Chapter 27
Metacognitive Strategies in Group Work in Mathematical Modelling Activities – The Students' Perspective

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Abstract Metacognitive competency can be described as a sub-competence of mathematical modelling competence. Although there is consensus about its relevance, until now research on metacognition in modelling processes is very limited. In particular, students' perspective on metacognitive competencies has not been examined yet. The present study aims at investigating students' perception of metacognition in modelling processes. Fourteen groups of students were interviewed at the beginning and at the end of a teaching unit. The results presented in the paper focus on one group, who used extensively, at the end of the study, cognitive strategies and skills showing a sense of direction in the formulation phase of the modelling process as an indicator of metacognitive strategies.

Keywords Cognitive strategies · Metacognition · Metacognitive strategies · Metacognitive knowledge · Metacognitive skills · Modelling problems · Monitoring · Planning · Regulating

27.1 Introduction

Based on the discussion of how to conceptualise modelling competencies (cf. Kaiser and Brand 2015), one of the main research aims in mathematical modelling in recent years was to investigate how to foster students' modelling competencies (for an overview, see Greefrath and Vorhölter (2016)). The overall modelling competence includes a metacognitive facet, which has been often neglected in past

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research, although there is a strong consensus about its relevance (Blum 2015). For example, students use metacognitive strategies in order to transit between stages in the modelling process and to identify and overcome cognitive barriers (Stillman 2011). However, until now the promotion of students' metacognitive modelling competencies has not been investigated in depth. As the usage of metacognition only takes place, if students are convinced of the benefits of it, it is necessary to survey students' perception of metacognition before fostering metacognition.

In this paper, we present first results of a research study, which examines the students' perspective on their metacognitive competencies within a cooperative working environment during modelling activities. Due to space restrictions we focus on one group of students and their metacognitive development.

27.2 Theoretical Framework

27.2.1 The Concept of Metacognition

The concept of metacognition was already introduced by Flavell (1979) and Brown (1978) in the 1970s (for details, see overview by Veenman (2011)). Despite this early work, no consistent definition of metacognition in the current discussion can be identified. However, the distinction between metacognitive knowledge (declarative and conditional knowledge) and metacognitive skills (procedural metacognition, metacognitive strategies and skills) is widely accepted (Veenman 2011). Besides, a third component is often included, which comprises metacognitive experiences and an appropriate attitude (Efklides 2008). Therefore, in this study, the following definition of metacognition is used, since this definition focuses on performance rather than knowledge:

> Metacognition is generally understood as knowledge, skills, and attitudes that are available, necessary, or helpful in order to initiate, organise, and control (implicit as well as explicit) processes of strategic decisions for learning or thinking. (Weinert 1994, p. 193, translated by the authors)

We further assume in accordance with Efklides (2008) that parts of metacognition not only take place on a conscious level, but using metacognitive strategies is sometimes an unconscious process. Thus, like Hartman (2001) in the following, we will distinguish linguistically between *metacognitive strategies*, which need to be applied consciously, and *metacognitive skills*, which often run automatically in the background and therefore are not necessarily conscious. Correspondingly, we will talk about metacognitive strategies, as the students themselves comment on the use of this strategies, which means that they are aware of the strategies or have at least become aware of them afterwards.

In addition, in modelling processes, not only metacognitive competencies of single students but also social metacognition relating to the whole group has to be considered (Goos and Galbraith 1996[1]). Besides, there are general metacognitive skills that can be transferred to different domains, and a personal repertoire of metacognitive strategies can be distinguished (Veenman 2011). However, the benefit of particular strategies may vary in different contexts. Furthermore, task-specific metacognitive knowledge depends on the nature of the task. In the following, we will elaborate on metacognition in modelling processes.

27.2.2 Metacognition in Modelling Processes

In the last decades, it became obvious that there are different perspectives on mathematical modelling that have an influence on the modelling problems chosen for reaching the connected aims. For working on the modelling problems we use in our studies (see, for example, Vorhölter (2019)), students have to develop their *own approach autonomously*. The modelling problems are solvable with *different mathematical procedures*, which had not necessarily been content of the lessons immediately before. The data required for solving the problem with the help of the developed model had to be researched (e.g., on the internet), judged or calculated. This description reveals that the handling of these tasks is demanding. Thus, metacognitive strategies can be helpful.

