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The relation between intellectual and metacognitive skills in early adolescence.

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Abstract. The first objective of this study was establishing to what extent metacognitive skill is associated with intelligence. As a second objective, the impact of hints on the execution of metacognitive skills was investigated. Both issues have major implications for the training and transferability of metacognitive skills during performance on a representative school task. First, a standardized intelligence-test was administered to a group of first-year secondary-school students. Next, these students solved six math word problems, three without metacognitive hints and three including these hints. Metacognitive skilfullness was assessed through systematical observation, while learning performance consisted of performance on a math task and grade point average (GPA). Results show that without hints metacognitive skilfulness is the main predictor of initial learning, while intelligence additionally enters the regression equation after the presentation of metacognitive hints. GPA also appears to be predicted by a combination of intellectual and metacognitive skills. Consequences for the early acquisition of metacognitive skills are discussed.

Keywords: intelligence, mathematics, metacognition, metacognitive cues, novice learning, skill development

Introduction

Metacognition has been recognized as a most relevant predictor of learning (Brown, 1978; Flavell, 1976, 1979; Glaser, 1990; Veenman & Elshout, 1995; Wang et al., 1990, 1993). This study addresses the issue whether metacognitive skills in early adolescence are entirely part of intellectual skills, or that they have an independent contribution to the learning process. Furthermore, it will be investigated whether metacognitive cues (or hints) may support the learning process through the activation of metacognitive skills that waveringly become available at this early stage of skill development.

Metacognitive skilfulness

Metacognitive skilfulness often is distinguished from metacognitive knowledge (Alexander et al., 1995; Baker, 1994; Kuhn, 1999; Schraw & Moshman, 1995; Veenman & Elshout, 1999). The latter concept refers to the declarative knowledge one has about the interplay between personal characteristics, task characteristics and the available strategies in a learning situation (Flavell, 1979). Metacognitive knowledge, however, does not automatically lead to appropriate execution of metacognitive skills. For instance, a student may *know* that checking one's answers is necessary, as indicated by his or her self-reports, and yet refrain from actually doing so for various reasons (Veenman, in press; Veenman et al., 2003). The task may be uninteresting or too difficult, or the student may lack the necessary domain-specific knowledge and skills for mastery of the task. In fact, metacognitive knowledge is based on subjective estimates of one's competency (Boekaerts, 1991) that may affect one's motivation to pursue a task or not. For that reason the present study focuses on metacognitive skills.

Metacognitive skills concern the procedural knowledge that pertains to the actual regulation of, and control over one's cognitive processes and learning activities (Brown, 1978; Brown & DeLoach, 1978; Flavell, 1992; Schraw & Moshman, 1995). They are occasionally referred to as executive skills (e.g., Kluwe, 1987). Task analysis, planning, monitoring, checking or evaluation, recapitulation, and reflection are behavioural manifestations of such skills that are (metacognitively) initiated during task performance. These skills can be acquired and eventually executed implicitly (Baker, 1994; Reder, 1996), though some argue that awareness of their metacognitive nature is prerequisite (Nelson, 1996; Schnotz, 1992).

Some researchers further distinguished a third category of metacognitive conditional knowledge, that is, knowledge about what to do when (Desoete & Roeyers, 2003; Schraw & Moshman, 1995). In Andersons' ACT theory, however, conditional knowledge is regarded as an intrinsic part of procedural knowledge, which is represented by condition–action rules (Anderson, 1996). Accordingly, in this study the execution of metacognitive skills implies the application of conditional knowledge.

Metacognitive skills appear to be highly interdependent. By means of thorough orientation on the task, a metacognitively skilled student is likely to focus on relevant information given in the task assignment, necessary for building an adequate task representation. Consequently, a detailed action plan can be designed, containing goals and directions for subsequent learning activities. Such an elaborate action plan entails the possibility of process control during task performance. Working systematically according to that plan may enable the student to keep track of progress being made. Evaluation or monitoring activities, which are necessary for detecting faulty procedures and mistakes, are more fruitful within the framework of such an action plan. Finally, elaboration activities like drawing conclusions, recapitulating, and generating explanations are more helpful if they are based on a clear trace of activities (Veenman et al., 1997).

