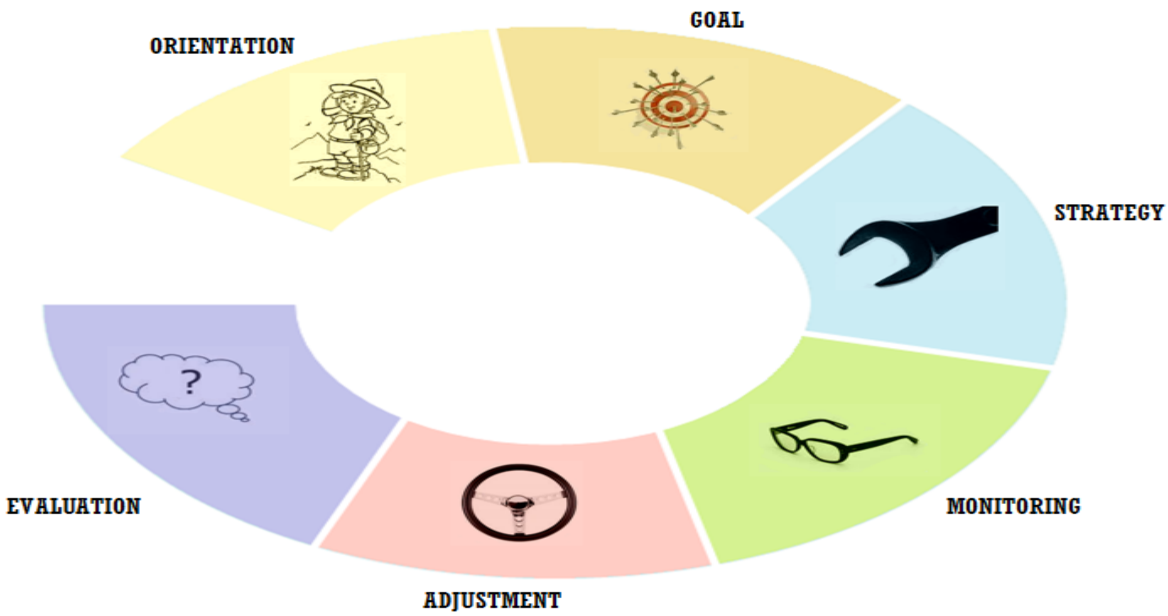
The influence of metacognitive questions on the learning process during mathematical tasks in teacher-student conversations: A design study



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Abstract

This design study examined to which extent posing metacognitive questions in teacher-student conversations led to improvement of the student's self-regulated learning. Therefore, the dynamic model of metacognitive skills (DMMS) was used as an educational tool. This model was developed to help weak mathematics students solve mathematical problems systematically through posing metacognitive questions (e.g., "What are you going to calculate?" and "How are you going to calculate it?"). Eight students with an average age of 16 and one teacher were involved in this study. The second lesson already made a difference: Students received less teacher guidance in the Dynamic Model condition than in the control group, which suggests that students in the first group showed more self-regulated learning.

1. Introduction

1.1 Metacognition, self-regulation, and self-regulated learning

In education, there is more and more attention for metacognition, self-regulation, and self-regulated learning. In literature many views and definitions of these terms can be found. Also, conceptual overlap between the three concepts is found frequently. However, all three concepts highlight different aspects (Dinsmore, Alexander & Loughlin, 2008). The concept metacognition was introduced by developmental psychologists who focused on a person's awareness of cognitive processes. Flavell (1979) defined metacognition as an individual's awareness and control of his own thinking processes and learning strategies. Whereas metacognition focuses on the awareness and control of thinking processes, self-regulation focuses on behavior, motivation, and cognition (Dinsmore et al., 2008). Zimmerman (1986) described self-regulation as the extent to which individuals are behaviorally, motivationally, and metacognitively proactive in their learning processes. The concept self-regulated learning focuses on academic learning while metacognition and self-regulation do not (Dinsmore et al., 2008). Zimmerman (1992) adds to his definition of self-regulation (Zimmerman, 1986) that by self-regulated learning a student sets goals, uses strategies to achieve these goals, and monitors the process in which the goals must be achieved. Zimmerman (1992) states that all learners regulate their learning process to some extent but self-regulated learners (1) are aware of the link between learning outcomes and regulatory processes and (2) use regulatory strategies to achieve academic goals (Zimmerman, 1990). The DMMS is based on the principles of self-regulated learning, and therefore, academic high school students were included in this study.

Hannafin, Land and Oliver (1999) emphasize that scaffolding of metacognition should have a prominent role in education. Scaffolding can take many forms, for example, cueing or the posing of metacognitive questions (e.g., "What is your goal?" and "What strategy do you use?"). Research shows that cueing a student to be metacognitive can help the student to improve his problem-solving skills (Conner, 2007; Kapa, 2001; Jacobs, 2004). For example, Kapa (2001) found that when students were cued during a task they became more successful in problem-solving activities than students who were cued only afterwards.

Many studies revealed that when a student's metacognitive knowledge and skills are improved, his learning outcomes improve as well (Thomas, 2003). Namely, when students are aware of their learning process they will get access to the development of their metacognitive strategies (Conner, 2007). Moreover, when students are self-guiding in their learning processes their skills improve and learners become independent learners (Zimmerman, 2002). Fortunately, in the recent years, teachers notice that it is natural to let students be responsible for their own learning processes (Tillema, Kessels & Meijers, 2000). Although there is some attention for metacognition, self-regulation, and self-regulated learning in education, several problems arise. Firstly, often students do not use metacognitive skills accurately during a problem-solving process and they do not learn these skills in education either. For example, unsuccessful students are not able to evaluate their answers critical enough. Consequently, they do not know they make mistakes (Garrett, Mazzocco & Baker, 2006). Secondly, more evidence is needed to show that posing metacognitive questions helps students acquire metacognitive skills and improves their learning outcomes. Also, there is insufficient evidence that metacognitive self-questioning (e.g., "What is my goal?") helps students to improve their metacognitive skills and learning outcomes. Thirdly, many studies focus on only a few metacognitive skills during a problem solving process (e.g., Osman & Hannafin, 1994; Grant, 2006; Garrett et al., 2006). However, it is necessary to involve all important metacognitive skills because when these skills are used accurately students can become self-regulated learners (Zimmerman, 2002).

1.2 Mathematical context

In this research posing questions will be a metacognitive scaffolding tool during mathematical problem solving tasks. Garrett and colleagues (2006) state that metacognition influences the way students perform their mathematical tasks. Namely, students must regulate the steps that are needed to achieve their goal. Successful mathematics students acquire successful problem-solving strategies themselves. However, weak students are not able to regulate their problem-solving processes and need help, for example, from teachers (Garrett et al., 2006). In the present study, weak mathematics students who attend individual mathematics lessons are included. The DMMS, which will be displayed later in this study, provided a systematic way of problem solving for mathematics tasks.