Referring to the general metacognitive competence, metacognitive modelling competencies can be divided into metacognitive knowledge and metacognitive strategies. Since the focus of this paper is on metacognitive strategies, metacognitive knowledge will not be considered in more detail in the following. Metacognitive strategies are composed of the following:

- *Strategies for planning* the solution process considering the task that has to be worked on, the group members involved and specific circumstances. Planning strategies can be identified, when cognitive strategies are used purposefully, for example, rereading the text, brainstorming, identifying missing information, separating relevant from irrelevant information as well as agreeing on a common understanding.
- *Strategies for monitoring* and, if necessary, regulating the working process, which can be realised, for example, by using the modelling cycle as a tool. Identifying cognitive barriers and seeking help by, for example, asking the teacher and classmates or researching on the internet are indicators for monitoring strategies and regulation strategies.
- *Strategies for evaluating* the work in order to improve the modelling process. Indicators for using strategies to evaluate the work are questions and statements about unsuccessful group work or personal involvement in the group work.

[1] For a short overview about the usage of metacognitive strategies in groups while working on modelling problems, see Vorhölter (2019).

Referring to Goos (1998), Stillman (2011) describes the usage of students' metacognitive strategies during modelling activities while experiencing difficulties. She also identifies different types of productive metacognitive acts and non-productive metacognitive acts during mathematical modelling. Therefore, the aim of the usage of metacognition is gaining a sense of direction, especially in the model formulation phase (Treilibs 1979) and not losing track of one's own approach.

27.2.3 Empirical Research Results of Metacognition in Modelling

Research on metacognition in modelling is at its beginning. However, there exists comprehensive research on metacognition in problem-solving processes and in mathematics education in general (for an overview, see Desoete and Veenman (2006), Schneider and Artelt (2010)). In the following, we will limit the presentation of research results to the field of modelling.

In her study, Maaß (2006) analysed the metacognitive modelling knowledge of students. She demonstrated that their knowledge of the modelling process as part of the metacognitive knowledge increased in the course of the study. In addition, she could reconstruct misconceptions about the students' modelling processes and a connection between metacognitive knowledge and modelling competence; that is, due to missing or low meta-knowledge about the modelling process, problems could arise while working on modelling problems.

In her studies, Stillman (2004, 2011) focused on emerging problems in the form of cognitive blockages and how students can overcome these problems by using metacognitive strategies. Thereby, they were able to progress and to transit between different stages in the modelling process. She reconstructed different kinds of cognitive and metacognitive strategies that can help to avoid difficulties or facilitate the working process, for example, strategies for overcoming memory-related problems, strategies for overcoming representational problems and strategies for benefiting from facilitating perceptual conditions (Stillman 2004). The importance of a well-developed repertoire of cognitive and metacognitive strategies, of an extensive knowledge of mathematical concepts, facts and procedures as well as the relevance of experiences in the use of it became apparent.

In the last years, various studies focusing on the usage of a modelling cycle as metacognitive tool were carried out (Blum 2015; Maaß 2006; Schukajlow et al. 2015). Especially in the case of difficulties, the modelling cycle can serve as a metacognitive aid as students can orient themselves on it (Blum 2015). Schukajlow and Leiss (2011) investigated the self-reported use of cognitive and metacognitive strategies during modelling activities. The results of this study show no significant correlation between self-reported strategies (neither in general nor task-oriented) and mathematical modelling competency (Schukajlow and Leiss 2011). This result can be explained in two ways: On the one hand, it is possible that the use of a certain strategy does not have a high influence on the working process; on the other hand, the method for measuring those metacognitive strategies via self-reports may not be valid or precise enough. However, "[t]here are many indications that metacognitive activities are not only helpful but even necessary for the development of modelling competency" (Blum 2011, p. 22).

27.2.4 Research Questions

As the application of metacognition is demanding, students should be introduced to the use of it over a long period of time. Furthermore, fostering students' metacognition will only be successful if students become aware of the benefits of using metacognition. Therefore, students' perception of the usage of metacognitive strategies is important in order to develop appropriate teaching units and teacher interventions. Therefore, the following research questions are examined in this paper:

1. Which metacognitive strategies do students express at the beginning and at the end of an intervention study?
2. How do students' metacognitive strategies develop from the beginning to the end of the study?
3. How do the students evaluate this development with regard to group work and the work on the modelling problem?

Thus, the aim of the study is to investigate students' perspective on metacognitive strategies in group work during mathematical modelling.