Intellectual ability as the repertoire of cognitive skills

There exist many conceptions of intelligence (see Brody, 1992; Carroll, 1993; Sternberg, 1990). Here, a rather pragmatic point of view is adopted. Intelligence may be perceived as the magnitude and quality of the human cognitive toolbox, which contains basic cognitive operations (Elshout, 1983). Comparing two symbols and recovering a word meaning from long-term memory are examples of such basic operations. The content and quality of this toolbox is not only determined by the biological substratum (e.g., hereditary factors or, conversely, brain damage), but increasingly by the opportunities one seeks and the environment offers for acquiring useful cognitive strategies (e.g., at home or in educational settings). In the same vein, Humphreys (1968, 1989), Snow (1989) and 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. An intelligence test samples this broad repertoire. The main question here is whether metacognitive skills are essentially part of this cognitive toolbox or repertoire. Sternberg (1990) and Davidson et al. (1994), for instance, regard metacognitive skills as a core process component in their triarchic theory of intelligence. Metacognitive skills, however, may also develop relatively independent from intellectual skills. Slife et al. (1985) adequately formulated this research issue with the question '...whether metacognition can be reduced to cognition'.

Intellectual ability, metacognitive skilfulness, and learning performance

There are three, mutually exclusive models for describing the relation between intellectual ability and metacognitive skilfulness as predictors of learning (Veenman & Elshout, 1991; Veenman et al., 1997). The first model regards metacognitive skilfulness as a manifestation of intellectual ability, or as an integral part of the cognitive toolbox. According to this intelligence model, metacognitive skills cannot have a predictive value for learning, independent of intellectual ability. In a second, contrasting model, intellectual ability and metacognitive skilfulness are regarded as entirely independent predictors of learning, that is, as entirely separated toolboxes. Finally, according to the mixed model, metacognitive skilfulness is related to intellectual ability to a certain extent, but it also has a surplus value on top of intellectual ability for the prediction of learning. The execution of operations from the cognitive toolbox may rely on metacognitive regulation to a certain extent, but the (acquired) metacognitive repertoire has an additional virtue in guiding learning processes. For instance, both high and low intelligent students appear to profit from moving around carefully, step-by-step, as they encounter a new, highly unfamiliar task (Veenman et al., 2002).

Several researchers (Cheng, 1993; Hannah & Shore, 1995; Span & Overtoom-Corsmit, 1986; Shore & Dover, 1987; Zimmerman & Martinez-Pons, 1990) have reported significant differences in metacognitive-strategy usage between intellectually gifted and average students. Allon et al. (1994), on the other hand, reported low correlations between WISC-R intelligence and metacognition obtained retrospectively by questioning participants about their problem solving activities. Moreover, Swanson (1990) obtained support for the independency notion with children performing two Piagetian tasks. His experimental design, however, which forced intelligence and metacognition to be orthogonal factors, does not permit the conclusion that both predictors are fully independent (see Veenman & Elshout, 1991). Indeed, follow-up studies (Maqsud, 1997; Swanson et al., 1993) showed that metacognition was only partially independent of intelligence. Slife et al. (1985) showed that the metacognitive functioning of students with learning disabilities was less adequate relative to that of regular students, although both groups were matched on intelligence and domain knowledge. Apparently, their metacognitive functioning was not utterly determined by intellectual ability. In the same vein, Berger and Reid (1989) concluded from their study with mentally retarded individuals, high or low intelligent students with learning disabilities, and normal achieving adults that ‘IQ mediates metacognition, but does not explain it’. Stankov (2000) more specifically argued that metacognition is partly independent of fluid intelligence. Further support for the mixed model has been gathered in our own research, either with computer simulations in the domains of physics, statistics, and behavioural psychology, with studying texts in the domains of law, geography, and earth sciences, or with problem solving in the domains of math and thermodynamics (Elshout &

Veenman, 1992; Elshout et al., 1993; Veenman, 1999; Veenman & Elshout, 1991, 1999; Veenman et al., 1994, 1997, 2002). In an overview. of this research with university freshmen, Veenman (1999) showed that the variance accounted for in learning could be attributed uniquely to intellectual ability for 13.0% and uniquely to metacognitive skilfulness for 16.3%, while both predictors shared another 17.2% of variance. Minnaert and Janssen (1999), on the other hand, could not decide between the independency and mixed model when predicting freshmen's academic performance.