Conner (2007) claims that when students acquire metacognitive skills in certain contexts these skills can be beneficial in other contexts as well. Billing (2007) states that transfer of metacognitive strategies is enhanced when learners notice that problems resemble each other and when learners are expected to solve the problems themselves.

On the contrary, transfer is reduced when the tasks are very specific. In this study mathematical problems resemble each other.

1.3 Models with metacognitive skills

In this section, two models which include metacognitive skills are discussed. In both cases, these skills are used to solve a problem solving task systematically. Firstly, Zimmerman (2008) developed a micro-analytic methodology to assess self-regulated learning. He calls this model phases and sub processes of self-regulation. Three phases are presented in this model: the forethought phase, the performance phase, and the self-reflection phase. In each phase two central concepts occur which are explained in Figure 1. Next to this model, Zimmerman (2008) developed questions which can be answered while students solve mathematical problems. For example, self-efficacy was measured by the question "How sure are you that you will be able to solve this mathematical problem?"

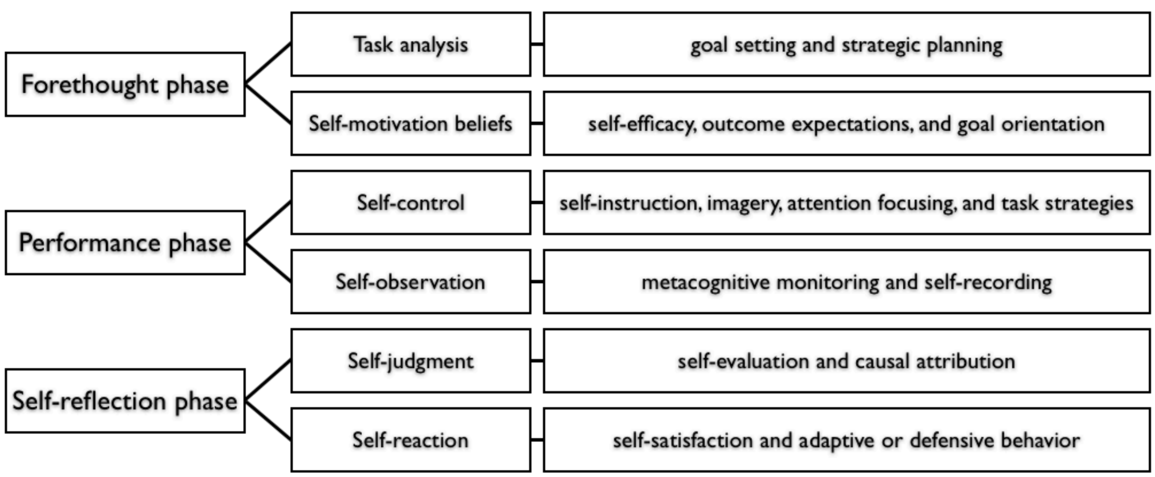

Figure 1. Phases and sub processes of self-regulation (Zimmerman, 2008).

Secondly, Dam and Vermunt (2003) developed a model (see Figure 2) with eight skills: (1) *orientation* (investigation of what needs to be done, activation of preknowledge), (2) *plan* (goal setting, action plan, and prediction of what the learning process will look like), (3) *monitoring* (the learner notices whether he goes in the right direction to achieve the goal) (4) *test* (investigation of whether the learning goal is accomplished), (5) *diagnosis*

Figure 2. Regulative learning activities (Dam & Vermunt, 2003).

(attribution of causation and identification of what needs to change), (6) *adjustment* (adaption of the strategy to accomplish the goal), (7) *evaluation* (judgment in the end of the learning process to see whether student has accomplished his learning goal and to what extent the learning process went as expected), and (8) *reflection* (thinking about the learning process, for example, about learning activities or experiences, and focus on what needs to be done in the future). According to Dam and Vermunt (2003) the eight skills described must be performed subsequently during a problem solving task.

In the models discussed above the authors describe series of metacognitive skills as a linear process in which the different steps must be taken in a specific order. On the contrary, Turner (2006) claims that in real life self-guidance is a non-linear process. She states, for example, that a self-guided learner does not monitor just once during a learning task, but continuously. Therefore, according to Turner (2006), the self-guidance process can be seen as a dynamic process.

1.4 Dynamic model of metacognitive skills

In the present study, the application of various metacognitive skills is seen as a dynamic process in which earlier phases can be revisited. A selection of metacognitive skills is made by the author and is integrated in the dynamic model of metacognitive skills (see Figure 3). This model consists of six phases: orientation, goal, strategy, monitoring, adjustment, and evaluation. Orientation is included because it is important for a student to know which task he is going to do and to connect his preknowledge to new knowledge (Dam & Vermunt, 2003; Osman & Hannafin, 1994). A goal gives the student a clear indication of what he should achieve during the problem solving task (Petterson, 2006). The student must choose a strategy because he should figure out how to do the task and in which sequence he must do certain things (Zimmerman, 2002). Monitoring is included in the model because the student must judge whether or not he goes in the right

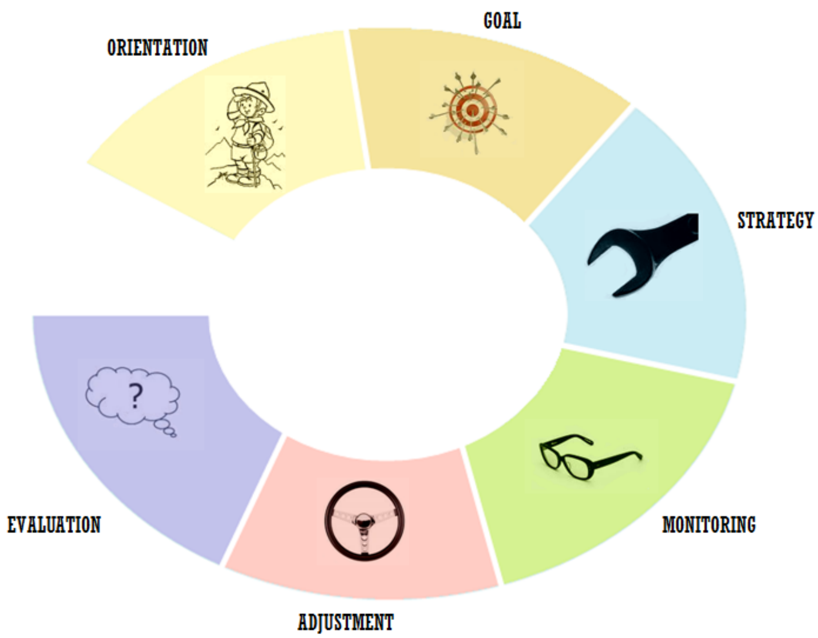

Figure 3. Dynamic model of metacognitive skills.

direction during the problem-solving process (Dam & Vermunt, 2003). If the goal is not reached yet, he can adjust one or more of the steps that were taken previously. Finally, evaluation gives the student an indication of whether or not his goal is accomplished by the end of the problem solving task and what he should do differently in the future.

