedeelte van de productieregels kunnen betekenen. Als leerders in staat zijn metacognitieve vaardigheden te transfereren naar een andere context dan waarin zij verworven zijn, zou er weer ruimte kunnen komen voor toename in frequentie en kwaliteit.

Implicaties voor de onderwijspraktijk

Ook in de vroege adolescentie blijkt metacognitie, naast intelligentie, een sterke voorspeller van leerresultaat. De gepresenteerde resultaten kunnen bijdragen aan een zo effectief mogelijke ondersteuning door docenten en methodeontwikkelaars bij de verwerving en ontwikkeling van metacognitieve vaardigheden door leerlingen. De studies in dit proefschrift hebben aangetoond dat frequentie en kwaliteit van metacognitieve vaardigheden weliswaar spontaan, zonder expliciete training, toenemen tijdens de vroege adolescentie, maar dat deze ontwikkeling niet in een rechte opwaartse lijn verloopt. Tevens is gevonden dat in de ontwikkelingsfase van de vroege adolescentie zich grote individuele verschillen voordoen evenals verschillen in groeitempo tussen de subschalen van metacognitie. Samengevat, het ontwikkelingspad van metacognitieve vaardigheden is hobbelig: groei, stabilisatie en zelfs regressie na groei wisselen elkaar af. Een stevig verankerd structureel gebruik van metacognitieve vaardigheden is niet het gevolg van uitsluitend spontane ontwikkeling noch kan een dergelijk gebruik bereikt worden door kortdurende eenmalige interventies. Bijdragen aan de ontwikkeling van metacognitieve vaardigheden is dan ook een langdurige uitdaging voor docenten en methodeontwikkelaars. In de laatste decennia hebben vele studies aangetoond dat metacognitie met succes trainbaar is. In de literatuur (Veenman e.a., 2006) is een drietal condities geformuleerd waaraan effectieve trainingsprogramma's moeten voldoen. Ten eerste dient de training aangeboden te worden over een lange periode, ten tweede dienen leerlingen overtuigd te zijn van het nut van de te trainen vaardigheden ('informed training') en ten derde dient de training plaats te vinden in de context van een domein. Op basis van de resultaten van dit proefschrift zou een vierde conditie kunnen worden toegevoegd, namelijk dat de verschillende componenten van metacognitieve vaardigheden getraind dienen te worden op het daarvoor meest geschikte moment tijdens de ontwikkeling. De training van bepaalde vaardigheden zou moeten worden afgestemd op de spontane ontwikkeling van die vaardigheden. Bijvoorbeeld, als leerlingen van een bepaalde leeftijd spontaan vrijwel geen reflectie op het eigen leren aan de dag leggen, is het waarschijnlijk weinig effectief om reflectie als een metacognitieve activiteit uitvoerig te trainen op dat moment. Anderzijds, door tijdens een kritieke periode de training van een bepaalde vaardigheid sterk te benadrukken, kan regressie na groei wellicht voorkomen worden.

Een andere voor de onderwijspraktijk relevante bevinding uit dit proefschrift is dat naast een spontane groei van metacognitieve vaardigheden, er tevens sprake is van een spontane transformatie van de aard van metacognitieve vaardigheden. Rond het 15^{e}

jaar vindt een volledige generalisatie van deze vaardigheden plaats. Het gevolg hiervan is dat leerlingen vaardigheden die zij hebben verworven binnen specifieke taken en domeinen, nu ook meer kunnen transfereren naar en toepassen op nieuwe taken en domeinen. Hoewel de aard van metacognitieve vaardigheden (deels) spontaan lijkt te veranderen, kunnen docenten ook op het gebied van het bevorderen van transfer een belangrijke rol vervullen. Zij kunnen leerlingen wijzen op en trainen in de mogelijkheid bepaalde vaardigheden toe te passen op andere taken en domeinen. Een actieve benadering van de mogelijkheid voor transfer door docenten verlangt dat docenten over de grenzen van hun eigen vak kijken.