In conclusion, many of the afore-cited studies provide substantial evidence in favour of the mixed model. A limitation of several studies, however, is that their focus is restricted to the relation between intelligence and metacognition, thereby excluding the relation of both predictors with learning performance. The limitation of another subset of studies with a complete data set is that they primarily pertain to university students, whose metacognitive skills have been developed and balanced out for several years. It remains unclear, so far, whether the mixed model can be generalized to younger age groups at the onset of metacognitive-skill development. Although metacognitive awareness and knowledge may arise at an earlier age (Istomina, 1975; Kluwe, 1987; Kuhn, 1999), the development of metacognitive skills sets in at the age of 10–12 years (Berk, 2003; Campione et al., 1982; Flavell & Wellman, 1977; Kuhn, 1999). A review study of Alexander et al. (1995) was inconclusive about whether the early development of metacognitive and intellectual skills occurs as an intertwined process. Unfortunately, their study did not address the relation of both skills with learning performance. Therefore, the first research question in the present study is whether the mixed model applies to younger students who are still in the process of acquiring a vast repertoire of metacognitive skills.

Metacognitive cueing

A second research question addresses the impact of giving metacognitive cues or hints as a 'reminder'. Even if students have their recently acquired metacognitive skills available, they may not spontaneously produce those skills (Brown & DeLoache, 1978; Flavell, 1976; Mayer, 1992; Veenman et al., 2000). Such a production deficiency of available skills may result from inflexibility in the application of those skills, from a lack of conditional knowledge about when to apply those skills appropriately, and from a cognitive overload caused by task difficulty. Although metacognitive hints cannot overcome an availability deficiency (i.e., the lack of skills), they may activate metacognitive skills that are available but not spontaneously produced (Veenman et al., 2000). In the present study metacognitive cues are presented merely as a reminder of the metacognitive skills students already have at their disposal, but they are not inclined to produce spontaneously. The relevance of this kind of research is that it may shed light on the conditions under which metacognitive skills develop at an early stage, and what instructional treatments may encourage this developmental process.

Method

Participants

Forty-one secondary-school students in the age of 12–13 years from a small middle-class town in The Netherlands (Delft) participated in the experiment. Parental consent was requested and given. Distribution of sex was about equal. All participants but one were Caucasian.

Intellectual ability

Intelligence was assessed through the administration of the shortened version of the Groninger Intelligence Test (GIT; Kooreman & Luteijn, 1987) during class. The GIT is a standardized Dutch Intelligence test that has been sufficiently validated against Wechsler scales (Evers et al., 1992). This paper-and-pencil intelligence test consists of three subtests: mathematical speed (measuring the number factor), a spatial filling-out task (measuring the visualization factor), and verbal analogies (measuring the inductive and deductive reasoning factor; Carroll, 1993). Internal consistencies of the separate tests ($0.75 \leq \alpha \leq 0.87$) as well as of the entire GIT ($\alpha = 0.87$) were adequate.

Task

In an individual session participants solved six word problems while thinking aloud. These problems were adapted from Henfi (1990) by Veenman et al. (2000). According to Henfi, the selected problems represented the mastery level for students by the age of 12–13 years. Three categories of problems were presented: distance versus time problems, fraction versus percentage problems, and surface area versus volume problems. For instance, a distance versus time problem was:

> “At 10 a.m. Mr. Smith leaves Amsterdam for Brussels by car. Maximum speed of his car is 90 miles per hour. He drives to Brussels

> with a mean speed of 50 miles per hour. The distance from Amsterdam to Brussels is 140 miles. One hour after Mr. Smith has left, Mr. Jones leaves Brussels by car. Mr. Jones takes his time and drives to Amsterdam with a mean speed of 40 miles per hour. At what time do Mr. Smith and Mr. Jones meet?"

Although the problem contained some redundant information (e.g., the maximum speed of Mr. Smith's car), forcing subjects to distinguish between relevant and irrelevant information (Davidson, 1986), most of the information in the given problem was essential for solving the problem.

First, three problems were presented without cueing. These no-cue problems measured the spontaneous *production* of metacognitive skills. Next, subjects had to solve three similar problems, that is, with the same deep structure of the three problems mentioned before but with different surface characteristics, during which a short list of metacognitive cues was presented on a printed sheet. This list consisted of six metacognitive cues merely as a *reminder*, which could help subjects to overcome their production deficiencies: (1) Try to say in your own words what you need to know; (2) What numbers do you need in order to solve the problem?; (3) What action steps do you have to take in order to solve this problem?; (4) After each step, consider whether you are still making progress in solving the problem; (5) Check your outcomes; and (6) Can you draw a conclusion with regard to the question? These metacognitive cues corresponded with categories of metacognitive-skill assessment shown below (2 and 3; 6; 11–13).