Like Zimmerman's (2008) model, the DMMS consists of three phases: a pre-phase, an performance phase, and a post-phase (see Figure 4). In this case, the pre-phase includes orientation, goal setting, and strategy choosing; the performance phase consists of monitoring and adjustment; and the post-phase includes evaluation. But, in the DMMS the sub phases can be revisited, while in Zimmerman's (2008) model the phases need to be visited subsequently. Although he states that there is a specific order in which the student must go through the three phases, Zimmerman (2008) emphasizes that self-regulated learning involves a dynamic feedback loop. This means that a student needs personal feedback on his performance during a problem-solving task and that he goes through this process multiple times. In this study, students will solve multiple problems with the DMMS during teacher-student conversations.

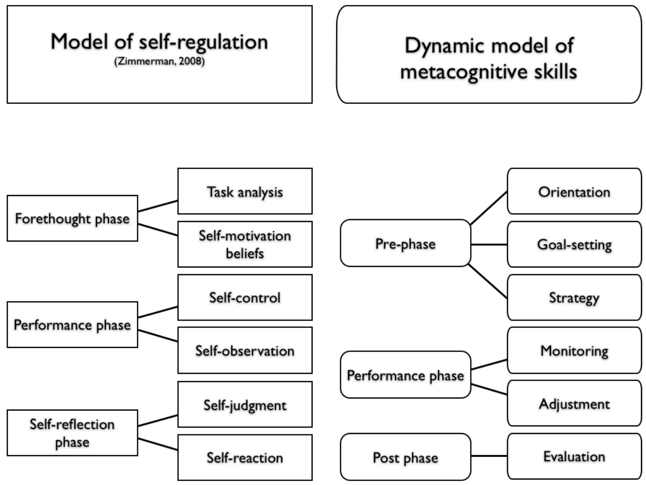

Figure 4. Phases of metacognitive skills: comparison of two models.

1.5 Feedback

Sadler (1989) describes feedback as information about how successfully someone has done or is doing something. Through feedback teachers as well as students can realize what the student's strengths and weaknesses are and then they can make performance improvement possible (Chase & Houmanfar, 2009). Premises for adequate feedback are that the student is able to adjust one's performance to the received information (Daniels, 1994; Sadler, 1989) and that a teacher not only lets the student know whether or not an answer is correct but also explains why (Bangert-Drowns, Kulik, Kulik & Morgan, 1991). Namely, when a student does not receive feedback when he is elaborating on reasons for success and failure, he may adopt the wrong strategy (Anseel, Lievens & Schollaert, 2009). Moreover, the use of metacognitive skills make feedback efficient (Anseel et al., 2009; Sadler, 1989; Kramarski & Zeichner, 2001). For example, Sadler (1989) states that monitoring the quality of one's performance is a premise to improve performance. Next, Anseel and colleagues (2009) showed that in a web-based work simulation the combination of feedback and reflection led to improvement of performance. When feedback was used without reflection there was less improvement and when reflection was used without feedback there was no improvement at all. In this research metacognitive feedback is provided by a teacher. Eventually, students will ask themselves questions and, if necessary, they will be corrected by teachers.

1.6 Questioning

Questions can play an important role in making a student's learning process more efficient. For example, questions can help students to: (1) activate their preknowledge (Osman & Hannafin, 1994), (2) enhance their understanding of the task (Kramarski & Zeichner, 2001), (3) enhance their understanding of the desired situation (Chase & Houmanfar, 2009), (4) improve their cognitive processes (Kaberman & Dori, 2009), (5) use metacognitive skills (Conner, 2007), and (6) enhance metacognitive skills (Taylor et al., 2002; Chi, Bassok, Lewis, Reimann & Glaser, 1989). During a problem-solving task questions can be posed by teachers or by students themselves through self-questioning. Taylor and colleagues (2002) describe self-questioning as a procedure in which students ask themselves questions about the text they read. In the present study, metacognitive questions will be used during teacher-student conversations in order to make improvement of metacognitive skills possible.

1.7 Research questions

This study investigates whether the use of the DMMS leads to more self-regulated learning of the student during individual mathematics lessons. Therefore, three research questions are provided. The first question is: *Does the use of the DMMS lead to less teacher guidance?* It is hypothesized that when students use metacognitive skills their self-regulated learning will be enhanced (Manning & Glasner, 1996). And, when self-regulation is enhanced teacher guidance becomes less frequent (Hannafin, Land & Oliver, 1999). The second research question is: *To what extent do students answer metacognitive questions?* It was hypothesized that when metacognitive questions are asked, metacognitive understanding is enhanced (Davey & McBride, 1986), and metacognitive skills are both used (Puntambekar, 1995) and enhanced (Taylor et al., 2002; Chi et al., 1989). The final question is: *What are the students' and teacher's perceptions concerning the working mechanisms of the DMMS?* For this question no hypothesis is provided because this part of the study was exploratory research.

2. Method

2.1 Participants

Eight students (1 male, 7 females) with an average age of 16 (*M* =16*, SD* =.53, *Min* =15*, Max* =17) and one mathematics teacher (male) were involved in the study. The students attended different academic high schools and, therefore, they had different subject-matter knowledge in their mathematics lessons. The students were in the fourth and fifth year of secondary school and in the preliminary years of university education in The Netherlands. They were randomly assigned by the researcher to groups of four and each group formed one condition (see Section 2.2). The research condition was heterogeneous and the other condition was homogeneous. All students were involved in individual mathematics lessons because they were weak students in this subject. None of the students was diagnosed with a learning disability.

2.2 Design

A longitudinal design study was conducted because it is likely that students need more than one training to improve their mathematical skills. There were two conditions: the Dynamic Model condition (*n* = 4) and the within-design condition (*n* = 4). By comparing these conditions it would become clear if students responded better to mathematics lessons when metacognitive questions were posed or when instructions were given only. Three measurements were taken during individual mathematics lessons in each condition (see Figure 5). Teacher-student conversations were registered on digital voice recorders.

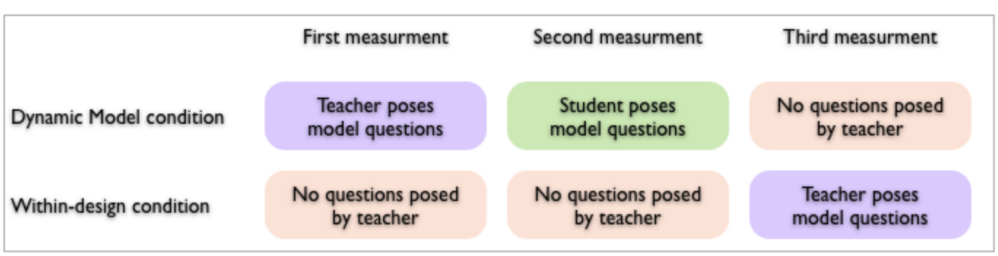

Figure 5. Overview of conditions and measurements.