Tot slot

Voor zover bekend is in dit proefschrift voor de eerste maal de ontwikkeling van metacognitieve vaardigheden van jonge adolescenten onderzocht in een longitudinale opzet. Als gevolg van de arbeidsintensieve meetmethode van metacognitieve vaardigheden (analyse van hardop denkprotocollen) is de omvang van het aantal proefpersonen, scholen en het aantal jaren dat proefpersonen zijn gevolgd, beperkt gehouden. Deze beperking zou van invloed kunnen zijn op de generaliseerbaarheid van de resultaten. De uitdaging voor toekomstig onderzoek is om de ontwikkeling van metacognitieve vaardigheden van een grotere groep adolescenten over een langere periode te volgen.

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Appendix A
Criteria for assessing the quality of metacognitive skillfulness in history

	Score
Orientation	
• Not reading the title and/or subtitles of paragraphs	0
• No activity prior to task performance	1
• Some orientations while reading, not (entirely) prior to task performance	2
• Obvious orientation at text level (e.g., looking at the structure of the text; reading subtitles of paragraphs) prior to task performance	3
• Aforementioned activities, including deeper (e.g., stating expectations about the content of the text prior to reading; activate prior knowledge)	4
Planning	
• Absent	0
• Superficial action (e.g., rereading arbitrary parts without specific goal)	1
• Navigating through text with a goal or another planned activity (e.g., selectively marking text parts; take notes)	2
• Aforementioned activities plus good time management	3
• Aforementioned activities plus executing a plan that was thought of in advance, (e.g., first reading whole text, followed by reading each paragraph and paraphrasing each paragraph in one's own words before reading the next paragraph)	4
Evaluation	
• Absent	0
• Just utterances like "I don't understand this", not followed by any action	1
• Self-corrections after having noticed failure or misunderstanding	2
• Variety of deeper evaluation and/or monitoring (e.g., checking comprehension, self-control by selecting text parts looking for information)	3
• Aforementioned plus explicitly formulating the learning outcome of this evaluation process	4

Elaboration

- Absent 0
- Some shallow elaborations elicited by questions/assignments in the text, not spontaneously 1
- Some shallow elaborations during text reading (e.g., paraphrasing almost literally) 2
- As below, but not during the whole task performance 3
- Deeper elaborations with clear conclusions formulated in whole sentences 4

Appendix B
Criteria for assessing the quality of metacognitive skillfulness in math

	Score
Orientation	
• Absent	0
• Reading the assignments/task demands carefully prior to task performance	1
• Reading the assignments/task demands prior to task performance plus superficial orientations (e.g., verifying the number of assignments)	2
• Obvious orientation (visualizing the problem by making a sketch or by schematizing important information) prior to task performance	3
• Aforementioned activities, but deeper and more complete (e.g., activating prior knowledge; relating to a previously encountered, similar problem)	4
Planning	
• Absent	0
• Action plan consists in consulting explanation sheet, not followed by any action	1
• Action plan is executed only partly,followed by trial-and-error	2
• Action plan is executed partly, followed by a new plan	3
• Problem is solved by action plan that was formulated in advance	4
Evaluation	
• Absent	0
• Just utterances like "I don't understand this", not followed by any action	1
• Self-corrections after having noticed failure or misunderstanding; uncertainty leading to consult the explanation sheet	2
• Variety of deeper evaluation activities (e.g., checking comprehension, self-control, verifying the outcome systematically, questioning the appropriateness of the plan)	3
• Aforementioned plus explicitly evaluating the outcome of the learning process	4

Elaboration

- Absent 0
- Occasionally relating the outcome to the assignment or problem statement 1
- Systematically relating the outcome to the assignment or problem statement 2
- Concluding which information was important to solve the problem; stating which information was redundant 3
- After having solved the problem, student reflects on what was learned and its usefulness for future situations 4

Appendix C
Correlations between intellectual ability, metacognitive skills, and learning performance over the years