Subjects were instructed in advance to apply these cues while solving the three math problems. The experimenter, however, did not further advocate the application of cues during the problem solving process. This cueing procedure was intended to unveil metacognitive skills that were not spontaneously produced, without explicitly training or implementing those skills. Therefore, cued items may measure the *availability* of metacognitive skills (Veenman *et al*., 2000). The order of presenting no-cue items first, followed by cued items, was fixed and could not be alternated because when presented in the reversed order, no-cue items could be affected by earlier cuing effects. For each series of no-cue versus cued problems, a time limit of 20 min was imposed.

Learning performance.

A first measure of learning performance concerned the adequacy of solving the six problems. For each problem, it was established whether the answer was correct (1 point) or incorrect (0 points). Correctness of the problem solving procedure was not taken into account in order to avoid confounding of math performance with measures of metacognitive skilfulness. Mean scores were calculated over the no-cue problems and the cued problems separately (Cronbach's alphas being rather low due to short test lengths, for example, 0.43 for no-cue and 0.44 for cued problems).

The second measure of learning performance consisted of the grade point average (GPA) for math, ranging from 0 (very poor) to 10 (excellent). GPA was assessed in June at the end of the school year, covering mean math performance over the preceding year.

Metacognitive skilfulness

Metacognitive skilfulness was assessed through systematical observation (SO) during the problem solving process (Veenman et al., 2000). All participants were instructed to 'think aloud' while individually solving the six math problems. The experimenter only urged them to continue thinking aloud whenever they fell silent with a standard instruction: 'Please, keep on thinking aloud'. No help whatsoever was provided for by the experimenter. From research (Ericsson & Simon, 1980, 1984; Veenman et al., 1993) it is known that merely thinking aloud does not interfere with cognitive and metacognitive processes. Thinking aloud may only slow down those processes.

For each problem, the experimenter concurrently scored the subject's metacognitive behaviour (SO) on the presence of 15 activities:

(1) entirely reading the problem statement (as incomplete task analysis leads to trial-and-error behaviour);
(2) selection of relevant data (task analysis);
(3) paraphrasing of what was asked for (task analysis and goal setting);
(4) making a drawing related to the problem (task analysis);
(5) estimating a possible outcome (goal setting);
(6) designing an action plan before actually calculating (planning);
(7) systematically carrying out such plan (to avoid haphazard behaviour);
(8) calculation correctness (avoid sloppiness);
(9) avoiding negligent mistakes (such as inattentively switching numbers);
(10) orderly note-taking of problem solving steps (in order to keep an overview of problem-solving steps and create an opportunity for checking outcomes);

(11) monitoring the on-going process;
(12) checking the answer;
(13) drawing a conclusion (recapitulating);
(14) reflecting on the answer (referring to the problem statement);
(15) relating to earlier problems solved (reflection with the aim to learn from one's experiences).

These activities are characteristic of metacognitive skilfulness in general (Brown, 1978; Sternberg, 1990; Veenman et al., 1997; Wang et al., 1990), but in particular of metacognitive skilfulness during math exercises (De Corte & Verschaffel, 1980; Davidson, 1986; Gagné et al., 1993; Schoenfeld, 1983). Activities 1–5 represent the subject's orientation on the problem before acting, activities 6–10 depict the systematical orderliness while acting, activities 11 and 12 delineate the evaluation activity during and after problem solving, while activities 13–15 represent reflections after solving the problem. The experimenter rated each problem for each subject on these 15 activities. A zero was given if the activity was absent, whereas a score of two was given if the activity was clearly present. In case an activity was initiated but not completed, a score of one point was granted. As SO ratings had to be assessed by the experimenter concurrent with the subjects' ongoing process of solving of math problems, the experimenter practiced this SO rating procedure in advance on several other participants not included in the sample until she felt confident that an adequate level of rating fluency was reached. For each metacognitive activity the mean score was calculated over the three no-cue versus cued problems separately. Finally, SO-sumscores were calculated over the 15 metacognitive activities for no-cue versus cued problems (Cronbach's α being 0.82 for both no-cue and cued problems).