In the first measurement of the Dynamic Model condition the DMMS (see Appendix 1) was presented to the student. The teacher asked the questions displayed on the DMMS. If the student did not know how to answer a question or if a wrong answer was given the teacher posed maximally two follow-up questions. Examples of such questions can be seen in Appendix 2. Next to the questions key terms were formulated on the model. Near every question a symbol was displayed because Mayer (1999) found that students solve problems in a better way when they can hold relevant verbal and visual representations in working memory simultaneously. The color of every phase (e.g., orientation) had its own color because there is evidence that the use of colors can increase retention (Pett & Wilson, 1996). In the second measurement the questions were removed from the DMMS (see Figure 1). The student tried to remember the questions and attempted to pose these questions through self-questioning. If the student could not remember a question the teacher posed the question. During the first two measurements the teacher corrected the student only if the student could not find an answer after three questions were posed.
In the third measurement the DMMS was removed entirely. The teacher did not pose any questions during the lesson and instructions were given only.

In the within-design condition also three measurements were included. In the first two measurements no questions were posed by the teacher but only instructions were given, like in the third measurement in the Dynamic Model condition. For example, the teacher would say: “Please, tell me what formula you are going to use” or “Use this formula.” The third measurement of this condition resembled the first measurement of the Dynamic Model condition. Semi-structured interviews were held in both conditions to verify the participants’ perception about the use of the DMMS (see Appendix 3).

2.3 Procedure

In every condition the teacher asked the student to think aloud in the beginning of and during the lesson. In this way, problem solving strategies can be made visible (Perez, Fleming Johnson & Emery, 1995). Each lesson was a 60-minute session. When the student made his first problem solving task he read this task aloud. In the Dynamic Model condition, the DMMS was presented to the student and the teacher made sure that the student understood the questions on the DMMS (see Appendix 1). In each lesson he emphasized that the student could revisit earlier phases on the DMMS if the student thought this was necessary. In the first measurement five problem solving tasks were made by the student with the model. The teacher read the DMMS questions aloud. If the student could not find an answer the teacher posed two follow-up questions before he corrected the student. When five tasks were made the teacher was free to use his own teaching strategy during the rest of the lesson. In the second measurement the DMMS was presented again but the questions were removed. Again, five problem solving tasks were made with the DMMS. The student tried to remember the questions and asked himself these questions. If the teacher noticed that the student did not remember a question or that the student posed a wrong question, the teacher posed the correct question. The student was, again, only corrected after three questions were posed. In the third measurement the DMMS was removed and the teacher did not pose questions anymore. The teacher gave the student the opportunity to solve the mathematical problem. When the student did not succeed the teacher corrected the student.

In the within-design condition the teacher posed no questions at all and only instructions were given to the student during the first two measurements. The teacher asked the student to read the problem solving task aloud. Then, the student tried to solve the problem. When a teacher normally would say: “Which formula do you use for this assignment?” he could, for example, say: “Please tell me what formula you use.” When the student gave an incorrect answer the teacher corrected the student immediately. The third measurement in the within-design condition resembled the first measurement in the Dynamic Model condition.

After taking three measurements in both conditions the teacher and the students were involved in semi-structured interviews (see Appendix 3). In these interviews stimulated recall was used to verify how the participants perceived the DMMS, how it was used, and what the students achieved. The interview questions were based on the last three stages of Kirschner’s (2002) six-stage model for the research of CSCL (Computer-

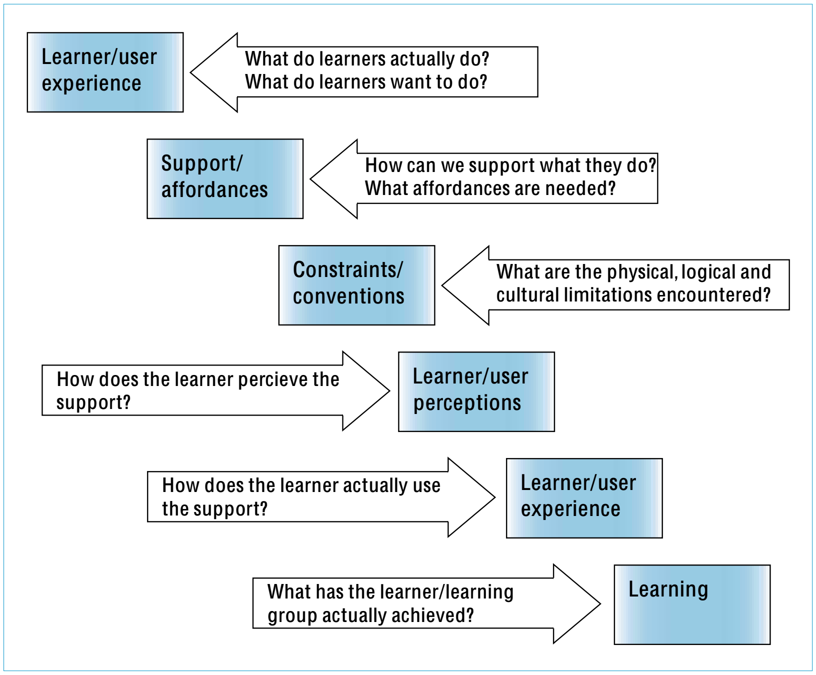

Figure 6. Six-stage model for research of CSCL-environments (Kirschner, 2002).

Supported Collaborative Learning)-environments. These stages discover how the participants perceive support, how they use it, and what they actually learn (see Figure 6).

2.4 Instruments

Teacher guidance. In this study teacher guidance was scored by counting the number of sentences in which instructions or corrections from the teacher were provided.

Model questions. The number of metacognitive questions which were displayed on the DMMS were scored as model questions. Also, when questions of this model were posed when the DMMS was not used these questions were scored in order to make a comparison between the two conditions possible.

Follow-up questions. The number of questions which followed the model questions were scored as follow-up questions.

Model answers. In all measurements the number of statements which were or could be an answer to model questions were encountered as model answers in order to

Table 1

Quality analysis of model answers.