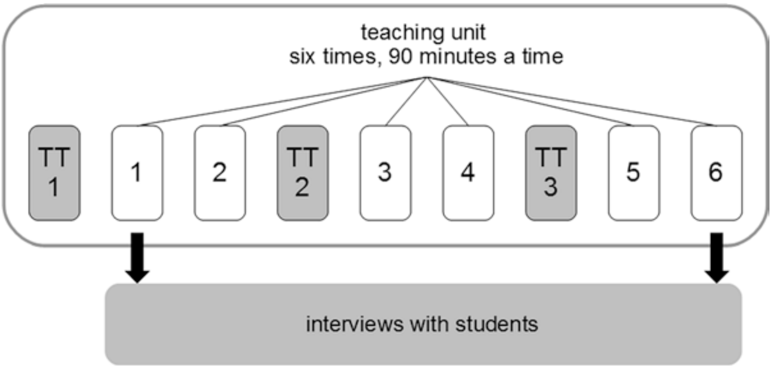

Fig. 27.1 Design of the study (*TT* teacher training)

27.3 Design and Methods of the Study

This study is embedded in the research project MeMo (Metacognition in Modelling) at the University of Hamburg (Vorhölter et al. 2019). This research project aims at evaluating a teaching unit fostering students' usage of metacognitive strategies during modelling processes.

The eighteen participating classes of grade nine and ten worked on six different modelling problems for a 90-min lesson (see Figs. 27.1, 1–6). The teachers were prepared for the study in three teacher trainings of three hours (see Fig. 27.1, TT1-3), where theoretical aspects of mathematical modelling as well as useful teacher interventions within modelling activities were presented to them. The modelling problems they had to use in class were introduced to them, and possible cognitive obstacles as well as suitable interventions were discussed. The modelling problems were complex, reality-based tasks which can be solved in different ways (for an example, see Vorhölter (2019)). All teachers were introduced to the modelling cycle in the teacher training and were asked to refer to it when students asked for help as well as during students' presentation of possible solutions.

The presented study is a qualitatively oriented study focusing on students (for the parallel study on teachers, see Wendt et al. this volume). For data collection, the three-step design of Busse and Borromeo Ferri (2003) was used, which includes a group observation with videotaping, a stimulated recall and a guided interview. While working on the first and last modelling problem, 57 groups of students were videotaped. The videos of 14 of these groups were analysed focusing on situations, in which cognitive and metacognitive strategies as well as metacognitive knowledge were demonstrated. On the following day, the selected situations formed the basis for the stimulated recall. After having seen the scenes, students were asked to describe the situations, their thoughts and their feelings during the situations. In addition, a few focused questions adapted to the previous statements of the students about the use of cognitive and metacognitive strategies were asked afterwards. The interviews were carried out on an individual basis with all students of a group.

For data analysis, a qualitative content analysis (Kuckartz 2016) is used. The codes used were developed inductively as well as deductively, based on literature reviewed and the authors' experiences with, and observations of, modelling processes (Vorhölter et al. 2019). Students' statements were coded as metacognitive (and not only cognitive) if the broader context of the statements indicates that the usage of the strategy was aiming at initiating, organising and controlling (Weinert 1994, p. 193) of the modelling process. The data has been coded several times with the content-structuring analysis by Kuckartz (2016) and presented in case summaries. Finally, the results were discussed and revised in expert groups.

27.4 First Results

In the following, we focus on one group of three boys from a higher track school in Hamburg, who were taught by Ms. Schmidt, a young female teacher (for further information about Ms. Schmidt, see Wendt et al. this volume). The group was chosen because they changed their working behaviour from working alone to working as a group during the study, which has positively influenced the use of metacognitive strategies.

27.4.1 Results Concerning Metacognitive Strategies of Planning

At the beginning of the study, the group used several cognitive strategies to understand and simplify the real problem; for example, they distinguished relevant from irrelevant information, and they identified missing and given information as well as assumptions made. However, a metacognitive usage of these strategies could not be reconstructed. In addition, the students mentioned at the beginning of the study advantages of, and necessity for, a planning phase of the modelling process. After working on the first modelling problem, they recognised the importance of cooperating in the group as a requirement for working on the same approach, which is a part of the planning strategies, and intended afterwards to use more planning activities during the modelling activities. During the next lessons, they developed their own procedure for planning. Apart from the cognitive strategies they had already used at the beginning, they did brainstorming and task sharing. Thereby, they extended their use of cognitive strategies and used them on a metacognitive level.