In order to validate SO measurements, the thinking-aloud protocols of six participants were transcribed and subsequently analysed on the quality of metacognitive skilfulness (PA), using the judgmental procedure of Veenman and Elshout (1991, 1995, 1999) and Veenman et al. (1994, 1997, 2000). This judgmental procedure is not only based on the mere presence of metacognitive activity, but it also accounts for the quality of executed metacognitive activities. For instance, one may fully read the problem statement but one may read it superficially, for example, by being inattentive to selecting relevant from irrelevant problem elements. Similarly, monitoring activities may be constrained to passively noticing that 'something is going wrong', or it may expand to actively restoring the ongoing problem solving process. The judgmental approach also considers whether metacognitive skills are executed at the right place and the right time during the problem solving process (e.g., orientation and planning should precede calculation activities). Protocol analyses were performed by two judges who received no prior information about the subjects' level of intelligence. They performed the analyses together, arguing until agreement was reached. Although this method of protocol analysis lacks the possibility of assessing an inter judge reliability, it enables the judges to scrutinize their judgments mutually, which enhances reliability (Veenman & Elshout, 1995; Veenman et al., 1997). For the six protocols, each problem was judged on the quality of metacognitive skilfulness with regard to five subscales: orientation, systematical orderliness, accuracy, evaluation, and elaboration (roughly corresponding to the activities represented by SO-step 1–5; 6 and 7; 8–10; 11 and 12; and 13–15, respectively). It must be emphasized that metacognitive skilfulness was judged on the quality of performing regulatory activities, *not* on the correctness of information these activities produced. For instance, evaluating one's answer would contribute to one's evaluation score, even though the outcome of this evaluation might eventually prove to be wrong. Scores on each subscale ranged from 0 to 4. Mean scores were calculated over all problems, resulting in one PA score for each of the six participants. It should be noticed that in earlier studies with exactly the same procedures for assessing metacognitive skills (Veenman, in press; Veenman et al., 2000), convergent validity ($r = 0.78$, $N = 30$) was established by comparing protocol measures (PA) with behavioural ratings (SO).

Procedure

The paper-and-pencil intelligence test (GIT) was administered during class prior to the individual test sessions, which sessions took place in a quiet room at school. During individual sessions, each participant solved the six problems while thinking aloud. Firstly, three problems were solved without metacognitive hints. Next, the experimenter explained the content of the six metacognitive hints, which were presented on paper while solving the following three problems. Math GPA was gathered afterwards from administration files.

Results

Descriptives

The mean intelligence score was 99.10 (sd = 8.37). Mean scores for each of the 15 SO-activities are presented in Table 1. Further analyses were performed on the mean scores calculated over these 15 activities. Mean scores of learning performance are presented further below.

Metacognition

Quality of metacognitive skilfulness, judged from the thinking-aloud protocols (PA) of the six participants, correlated 0.89 ($p < 0.01$) with their corresponding overall observational measures (SO). Due to this convergent validity, further analyses could be performed on the observational data of all participants. A paired t-test contrasting the overall

Table 1. Means (and sd) for metacognitive activities on no-cue and cued problems. Significance of the difference between no-cue and cued problems

Activity	No-cue	Cued	One-tailed p-value
(1) Reading the problem statement	1.93 (0.12)	2.00 (0.00)	n.s.
(2) Selection of relevant data	1.11 (0.56)	1.67 (0.43)	$p < 0.001$
(3) What was asked for	0.05 (0.16)	0.27 (0.37)	$p < 0.001$
(4) Making a drawing	0.08 (0.26)	0.01 (0.05)	n.s.
(5) Estimating outcomes	0.02 (0.07)	0.24 (0.34)	$p < 0.001$
(6) Designing an action plan	0.95 (0.35)	1.28 (0.42)	$p < 0.001$
(7) Syst. carrying out such plan	0.70 (0.36)	0.79 (0.40)	n.s.
(8) Calculation correctness	0.87 (0.59)	0.97 (0.66)	n.s.
(9) Avoiding mistakes	0.67 (0.64)	0.90 (0.56)	$p < 0.01$
(10) Orderly note-taking	1.11 (0.69)	1.11 (0.65)	n.s.
(11) Monitoring the process	0.92 (0.66)	1.25 (0.66)	$p < 0.001$
(12) Checking the answer	0.53 (0.65)	0.73 (0.68)	$p < 0.04$
(13) Drawing a conclusion	1.53 (0.44)	1.52 (0.49)	n.s.
(14) Reflecting on the answer	0.03 (0.13)	0.14 (0.33)	$p < 0.02$
(15) Relating to earlier problems	0.14 (0.27)	0.27 (0.37)	$p < 0.04$