Key word	Quality	Student's performance
Orientation	0	The right task and pre-knowledge are not made explicit
	1	The right task is made explicit
	2	Pre-knowledge is made explicit
	3	Both task and pre-knowledge are made explicit
Goal	0	No goal is formulated or the goal is inaccurate
	1	A clear goal is formulated
Strategy	0	There is no strategy defined or it is inaccurate
	1	A statement is made but no elaborated reasons are used
	2	One elaborated reason is used to support the statement
	3	Multiple elaborated reasons are used to support the statement
Monitoring	0	It is not made explicit how the student is doing or the idea is inaccurate
	1	A statement is made but no elaborated reasons are used
	2	One elaborated reason is used to support the statement
	3	Multiple elaborated reasons are used to support the statement
Adjustment	0	No adjustment is made explicit or the adjustment is inaccurate
	1	Adjustment is made explicit
	2	One elaborated reason is used to support the statement
	3	Multiple elaborated reasons are used to support the statement
Evaluation	0	No evaluative statements are used or the statements are inaccurate
	1	A statement is made but no elaborated reasons are used
	2	One elaborated reason is used to support the statement
	3	Multiple elaborated reasons are used to support the statement

compare both conditions. For example, if a student said: "I have to use this formula: ax+b" this was interpreted as a strategic model answer, also when the DMMS was not used in the lesson. Both the number of model answers per category (e.g., orientation) and their quality were analyzed. The scoring method for the model answer's quality is presented in Table 1.

Interviews. The goal of the interviews was to identify the working mechanisms of the DMMS. The students' perception about working with the DMMS and the reasons behind their opinion were verified (see Appendix 3). Students were asked for their opinion about each model question. Also, it was discovered whether they knew the reasons for the different phases displayed on the model. Students were asked if they used the model when they solved mathematics tasks individually and when they made tasks for other subjects than mathematics. Finally, students were asked if they preferred mathematics lessons with or without the DMMS and how they would improve the model if they had the opportunity. The teacher's perception about using the model was also verified and it was asked why he thought so. Next, the teacher was asked to make the goal of the DMMS clear in his own words and whether or not he supported this goal. The teacher's opinion about the usefulness of the model was verified. Finally, the teacher was asked if he thought the model added value to the educational setting, how he would improve the model, and why he thought that was necessary.

3. Results

3.1 Teacher guidance

An overview of teacher guidance in all measurements is shown in Table 2. A Mann-Whitney U-test revealed that less teacher guidance was provided in the Dynamic Model condition (M = 22.25, SD = 6.40) than in the within-design condition (M= 48.75, SD = 20.92, U(0), z -2.32, p =.02) in the second measurement. Also, less teacher guidance was provided in the third measurement of the Dynamic Model condition (M = 23.50, SD = 9.47, Min = 16, Max = 37), in which the model was removed, compared to the second measurement of the within-design condition (M = 48.75, SD = 20.92, Min = 31, Max = 77, U(2), p =.08). A Friedman test showed no differences concerning teacher guidance in all measurements within the Dynamic Model condition ($\chi^2(2)$ =.50, p =.78) and within the within-design condition ($\chi^2(2)$ =.50, p =.78).

3.2 Quantity of model answers

In the condition in which the DMMS was used participants gave more model answers than in the other condition. A Mann Whitney U-test showed that students in the Dynamic Model condition (M = 44.50, SD = 9.47) gave more model answers than the within-

Table 2
Means and standard deviations for two conditions concerning teacher guidance.

		Lesson 1		Lesson 2		Lesson 3	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dynamic Model condition	4	24.00	10.07	22.25	6.40	23.50	9.47
Within-design condition	4	36.75	10.31	48.75	20.92	44.00	29.36

Table 3
Model questions, model answers, and follow-up questions.

Condition	T	Model questions				Follow-up questions		Model answers	
		Teacher		Student		Teacher		Student	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
DM	1	21.75	10.47	3.00	2.58	11.00	7.74	44.50	9.47
	2	14.00	10.80	10.00	10.39	9.00	4.55	39.50	1.00
	3	0.00	0.00	2.25	1.50	0.00	0.00	12.50	9.11
WD	1	0.00	0.00	1.50	2.38	0.00	0.00	15.00	3.83
	2	0.00	0.00	1.25	0.96	0.00	0.00	11.50	8.35
	3	35.75	3.86	2.50	3.11	12.75	4.92	53.75	3.30

design group (M = 15, SD = 3.83) in the first measurement (U(0), z -2.32, p =.02) (see Table 3). In the second measurement the Dynamic Model condition (M = 39.50, SD = 1.00) scored higher than the within-design condition (M = 11.50, SD = 8.35, U(0), z -2.37, p =.02) as well. The within-design condition (M = 53.75, SD = 3.30) scored higher than the Dynamic Model condition (M = 12.50, SD = 9.11) in the third measurement (U(0), z -2.32, p =.02).

The Friedman test showed that there was a difference within groups in both conditions (DM condition, $\chi^2(2)$ = 6.5, p =.04, WD condition, $\chi^2(2)$ = 6, p =.05). A post-hoc test, namely, the Wilcoxon Signed Ranks test, showed that participants in the Dynamic Model condition gave more model answers in the first lesson (M = 44.50, SD = 9.47) than in the third lesson (M = 12.50, SD =9.11, W = 0, z -1.83, p = .07) and more in the second lesson (M = 39.50, SD =1.00) than in the third lesson (M = 12.50, SD =9.11, W = 0, z -1.83, p =.07). In the Within-design condition students gave more model answers in the last lesson (M =53.75, SD = 3.30) than in the first (M= 15.00, SD =3.83, W = 0, z -1.83, p =.07). Also, in the last lesson (M =53.75, SD = 3.30) they gave more model answers than in the second lesson (M =11.50, SD = 8.35, W = 0, z -1.83, p =.07).

3.3 Quality of model answers

An overview of the model answers's quality can be seen in Table 4. In the next section, the model answers will be discussed per metacognitive phase.

Orientation. A Mann-Whitney U test showed that participants scored higher in the condition in which the model was used concerning orientation quality (t_1, U(0),

z -2.46, p =.03; t_2, U(0), z -2.37, p =.03). A Friedman test showed that differences were found within the Dynamic Model condition ($\chi^2(2)$ = 6.50, p =.04). The quality was higher in the first lesson than in the third lesson (W = 0, z -1.83, p =.07) and in the second lesson the quality was higher than in the third lesson (W = 0, z -1.83, p =.07). A Friedman test showed a difference within groups in the within-design condition ($\chi^2(2)$ = 7.54, p =.02) as well. The orientation quality was higher in the third measurement than in the first (W = 0, z -2.00, p =.05) and it was also higher in the third measurement than in the second (W = 0, z -1.89, p =.06).

Goal. The condition in which the DMMS was used scored always higher concerning goal quality (t_1, U(0) p =.01; t_2, U(0), p =.01; t_3, U(0), p =.01). Friedman's test showed that there were differences found within the Dynamic Model condition ($\chi^2(2)$ = 6.53, p =.04). Students scored higher in the first lesson than in the third (W = 0, z -1.84, p =.07) and they scored higher in the second lesson than in the third (W = 0, z-1.89, p =.06). There were also differences found in the within-design condition ($\chi^2(2)$ = 8, p =.02). Students showed higher goal quality in the third lesson than in the first (W = 0, z-1.89, p =.06) and a higher quality was observed in the third lesson compared to the second lesson (W = 0, z-1.89, p =.06).