> Dustin: # Well … # And then ar- eh at first, we wanted to have a look and discuss the way of solving the problem, because this has always helped us and every member of the group can do something. And you can monitor mutually. […] It actually just keeps getting ahead. All of the group members can participate, nobody has open questions and you can then, as already said, also monitor mutually.

In this quotation from the end of the study, the student clarified that a planning phase is important because in this way, all group members use the same approach and can discuss their questions. Therefore, no open questions are left and the students can monitor their processes mutually, which shows the connection between the different procedural strategies of metacognition.

27.4.2 Results Concerning Metacognitive Strategies of Monitoring

At the beginning of the study, the three boys did not work together as a group: Most of the time, they worked on their own or split up into two subgroups and worked on different approaches. However, they were not satisfied with their group work and mentioned that working together cooperatively and monitoring mutually would have improved their solution.

> Dustin: If we had exchanged our ideas, we would have realised that Furkan's approach was the right, ugh, better one. Then, we could have worked on Furkan's approach together and perhaps, we had found a solution faster.

At the end of the study, the boys monitored, according to their own description, their processes in the following phases of the modelling process:

- The process of making assumptions
- The selection of the mathematical model
- Precision of the mathematical work
- Interpretation of the solution
- Validation of the solution
- Usage of the modelling cycle and phases of the modelling cycle

Overall, at the end of the study, the boys monitored not only their own behaviour but also the behaviour of their group mates. They experienced the benefits of working together in a group and monitored their processes mutually. Thus, the importance of the group process for the development of social metacognition becomes apparent (see Sect. 27.2.1).

27.4.3 Results Concerning Metacognitive Strategies of Regulation

Most strategies for regulating the modelling process are based on monitoring strategies. Thus, it is not astonishing that the boys did not mention many strategies for regulating in their first interviews. However, at the end of the study, they mentioned more strategies for regulating their working process. The strategies named can be divided into those used within the group and those aiming at getting external help (see Table 27.1). At first glance, the strategies presented seem to be of a cognitive nature. However, the broader context of the statements made clear that they were used purposefully for improving the modelling process. Thus, these remarks were coded as metacognitive.

At the beginning of the study, the only *group-related strategy* for regulating that could be reconstructed was choosing a different model when recognising that theirs

Table 27.1 Strategies mentioned for regulating the modelling process

Focus	Timing	
	Beginning of the study	End of the study
Group related	Choosing a different mathematical model	Rereading the task for developing a real model
		Choosing a different mathematical model
External help	Doing research on the internet	Comparing with notes about the other modelling problems
		Using a formulae book
		Doing research on the internet
		Asking the teacher
		Asking classmates

is not useful. At the end of the study, they also reread the task when developing the real model.

In addition, they made use of *external help*. At the beginning, they used information from the internet to solve the problem. Besides, at the end of the study, they looked at their notes from the other modelling problems to find a hint on how to proceed and used a formulae book to find a formula. Furthermore, they asked the teacher and classmates, when they needed help. Overall, they were able to extend their usage of regulation strategies. As these strategies are more basic and self-evident, it can be assumed that the boys did not learn these strategies explicitly but became aware of their value for working on a modelling problem.

27.5 Conclusions

The group presented has extended their usage of metacognitive strategies. At the beginning of the study, cognitive strategies were used more seldom and not always aiming at improving the modelling process in contrast to an extensive and purposeful usage at the end of the study. Furthermore, the students realised the necessity of using metacognitive strategies.

They mentioned that they had learnt to transfer a real problem into a mathematical model, that is to say, they have achieved *metacognitive knowledge* about task requirements and strategies. For example, they had the experience that it is necessary to simplify the real problem by making adequate assumptions. Additionally, they developed a critical attitude regarding their modelling process. This became clear by monitoring their modelling process, where a sense of direction developed. Furthermore, they improved the communication within the group by explaining all steps of their working process to the other group members, that is to say that they shared their metacognitive competencies.

To summarise, these first results show that the promotion of metacognitive strategies or overall metacognitive competencies is possible, if it is explicitly promoted by the teachers and the learning environment. The first impression from the analysis of further groups suggests that the usage and the development of the usage of metacognitive strategies are strongly dependent as well on the individual as on the group they were in. However, the results of this study depend on the teachers, the school context, the selected modelling problems and the selected group. Thus, it will be necessary to extend these results to other groups of this study in order to create a typology of different types of students' perspectives on metacognitive strategies during modelling processes.

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