no-cue SO versus cued SO revealed a significant effect of cueing ($t = 5.55$, df = 40, $p < 0.001$). Mean scores started out with 10.63 (*sd* = 3.68) for the first three problems without cues, and ended up with 13.13 (sd = 3.84) for cued problems. If metacognitive activities are inspected more in detail, Table 1 shows that five out of six metacognitive activities (i.e., activities 2, 3, 6, 11, and 12) were enhanced by cueing, as was intended. Drawing a conclusion perhaps lacked such cueing effect as participants already spontaneously performed this activity without cueing (see Table 1). Moreover, cueing showed significant, though less profound indirect effects on the activities of estimating outcomes (5), avoiding negligent mistakes (6), reflecting on the answer (14), and relating to earlier problems (15).

Learning performance

A paired *t*-test contrasting no-cue versus cued performance revealed a significant effect of cueing ($t = 4.09$, df = 40, $p < 0.001$). Means were 0.41 (sd = 0.29) for no-cue items, and 0.68, (sd = 0.46) for cued items. In order to check whether this cueing effect on learning performance was not merely an expression of a general learning effect over the six problems, an additional testing procedure was adapted from Kazdin (1982). For each participant separately, a regression formula was calculated from the three no-cue scores of learning performance, which formula was used for the prediction of the participant's score on a hypothetical fourth no-cue problem. Finally, the predicted no-cue scores of all participants were compared to their actual scores on the fourth cued problem ($t = 4.04$, df = 40, $p < 0.001$). The mean score on the fourth cued problem (0.56, sd = 0.50) was significantly higher than the mean predicted no-cue score (0.19, sd = 0.22). In fact, the gradients of the regression lines for prediction of no-cue scores must have been slightly negative on the average. Therefore, the general learning explanation can be ruled out.

Correlational analyses

Correlations among intellectual ability, metacognition, and learning performance on the six problems were calculated for no-cue versus cued problems separately, as well as for Math GPA (see Table 2). Next, semi-partial correlations (Nunnally, 1967) were calculated by partialing intellectual ability from the correlations between metacognition and learning performance. These semi-partial correlations are indications of the unique contribution of metacognition to learning performance, independent of intellectual ability.

Results in Table 2, last column, clearly show that metacognition has its own virtue in predicting learning, independent of intellectual ability. Furthermore, for no-cue problems, correlations of intellectual ability with either metacognitive skilfulness or learning performance appeared to be rather low. Such low correlations were not found for cued problems and GPA measures. We will return to this issue in the discussion.

Using regression-analytic techniques for the partitioning of variance (Pedhazur, 1982), the unique and shared sources of variance in learning performance was subdivided for intellectual ability and metacognitive skilfulness. Firstly, the squared multiple correlation of intellectual ability and no-cue metacognition for predicting no-cue learning performance was calculated from the correlation between intelligence and learning and the semi-partial correlation of metacognitive skilfulness and learning presented in Table 2 ($R^2 = (0.17)^2 + (0.47)^2 = 0.25$). Apart from the semi-partial correlation between no-cue metacognition and learning performance with intellectual ability partialed from metacognition (0.47, see Table 2), the semi-partial correlation between intellectual ability and no-cue learning performance with no-cue metacognition partialed from intellectual ability ($r = 0.14$) was calculated. The proportion of variance shared by both predictors could be calculated by subtracting both squared semi-partial correlations from the squared multiple correlation (shared $r^2 = 0.25 - (0.47)^2 - (0.14)^2 = 0.009$). Consequently, it was estimated that for no-cue problems, intellectual ability uniquely accounted for 2.0% of the variance in learning performance, metacognition uniquely accounted for 22.1% of the variance, while both predictors had 0.9% of the variance in common.

Table 2. Correlations among intellectual ability, metacognition, and performance

	Intellectual ability	Metacognition	Semi-part meta[1]
Performance no-cue	0.17	0.48**	0.47**
Metacognition no-cue	0.06		
Performance cued	0.48**	0.61**	0.48**
Metacognition cued	0.33*		
GPA	0.50**	0.40**	0.30*
Metacognition overall	0.22		

$^{*}p < 0.05$.
$^{**}p < 0.01$.
[1] Semi-part meta means semi-partial correlation with intellectual ability partialed from the correlation between metacognition and performance.