Strategy. No differences were found between groups concerning strategy quality (t_1, U(6), z -.58, p =.56; t_2, U(4.5), z -1.02, p =.31; t_3, U(3.5), z -1.31, p =.19). Within groups there were differences found in the Dynamic Model condition ($\chi^2(2)$ = 6, p =.05) only. In the first lesson students showed a higher strategy quality than in the second

Table 4
Quality of model answers.

N	Condition	Orientation			Goal			Strategy			Monitoring			Adjustment			Evaluation		
		t_1	t_2	t_3	t_1	t_2	t_3	t_1	t_2	t_3	t_1	t_2	t_3	t_1	t_2	t_3	t_1	t_2	t_3
1	DM	6	4	0	5	4	0	21	16	7	6	9	0	2	3	0	8	4	0
2	DM	9	14	0	4	4	0	9	5	6	5	6	3	8	7	1	5	5	0
3	DM	14	11	0	3	4	0	9	6	4	4	5	3	5	2	0	3	5	0
4	DM	8	7	0	4	5	0	28	11	17	6	5	6	13	3	5	5	4	0
5	WD	0	0	13	0	0	4	17	22	10	0	1	5	0	0	6	0	0	5
6	WD	0	0	13	0	0	4	16	4	17	2	1	7	1	0	11	0	0	6
7	WD	0	1	13	0	0	5	7	4	14	6	1	7	1	1	1	0	0	6
8	WD	0	0	13	0	0	4	13	5	15	0	1	7	0	4	5	0	0	6

lesson ($W = 0$, z -1.83, p =.07) and they scored higher in the first than in the third lesson ($W = 0$, z -1.83, p =.07).

Monitoring. In the second measurement more monitoring quality was shown in the Dynamic Model condition ($U(0)$, p =.01) than in the within-design condition. The Friedman test did not discover any differences within the Dynamic Model condition ($\chi^2(2) = 2.8$, p =.25). However, within the within-design condition differences were found ($\chi^2(2) = 6$, p =.05). In the third lesson students scored higher compared to the first lesson ($W = 0$, z -1.84, p =.07) and in the third lesson they scored higher than in the second lesson ($W = 0$, z -1.89, p =.06).

Adjustment. Participants showed higher adjustment quality in the Dynamic Model condition than in the within-design condition during the first measurement ($U(1)$, z -1.76, p =.04). In the third lesson the within-design condition scored higher than the Dynamic Model condition ($U(2)$, z -1.76, p =.08). Furthermore, no differences were found.

Evaluation. The evaluation quality was always higher in the group with the DMMS than in the group without it (t_1, $U(0)$, z -2.48, p =.01; t_2, $U(0)$, z -2.49, p =.01; t_3, $U(0)$, z -2.53, p =.01). Differences within both groups were found (DM condition, $\chi^2(2)$ = 6.5, p =.04; WD condition, $\chi^2(2) = 8$, p =.02). Students in the Dynamic Model condition scored higher in lesson 1 than in lesson 3 (W =0, z -1.84, p =.07) and higher in lesson 2 than in lesson 3 ($W = 0$, z -1.86, p =.06). Students in the within-design condition scored higher in the third lesson than in the first ($W = 0$, z -1.89, p =.06) and higher in the third lesson than in the second ($W = 0$, z -1.89, p =.06). The inter-rater reliability of the measurements was substantial (Cohen's $\varkappa$ =.71).

3.4 Interviews with the students

The interviews showed how students perceived the DMMS, how they used it and what they thought they had achieved. 87,5% of the students said that working with the DMMS was a suitable way to solve mathematics tasks. According to them, it was a structured way to solve the mathematics problems where the students had less structure in their minds. It helped them to look at their problem solving process, for example, what they actually did to solve the problem, and what they would do differently in the future. The model was considered unnecessary by one student, even though this student made clear she found some model questions useful.

The goals of the questions were clear to all students. The students' opinions about the model questions were diverse. In the orientation phase the question “Which assignment do you have to make?” was considered unuseful by 75% of the students. They found that they already answered this question automatically. The other students stated that it was useful for them to think about which assignment they had to make because they had the tendency to be disorganized and make the wrong assignments. All students found the question “What do you know about the subject?” useful because it gave them the opportunity to think about what they already knew and how they could build on their preknowledge. Two students said that answering this question made it easier to come to a strategy. During the goal phase students found the question “What are you going to calculate?” useful because answering this question helped students to read accurately, become aware of the goal of the mathematics task, and remember their goal during the whole assignment. In the strategy phase the students considered the question “How are you going to calculate it?” useful. They pointed out it was necessary to be aware of how they had to calculate the task and it helped them to think before they acted. One student said that answering this question made it possible to make the calculation without asking herself how she had to it during the calculation itself. She had more room for her other thinking processes than she was used to. The other question in the strategy phase “Which formula do you use?” was sometimes considered useless by students because they did not work with formulas during every mathematics task. Also, the word 'calculate' was sometimes found inaccurate for the mathematics task. 75% of the students found the monitoring phase question “How is it going?” useless. They said that they answered this question automatically in their minds. 25% of the students thought that the question was useful because they could look back on what they did in the problem solving process thus far and see if they were satisfied with it. The question “How can you do it right?” in the adjustment phase was considered useful by all students. They said it was helpful to think about what they could do differently. For example, a student mentioned that it was good to learn from her mistakes and that it made her able to solve a similar mathematics problem faster in the future. In the evaluation phase the three model questions were useful according to students because it helped them to look back on the process, judge whether or not they performed well, and learn from their performances.

Four students stated that they preferred to work with the model in a mathematics lesson because the model’s structure helped them to solve mathematical problems in small steps. Two students said that they preferred working with the model only when they made mathematics tasks individually because in a mathematics lesson the teacher could help the students with the task. Two students preferred to work without the model: One student because she claimed that she had all phases of the model in mind and the other student because she thought it took too much time to use the model. Besides, the students claimed that the model's format with pictures, colors, and words was helpful to them because they could remember the questions more easily.

Students had various ideas of how the DMMS should be improved. Three students stated that the orientation phase and the goal phase should be integrated because they thought the answers on these questions were alike. Two students said it would be better to remove the question “Which assignment do you have to make?” because they answered this question automatically. One student wanted the question “What would you do differently in the future?” to be removed. Another student pleaded for adding a question to the strategy phase: “Which ways are there to calculate it and which way are you going to choose?” This student suggested that arrows should be added in the model in order to visualize that a student can go back to an earlier phase.