Legend

1. Intellectual ability (IA) Number Series 13 yrs
2. IA Verbal Analogies 13 yrs
3. IA Unfolding Figures 13 yrs
4. IA Memory 13 yrs
5. IA Number Series 14 yrs
6. IA Verbal Analogies 14 yrs
7. IA Unfolding Figures 14 yrs
8. IA Memory 14 yrs
9. IA Number Series 15 yrs
10. IA Verbal Analogies 15 yrs
11. IA Unfolding Figures 15 yrs
12. IA Memory 15 yrs
13. Metacognition Math quality (MetaMQl) Orientation 13 yrs
14. MetaMQl Planning 13 yrs
15. MetaMQl Evaluation 13 yrs
16. MetaMQl Elaboration 13 yrs
17. Metacognition History quality (MetaHQl) Orientation 13 yrs
18. MetaHQl Planning 13 yrs
19. MetaHQl Evaluation 13 yrs
20. MetaHQl Elaboration 13 yrs
21. MetaMQl Orientation 14 yrs
22. MetaMQl Planning 14 yrs
23. MetaMQl Evaluation 14 yrs
24. MetaMQl Elaboration 14 yrs
25. MetaHQl Orientation 14 yrs
26. MetaHQl Planning 14 yrs
27. MetaHQl Evaluation 14 yrs
28. MetaHQl Elaboration 14 yrs
29. MetaMQl Orientation 15 yrs
30. MetaMQl Planning 15 yrs
31. MetaMQl Evaluation 15 yrs
32. MetaMQl Elaboration 15 yrs
33. MetaHQl Orientation 15 yrs
34. MetaHQl Planning 15 yrs
35. MetaHQl Evaluation 15 yrs
36. MetaHQl Elaboration 15 yrs
37. Metacognition Math quantity (MetaMQn) Orientation 13 yrs
38. MetaMQn Planning 13 yrs
39. MetaMQn Evaluation 13 yrs
40. MetaMQn Elaboration 13 yrs
41. Metacognition History quantity (MetaHQn) Orientation 13 yrs
42. MetaHQn Planning 13 yrs
43. MetaHQn Evaluation 13 yrs
44. MetaHQn Elaboration 13 yrs
45. MetaMQn Orientation 14 yrs
46. MetaMQn Planning 14 yrs
47. MetaMQn Evaluation 14 yrs
48. MetaMQn Elaboration 14 yrs
49. MetaHQn Orientation 14 yrs
50. MetaHQn Planning 14 yrs
51. MetaHQn Evaluation 14 yrs
52. MetaHQn Elaboration 14 yrs
53. MetaMQn Orientation 15 yrs
54. MetaMQn Planning 15 yrs

55. MetaMQn Evaluation 15 yrs
56. MetaMQn Elaboration 15 yrs
57. MetaHQn Orientation 15 yrs
58. MetaHQn Planning 15 yrs
59. MetaHQn Evaluation 15 yrs
60. MetaHQn Elaboration 15 yrs
61. Learning Performance Math (LPM) 13 yrs
62. Learning Performance History (LPH) 13 yrs
63. LPM 14 yrs
64. LPH 14 yrs
65. LPM 15 yrs
66. LPH 15 yrs