Similarly, for cued problems, intellectual ability uniquely accounted for 9% of the variance in learning performance, metacognition uniquely accounted for 23% of the variance, while both predictors shared another 14% of variance. Finally, using the aggregated scores of metacognition on all problems for the prediction of GPA, intellectual ability uniquely accounted for 17.6% of the variance in GPA, metacognition uniquely accounted for 9% of the variance, while both predictors shared another 7.4% of variance.

Discussion

A major finding of the present study is that metacognitive cueing triggers a higher level of metacognitive activities that are explicitly addressed by such cues, as well as other metacognitive activities that implicitly prosper by cueing. Students apparently have certain metacognitive skills at their disposal, but these skills are merely initiated by a cueing procedure that reminds them of applying those skills. Consequently, most students are suffering from a production deficiency, rather than an availability deficiency. A simple cueing procedure may help them to overcome such a production deficiency (at least for math tasks in regular secondary education). Moreover, metacognitive cueing yielded better learning outcomes (cf. Muth, 1991). The results substantiated that this learning effect was not just a general effect of practice over the sequence of math tasks, as there appeared to be a clear disparity between performance on no-cue and cued problems.

With regard to the relation between intelligence and metacognitive skilfulness, all results disconfirm the intelligence model. Results on GPA and cued problems were in line with the mixed model. They clearly reflect that metacognitive skills have their own virtue in learning, partly independent of intellectual ability, even for young adolescents who are in an early stage of metacognitive skill development. Results obtained for no-cue problems, however, show very low correlations of intelligence with both metacognitive skilfulness and learning. Although a low correlation between intelligence and metacognition may be interpreted as evidence in favour of the independency model, none of the three models can account for the low correlation between intelligence and learning on no-cue problems. This finding needs a further explanation.

Elshout (1987), along with Raaheim (1988), introduced the notion of the threshold of problematicity. According to this theory, task novelty or task difficulty has an inverted U-shape relationship with the impact of intellectual ability on learning performance. Elshout (1987) argued that for every person there is a critical point on the task-complexity continuum, which he called the threshold of problematicity. Below the threshold smooth, internalized, and routine problem-solving activities may be observed (requiring little intellectual effort). Above this threshold, however, problem-solving behaviour with an increasing emphasis on weak domain-independent methods of search may be expected, because task-specific ability becomes increasingly inadequate. During the initial learning phase in a particular domain, learners are confronted with a task that is positioned above their threshold of problematicity. Unfamiliarity with this task or with the domain forces these learners to operate in a heuristic mode. There is, in fact, no material available for the cognitive toolbox to operate upon ('they cannot see the wood for the trees'). Research has shown that during this early learning phase, metacognitive skilfulness, rather than intelligence, initiates learning (Veenman & Elshout, 1999; Veenman et al., 2002). Metacognitive skills, such as carefully doing things step-by-step, help them to organise a complex task, thus reducing the burden on working memory.

This may have been the case while participants solved the no-cue problems, which problems were probably positioned beyond their manageable threshold of problematicity. This conclusion was not only supported by learning results, but also by remarks made in the verbal protocols (such as '1 cannot handle this', 'too difficult for me', and 'don't know how to do this'.) Most likely, metacognitive skills were not sufficiently automatised or embedded in this specific learning context in order to guarantee smooth performance. Solving a similar set of problems with metacognitive cues likely reduced working-memory load by reorganizing the problem representation and following a subsequent action plan, thus restoring the impact of intellectual resources on learning. Besides the evidence obtained from cued problems, this conclusion was also supported by the similar, more general pattern of correlations with GPA, which were in line with the mixed model.

The threshold of problematicity theory emphasizes that educators should present problems at an adequate level of skills available to students. A more advanced conclusion from the present study may be that educators should provide students with metacognitive cues in order to get the initial learning process started. Results show that the acquisition and attunement of metacognitive skills may be propelled by giving metacognitive cues during the initial acquisition of those skills. Additionally, they provide an opportunity for the investment of intellectual skills, after metacognitive skills reorganized the task. The emerging theoretical framework may be that (cued) metacognitive skills initially make a task manageable, while intellectual skills come in afterwards in order to operate more effectively upon the data gathered. In future research, this theoretical notion could be investigated with a between-subjects design of cued versus no-cued problems and a within-subjects, longitudinal measurement of both metacognitive skilfulness and math performance.

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