After the research was conducted students were asked if they still used the DMMS when they made mathematics tasks individually. This was not part of the research program. Students appeared to be using the model after the research program, especially the phases which did not occur automatically in their own problem solving processes. For example, one student said she used the orientation questions in order to make the right assignments for homework and not confuse them. Another student said to be more aware of the different steps to solve a mathematics problem and she preferred to work with the model because she needed more structure in her problem solving process. However, another student said the model added value for her mathematics skills but she experienced the training time, namely, two measurements, as not enough time to learn the skills accurately. 62,5% of the students used the DMMS also during problem solving tasks by other subjects, for example, economics, science, and history. Apparently, these students were able to transfer.

3.5 Interview with the teacher

The teacher stated that it was not easy to implement the DMMS into his educational practice. This way of teaching was quite another way than he was used to, and therefore, it took time for him to adapt. He thought this model had little added value for the mathematics lessons because he had to follow the model strictly and sometimes could not say what he normally would have said. However, he thought that the model would have more added value when students would work with it on an individual basis because it would help them to structure their thinking about solving the mathematics problem. According to him, the goal of the model was that students could ask themselves the model questions, eventually without the model. He supported this goal and told that he did not have his own teaching strategy to reach this goal.

The teacher agreed with some students that the question “Which assignment do you have to make?” was unnecessary, although he also stated that this question was a clear beginning for solving a mathematical problem. The orientation question about preknowledge was useful, although it sometimes was boring to ask this question five times in a lesson with the same mathematics subject. The questions in the goal and strategy phase were considered as useful. However, he claimed that in the strategy phase the question “Which formula are you going to use?” sometimes was irrelevant. He suggested other questions, for example, “Do you need a formula?”, “Which data do you need?” and “What is important in this story?” The monitoring question was a problem.

According to the teacher it was unnatural to ask this question in the middle of the problem solving process because he, and sometimes the student, monitored the student's performance. In practice, this question was posed when the problem was already solved, and therefore, the character of this question became evaluative. In the adjustment phase the same problem arised. Besides, the students answered that there was nothing to improve. The teacher attributed this to the fact that students already solved the problem with the teacher, thus, there was nothing left to improve. However, he claimed these questions were useful in a setting in which the student would work individually because the phases can help the student to verify what goes wrong and right, whether or not the student must seek help, and what the student should do differently in the middle of the problem solving process. He claimed that in the evaluation phase students were content only because the task was done. Then their goal was attained. Indeed, results show that the quality and accuracy of the evaluation answers was low.

The teacher claimed that there are several premises for a successful use of the model. Firstly, a task needs to be complicated for the student. Secondly, there needs to be a calculation in the mathematics task. Thirdly, students are not able to make the steps in the model themselves. He stated that the model should be used when students solve mathematics tasks individually because a teacher has the task to provide small steps for the students: Sometimes a teacher might find it useful to provide other steps than the DMMS provides. According to the teacher the evaluation question “Did you accomplish your goal?” should be removed from the model. To improve the model the evaluation questions should be replaced by a general question like: “How was it going?” or “What did you do during the problem solving process?”

4. Discussion

The aim of this study was to examine whether the use of the DMMS during mathematics lessons led to more self-regulated learning by the student. The working mechanisms of this newly designed model were verified and how the participants used the model was investigated. The first research question examined whether the use of the DMMS led to less teacher guidance. As expected, students in the Dynamic Model condition received less teacher guidance than the students in the within-design condition. This happened after one lesson. The second research question verified to what extent students answered metacognitive questions in both conditions. As hypothesized, students gave more model answers in the condition in which the DMMS was used than in the other condition. Also, the quality of model answers was higher in the condition in which the DMMS was used concerning orientation, goal, and evaluation quality.

However, some results were not expected beforehand. Firstly, it was expected that less teacher guidance would be provided in the Dynamic Model condition than in the within-design condition in the first measurement as well, but, this was not the case. This may be because the teacher did not pose all DMMS questions. Another explanation can be that students need to be trained to acquire metacognitive skills and that one training is not enough to enhance these skills significantly. It may take time to understand the new educational tool and work with it effectively. Secondly, it was expected that in the within-design condition less teacher guidance was needed than in earlier measurements in the same condition. However, no difference was found. Like in the other condition, one training may be insufficient to enhance metacognitive skills. Thirdly, it was expected that the condition in which the DMMS was used would score higher concerning all quality answers. The Dynamic Model condition scored higher in one measurement only concerning monitoring and adjustment quality. Besides, no differences were found between groups concerning strategy quality. This might be because students in the control group are already used to make strategy and monitoring statements in their problem solving processes and adjustment was not always necessary.

During the measurements a remarkable event occurred. It appeared that the teacher sometimes used a metacognitive cue instead of a model question. For example, he said: “The green part.” Then, the student answered the question, in this case the monitoring question, while the question was not posed. Thus, teacher's remark was a meaningful metacognitive cue for the student. These cues were scored as model questions.

The third research question investigated the participants' perceptions concerning the working mechanisms of the DMMS. 87.5 percent of the students claimed that working with the DMMS was a positive experience for them: They mentioned that the model provided a structured way to solve the mathematical problems. Most of the model questions were considered useful. However, the usefulness of the monitoring and adjustment phase was complicated because these phases were worked through after a mathematical problem was solved instead of during the problem solving process. This caused these phases to blend with the evaluative phase. The teacher claimed that when students would do mathematical tasks individually the model would be more useful because there would be no teacher to help the students monitor and adjust. He considered most questions useful for the student.

It appears that there are several premises for a successful implementation of the current model: (1) the mathematical task must be complex for students, thus, they are not able to solve the mathematics problem immediately, and (2) students do not posses the metacognitive skills in the DMMS yet. Presumably, the working mechanisms in this model were the orientation phase and the goal phase. Students stated that it was useful to be aware of their preknowledge and build on that during the mathematical task. Other researchers also found that high-level orienting questions help students to activate preknowledge and induce selection of information, knowledge integration, and application (Osman & Hannafin, 1994). Besides, students claimed that it was important to have the goal of the task in mind before they started to calculate. Research supports that when students set goals with the intent to comprehend information deeply he tends to be successful in his academic performance (Coutinho, 2007). All students agreed that these phases were causing them to think about the mathematical task first before they acted. One of the students said: "Orientation and goal-setting help me to come to a better strategy."

In this study, several limitations are visible. It must be noted that the scoring of the quality analysis might suggest that the model answers' quality was above the minimum level. In fact, most of the model answers had a low quality, especially in the evaluation phase. However, in the orientation phase often level 3, the highest quality, was seen in the conditions in which the model was used. Also, results cannot be generalized because of the small number of participants. However, this study aimed to discover how students and a teacher perceived the model and how they used it. The model worked well in this group, and therefore, this research is a starting point for future research.