Note: N=25

$p < .05$ if $r \geq .40$; $p < .01$ if $r \geq .50$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	.58															
3	.70	.56														
4	.18	.29	.29													
5	.56	.53	.49	.45												
6	.34	.59	.37	-.07	.59											
7	.49	.39	.82	.33	.55	.20										
8	.27	.06	.36	.44	.31	-.10	.53									
9	.48	.39	.38	.40	.78	.36	.55	.23								
10	.44	.58	.51	.11	.36	.63	.32	.03	.21							
11	.35	.43	.61	.36	.60	.29	.77	.21	.75	.32						
12	.17	.19	.43	.49	.41	.03	.63	.59	.37	.20	.40					
13	.03	.28	.13	.09	.19	.01	.33	-.09	.17	.16	.37	.34				
14	.55	.64	.58	.18	.61	.32	.70	.22	.55	.43	.61	.40	.48			
15	.27	.32	.29	.14	.52	.25	.38	.04	.25	.06	.34	.22	.61	.45		
16	-.04	.23	-.03	.39	.23	.20	-.01	.09	.24	.30	.18	.43	-.04	.06	-.31	
17	-.11	.25	-.24	.09	.05	.15	-.36	-.46	.17	.18	-.04	-.14	-.03	.08	-.17	.43
18	.36	.33	.12	.12	.33	.11	.00	-.22	.27	.26	.18	.03	.25	.44	.08	.42
19	.03	.41	.09	.24	.27	.25	-.10	-.09	.15	.21	.08	.02	-.09	.20	.06	.37
20	.19	.36	.02	.08	.12	.02	-.04	-.39	.06	.26	.15	.00	.42	.44	.13	.31
21	-.23	.02	-.21	.06	.06	.17	-.28	-.43	.09	.15	.06	-.38	.05	-.09	.03	.09
22	.39	.44	.30	.28	.67	.40	.35	.26	.68	.31	.39	.21	-.04	.60	.14	.15
23	.23	.45	.13	.24	.52	.50	.23	.04	.40	.41	.42	.07	.23	.39	.34	.35
24	.30	.41	.17	.23	.62	.29	.35	.03	.63	.22	.51	.04	.26	.55	.44	-.01
25	.00	.43	.25	.35	.26	-.05	.43	.27	.23	.23	.52	.44	.42	.39	.16	.37
26	-.07	.17	.09	.07	.08	-.04	.16	-.06	.18	.01	.18	.25	.12	.20	-.04	.15
27	-.15	.41	.00	.12	.20	.29	.06	-.38	.11	.18	.26	.06	.44	.25	.41	.22
28	.02	.46	.20	.45	.42	.20	.29	-.10	.36	.28	.39	.21	.34	.41	.30	.22
29	-.04	.00	-.06	.18	.08	.18	-.08	-.01	.10	.20	.00	.19	.07	-.28	-.22	.38
30	.34	.59	.37	.36	.53	.34	.48	.35	.67	.35	.61	.41	.33	.51	.11	.44
31	-.04	.23	-.03	.39	.23	.20	-.01	.09	.24	.30	.18	.43	-.04	.06	-.31	1.00
32	.36	.55	.29	.29	.43	.23	.32	-.05	.58	.50	.57	.20	.47	.54	.18	.43
33	.02	-.05	-.10	.24	.00	-.21	-.04	-.05	-.07	.04	.04	-.05	.28	.00	.24	.09
34	.05	.24	.00	.23	.33	.10	.10	-.10	.40	.30	.27	.32	.43	.33	.21	.44
35	-.24	.17	-.15	.06	.08	.30	-.15	-.28	.18	.33	.17	.05	.17	.15	-.04	.49
36	.07	.30	.00	.34	.39	.13	.06	-.12	.43	.33	.30	.23	.26	.38	.06	.51
37	-.01	.13	.18	.33	.26	-.08	.36	.31	.11	.07	.42	.23	.56	.21	.65	-.20
38	.51	.43	.53	.24	.66	.23	.65	.21	.63	.18	.62	.32	.28	.86	.54	-.09
39	.10	.25	.32	.24	.30	.30	.32	.07	.08	.12	.36	.23	.55	.17	.76	-.14

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	.59	.74	.54	.35	.58	.27	.52	.03	.45	.34	.51	.21	.46	.81	.58	-.02
41	-.18	.17	-.01	.41	.17	.15	-.05	.04	.05	.06	.01	.22	-.11	.11	.02	.31
42	.19	-.07	.04	.33	.24	-.08	.02	.22	.00	-.03	-.12	.30	.17	.18	.17	.33
43	-.16	.20	-.12	.39	.09	-.02	-.21	.01	.03	-.05	-.01	-.04	-.09	.09	.09	.30
44	.27	.35	.02	.05	.26	.11	.01	-.27	.24	.19	.18	.07	.32	.47	.13	.23
45	-.36	-.07	-.25	.16	.06	.04	-.21	-.30	.03	.12	.18	-.26	.29	-.18	.15	.00
46	.27	.15	.19	.10	.53	.42	.25	.11	.54	.16	.30	-.06	.03	.31	.23	-.10
47	-.27	-.11	-.18	-.03	.05	.19	-.20	-.23	-.01	.02	.13	-.17	.12	-.26	.21	.07
48	.44	.55	.25	.25	.63	.44	.21	-.15	.47	.38	.41	-.07	.28	.51	.48	-.01
49	-.08	.24	.12	.37	.25	-.06	.25	.17	.07	.15	.36	.43	.57	.23	.50	.19
50	-.03	.34	.16	.22	.19	-.06	.31	.00	.31	.17	.39	.34	.49	.39	.10	.20
51	-.30	.10	-.03	.09	.01	.17	.05	-.23	.00	.10	.25	.11	.50	.01	.36	.10
52	-.29	.03	-.14	.23	.24	.02	.11	-.13	.35	.02	.28	.14	.29	.22	.04	.17
53	-.05	.07	.00	.07	.07	.18	-.15	-.35	-.07	.25	.05	-.06	.11	-.11	-.16	.35
54	-.10	.04	-.07	-.03	.43	.51	.04	-.21	.43	.13	.28	.11	.20	.21	.31	.18
55	-.23	-.01	-.17	.46	.08	.18	-.24	-.06	.01	.15	-.02	.14	-.08	-.31	-.17	.66
56	.18	.52	.29	.30	.27	.25	.30	-.03	.38	.62	.48	.31	.53	.42	.13	.51
57	-.08	.04	-.08	.37	.04	-.23	.09	.19	-.07	.15	.05	.19	.40	.16	.17	.11
58	-.16	-.04	-.14	.28	.19	.10	-.05	-.09	.24	.32	.23	.00	.09	.00	.01	.35
59	-.12	.04	-.22	.09	.01	.18	-.34	-.24	-.07	.07	-.14	-.14	.00	-.13	-.06	.31
60	-.26	.10	-.19	.33	.11	.07	-.15	-.24	.19	.25	.12	.11	.15	.04	-.13	.52
61	.64	.64	.64	.42	.75	.40	.71	.49	.61	.44	.56	.47	.22	.86	.40	.09
62	.41	.50	.24	.23	.60	.33	.12	-.10	.39	.36	.19	.13	.11	.56	.24	.17
63	.33	.45	.14	.22	.69	.36	.28	.19	.59	.31	.39	.31	.26	.64	.36	.32
64	.29	.46	.14	.28	.45	.26	.09	-.13	.29	.47	.15	.12	.22	.57	.23	.19
65	.32	.42	.41	.36	.67	.40	.49	.29	.75	.41	.64	.51	.19	.62	.17	.37
66	.22	.46	.04	.00	.32	.25	.00	-.19	.32	.23	.12	.04	.21	.48	.00	.35

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
18	.48															
19	.56	.42														
20	.43	.81	.30													
21	.33	.27	.41	.17												
22	.26	.36	.38	.16	.13											
23	.13	.29	.38	.34	.40	.32										
24	.10	.30	.20	.23	.24	.70	.37									
25	.10	.15	.36	.27	-.09	.14	.27	.30								
26	.24	-.06	.24	.19	-.21	.18	-.08	.07	.44							
27	.36	.18	.47	.51	.31	.06	.63	.19	.40	.44						
28	.46	.33	.44	.50	.24	.47	.40	.51	.48	.52	.71					
29	.02	.08	-.33	-.07	.14	-.12	.03	-.19	-.16	-.35	-.15	-.09				
30	.25	.36	.29	.17	.13	.49	.43	.41	.53	.12	.19	.42	.23			
31	.43	.42	.37	.31	.09	.15	.35	-.01	.37	.15	.22	.22	.38	.44		
32	.52	.58	.43	.51	.28	.39	.55	.39	.55	.27	.46	.56	.07	.73	.43	
33	.04	.28	-.04	.41	.08	-.21	.04	.20	.21	.02	.14	.26	-.13	.09	.09	.19
34	.42	.61	.55	.57	.35	.34	.40	.37	.43	.27	.52	.58	.08	.48	.44	.69
35	..65	.40	.45	.33	.45	.14	.43	-.03	.08	-.07	.44	.28	.26	.29	.49	.50
36	.58	.68	.54	.64	.50	.44	.49	.37	.31	.22	.50	.67	.16	.48	.51	.67
37	-.28	-.13	-.02	.03	.00	.03	.21	.32	.52	.13	.28	.33	-.19	.21	-.20	.22
38	.02	.36	.17	.30	.05	.66	.30	.63	.18	.11	.15	.37	-.35	.38	-.09	.34
39	-.29	-.14	-.02	-.01	.05	-.16	.39	.08	.12	-.06	.43	.18	-.03	.08	-.14	.09
40	.15	.42	.35	.53	.02	.39	.45	.48	.38	.28	.51	.56	-.32	.36	-.02	.55
41	.39	.25	.45	.32	.09	.40	.05	.21	.12	.15	.25	.51	-.13	.14	.31	-.04
42	-.03	.49	.11	.34	.03	.04	.23	-.18	-.11	-.13	.02	-.02	-.09	.04	.33	.13
43	.50	.36	.82	.30	.42	.31	.32	.20	.22	.02	.36	.40	-.36	.18	.30	.24
44	.38.	.77	.23	.90	.02	.36	.27	.33	.18	.16	.38	.47	-.01	.23	.23	.40
45	.11	-.03	.10	.08	.75	-.05	.34	.17	.07	-.10	.33	.20	.14	.11	.00	.25
46	.00	.23	.21	-.04	.44	.54	.45	.47	-.22	-.14	.10	.29	.06	.34	-.10	.25
47	.14	-.01	.29	.04	.42	-.17	.53	-.12	-.03	-.15	.49	.11	.03	.01	.07	.19
48	.21	.53	.20	.47	.29	.61	.41	.81	.11	-.12	.26	.53	.04	.29	-.01	.37
49	-.07	.00	.23	.13	.05	-.05	.28	.27	.70	.16	.35	.26	-.13	.17	.19	.29
50	.31	.18	.33	.35	.00	.27	.17	.22	.75	.69	.51	.61	-.14	.49	.20	.65
51	.17	.03	.20	.21	.30	-.09	.48	.03	.20	.06	.67	.44	.10	.13	.10	.29
52	.38	.31	.29	.39	.35	.34	.26	.34	.30	.32	.50	.72	.08	.39	.17	.40
53	.11	.26	-.24	.21	.33	-.19	.02	-.16	-.27	-.26	-.01	-.08	.66	-.03	.35	.06
54	.23	.24	.13	.19	.36	.48	.38	.39	-.18	.12	.38	.38	.16	.21	.18	.17
55	.31	.22	.23	.18	.31	-.07	.36	-.19	-.05	-.09	.30	.26	.52	.11	.66	.16