5. Implications

5.1 Future research

Firstly, in future studies more participants are needed in order to generalize the results. Secondly, it can be discovered for which reasons students need less teacher guidance when the model is used. Namely, it is possible that students might need more than two trainings with the model before students can go through the metacognitive phases automatically and a positive effect remains visible. It is also possible that students need to keep making their metacognitive thoughts explicit to the teacher in order for the teacher to know to which extent he should guide the student. For example, in the first situation, more than two measurements could be conducted before the model is removed in the Dynamic Model condition. In the other situation, the model should not be removed at all and students need to keep answering the model questions aloud. Thirdly, it is interesting to find out if students who only receive instructions in mathematics lessons become more passive overtime. In this research no significant differences were found concerning teacher guidance between the first two measurements of the within-design condition, but, the mean was higher in the second measurement than in the first. This pattern might continue overtime and may be significant after multiple measurements. Fourthly, model answers were often not accurate in the monitoring, goal, and evaluation phase. It would be interesting to discover if the student would show more self-regulated learning when the teacher would ask follow-up questions or would correct model answers in order to let the student acquire the metacognitive skills. Fifthly, in this study students were attending the highest educational level of high school in The Netherlands. It can be examined whether students with a lower educational level also profit from the DMMS. Sixthly, it will be interesting to know if the DMMS can also be applied in other domains than mathematics. Finally, it will be helpful to investigate how people can learn to pose the right metacognitive questions for their specific domain in which problems need to be solved.

5.2 Improvement of the DMMS

The model can be used in various settings, namely, in mathematics lessons and when students work individually on mathematics tasks. In the first case, the monitoring and adjustment phase should be removed from the model because, in practice, it seems impossible to ask these model questions in the middle of the problem solving process. In the second case, the model should contain the current phases. In general, the question "Are you content?" in the evaluation phase should be removed because it did not help students to look back on their learning process. Instead, it is suggested to add the question "What did you do to come to your final answer?" In both cases, the words 'calculation' and 'formula' should be removed because a mathematics task does not always contain these elements. Instead, the question "How are going to make the assignment?" should be posed in the strategy phase. Also, it should be visible in the model that students can go back to earlier phases by visible cues, for example, arrows. These changes are based on the students' and the teacher's opinions.

In this research the DMMS appeared to be a useful educational tool for students. The model helps students to solve problems in a systematical way. Students even applied the model in other subjects, although this was not a formal part of the research. The DMMS is therefore a promising educational tool for the future.

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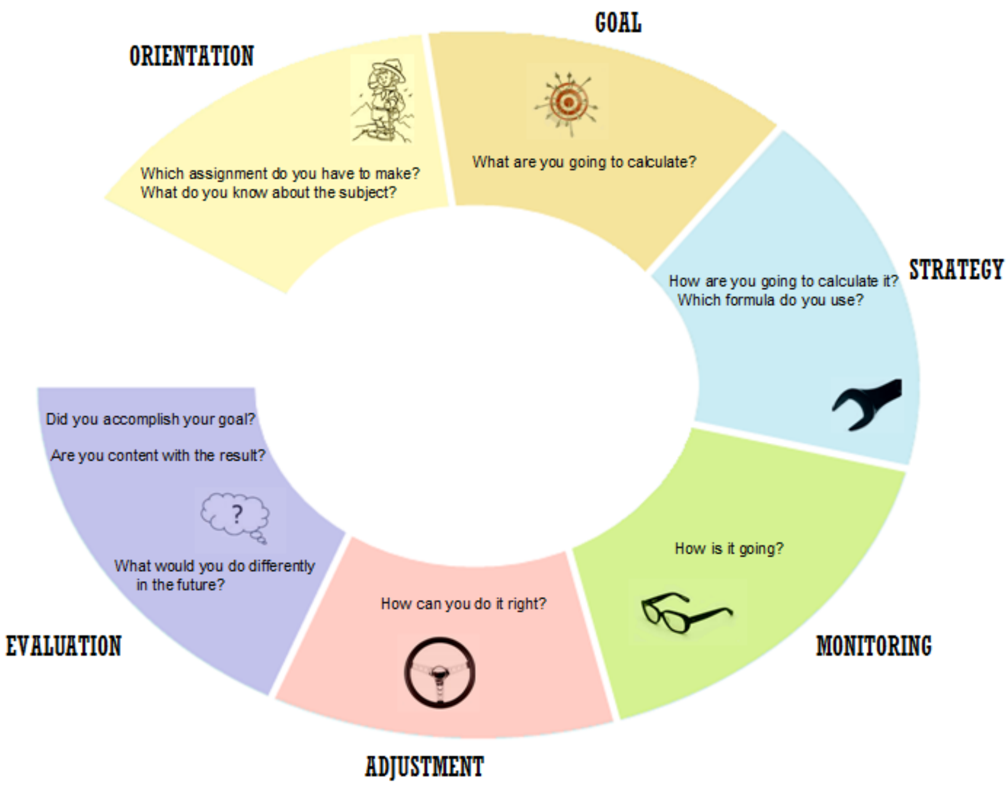
Appendix 1: Dynamic Model of Metacognitive Skills during the First Measurement



Appendix 2: Follow-Up Questions

Orientation	How can you find out what you must do?
	Can something or someone help you find it?
Goal	What is the purpose of the task?
	What can you do if you don't know?
Strategy	What comes in your mind first?
	Can you think of different ways to solve the problem?
Monitoring	What is going well?
	What is going wrong?
Adjustment	What are you going to do differently?
	How are you going to change your behavior?
Evaluation	Did you calculate what you wanted to calculate?
	Do you think you did it the right way?
	When you will be going to do a task that is very much alike, what would you focus on?

Appendix 3: Semi-structured interviews for teachers and students.

Questions for the students

1. What is your opinion about working with the DMMS? Why do you think so?
2. Did the DMMS add value to your mathematics lesson? Why?
3. What do you think of the questions that are posed on the DMMS? Why?
    a. Are they useful for you?
4. Do you know the reasons for the different phases on the DMMS? If yes, what are the reasons?
5. Do you use the questions from the DMMS when you solve mathematics tasks by yourself?
6. Do you use the questions from the DMMS for other subjects than mathematics?
7. If you compare the lessons with and without DMMS, what do you prefer? Why?
8. If you would have the opportunity to improve the DMMS, how would you improve it? Why?

Questions for the teacher

1. What is your opinion about working with the DMMS? Why do you think so?
2. What was the goal of the DMMS?
3. Do you support this goal?
4. Do you have another way to reach this goal?
5. To what extent is the DMMS useful for students? Why?
    a. In which cases do you think the DMMS is useful?
    b. Was the DMMS complete? Did you miss elements or were there unnecessary elements?
6. Do you think this DMMS can add value to an educational setting?
7. If you would have the opportunity to improve the DMMS, how would you improve it? Why?