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
56	.43	.46	.40	.43	.29	.23	.45	.26	.57	.25	.46	.54	.19	.67	.51	.90
57	.05	.00	-.16	.19	-.05	-.27	.05	.02	.29	.00	.09	.19	-.01	.15	.11	.22
58	.42	.30	.33	.24	.51	.11	.51	.09	.15	-.11	.37	.37	.30	.23	.35	.51
59	.34	.30	.41	.29	.27	-.16	.49	-.33	-.12	-.20	.42	.05	.19	-.02	.31	.22
60	.67	.50	.54	.52	.46	.23	.31	.18	.30	.24	.51	.69	.20	.36	.52	.52
61	-.03	.27	.23	.22	-.19	.66	.43	.53	.32	.16	.15	.41	-.24	.48	.09	.39
62	.44	.62	.47	.56	.24	.73	.31	.49	.12	.26	.29	.56	-.09	.24	.17	.41
63	.37	.52	.47	.42	.12	.73	.55	.69	.41	.20	.32	.54	-.23	.58	.32	.56
64	.51	.53	.35	.54	.26	.52	.19	.58	.18	.16	.21	.56	-.15	.26	.19	.40
65	.37	.31	.30	.06	.11	.64	.33	.43	.32	.05	.03	.29	.10	.66	.37	.55
66	.61	.71	.59	.59	.28	.48	.42	.25	.21	.25	.42	.49	-.04	.45	.35	.63

	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
34	.29															
35	-.09	.52														
36	.17	.83	.62													
37	.44	.16	-.13	.02												
38	.03	.23	.03	.33	.24											
39	.20	.00	.03	-.08	.67	.19										
40	.20	.37	.11	.41	.30	.72	.34									
41	.22	.26	.24	.36	.06	.24	.00	.11								
42	.29	.26	.14	.25	.03	.17	.18	.19	.13							
43	.15	.39	.43	.48	.13	.18	.07	.23	.65	.22						
44	.25	.55	.27	.61	-.04	.38	-.11	.48	.42	.24	.22					
45	.29	.22	.31	.23	.45	-.07	.36	-.06	.07	-.02	.24	-.09				
46	-.14	.28	.23	.43	-.01	.39	.15	.27	.00	.10	.17	.08	.12			
47	-.01	.21	.49	.21	.27	-.21	.53	-.12	.04	.01	.37	-.04	.54	.25		
48	.17	.32	.12	.46	.25	.56	.21	.56	.29	-.04	.22	.57	.15	.48	.01	
49	.21	.25	.00	.16	.69	.14	.54	.28	.05	.03	.24	-.02	.29	-.21	.20	.19
50	.08	.56	.14	.39	.34	.20	-.02	.40	.09	-.05	.10	.29	.15	-.14	-.07	.03
51	-.05	.26	.44	.31	.38	-.06	.63	.08	.14	-.05	.28	11	.44	.19	.79	.18
52	.20	.66	.44	.70	.12	.21	-.09	.22	.44	.00	.28	.48	.26	.41	.17	.28
53	.01	-.03	.37	.17	-.21	-.15	.10	-.09	-.07	.20	-.17	.07	.30	.00	.04	.15
54	-.07	.36	.44	.45	.09	.35	.29	.07	.36	.13	.17	31	.33	.55	.41	.45
55	.14	.26	.54	.43	-.06	-.33	.21	-.16	.34	.37	.36	.08	.30	.15	.50	.05
56	.25	.70	.56	.63	.27	.15	.20	.43	.02	.12	.23	.26	.33	.16	.22	.25
57	.72	.15	.11	.13	.41	.01	.22	.25	.07	.25	.04	.00	.23	-.19	-.12	-.05
58	.17	.59	.75	.66	.13	-.03	.04	.08	.10	.16	.33	.17	.45	.35	.52	.19
59	-.08	.32	.67	.36	-.22	-.27	.14	.07	.07	.36	.38	.24	.14	.20	.62	-.04
60	.29	.76	.65	.84	.00	-.04	-.13	.12	.54	.10	.53	.49	.32	.23	.33	.26
61	-.03	.20	.02	.33	.22	.77	.23	.75	.23	.18	.16	.33	-.29	.45	-.21	.53
62	-.09	.41	.16	.62	-.02	.59	-.08	.56	.40	.23	.34	.63	-.06	.34	-.15	.69
63	.13	.53	.21	.60	.22	.61	.07	.48	.38	.17	.41	.51	-.03	.40	.05	.60
64	.33	.40	.20	.59	.05	.53	-.07	.55	.47	.12	.34	.52	.05	.21	-.29	.65
65	-.22	.31	.41	.46	.08	.61	.07	.34	.24	.03	.21	.17	.00	.34	.00	.37
66	-.18	.57	.49	.74	-.25	.30	-.18	.44	.16	.20	.40	.59	-.13	.43	.11	.38

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
50	.38																
51	.43	.20															
52	-.02	.52	.33														
53	-.11	-.29	.13	.10													
54	-.04	-.01	.46	.44	.26												
55	.05	-.15	.46	.24	.53	.36											
56	.37	.60	.38	.36	.23	.17	.31										
57	.31	.16	-.02	.17	.06	-.24	.12	.35									
58	.07	.16	.36	.55	.20	.29	.56	.53	.25								
59	-.09	-.08	.41	.23	.18	.13	.60	.21	.00	.60							
60	.07	.41	.40	.80	.12	.36	.58	.58	.20	.71	.44						
61	.21	.20	-.02	.17	-.22	.18	-.12	.27	.15	.01	-.07	.02					
62	.10	.28	.04	.30	.01	.41	.03	.23	-.22	.11	.02	.35	.55				
63	.34	.35	.17	.38	-.32	.45	.01	.39	.04	.18	-.02	.38	.66	.69			
64	.20	.20	-.07	.32	.05	.24	.00	.35	.34	.14	-.13	.43	.54	.74	.66		
65	.26	.28	.11	.24	-.01	.37	.05	.44	.00	.26	-.04	.25	.63	.48	.66	.47	
66	-.01	.37	.26	.44	.00	.33	.16	.48	-.19	.27	.38	.54	.38	.69	.63	.48	.41

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Curriculum Vitae

Manita van der Stel was born in the city of Schiedam, the Netherlands on April 5, 1959. She graduated from the Stedelijk Gymnasium at Schiedam in 1977. She obtained a Master of Arts degree in Spanish linguistics at Leiden University in 1983. After holding various teaching jobs, she was appointed as board member for educational affairs at InterCollege, Inc., The Hague in 1986. Four years later, Manita joined the Hague University of Applied Sciences as a staff member. She obtained a Master of Science degree in educational psychology at Leiden University in 2003. Subsequently, she was employed as an educational advisor at the Haags Centrum voor Onderwijsbegeleiding (HCO) in The Hague. In 2005 Manita started the longitudinal research project that led to this dissertation. Manita is a member of the Dutch Institute of Psychologists (NIP) and the European Association for Research on Learning and Instruction (EARLI).