It’s all about metacognitive activities: computerized scaffolding of self-regulated learning

Molenaar, I.

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Students in elementary education often learn in small groups in open learning environments, such as the Internet, e-learning environments and games. Students will be working and learning in small groups with computers throughout their lives. They therefore need to be able to regulate their learning in multiple settings to become successful life-long learners in the global knowledge society. However, practice and research have shown that many students lack the skills to adequately regulate their learning.

This thesis describes a computerized scaffolding system that was developed to provide dynamic scaffolds that stimulate self-regulated learning. The goal of the scaffolding was to support small groups in complex computer-based learning environments to enhance their self-regulation and their learning.

The findings show that scaffolding stimulated students’ metacognitive activities and enhanced their knowledge. Scaffolding also supported group performance but did not affect students’ domain knowledge. Moreover, problematizing scaffolds in the form of questions generated greater effects on learning than structuring scaffolds in the form of statements. These findings contribute to the understanding of how computerized scaffolding in collaborative settings can facilitate students’ self-regulated learning and their metacognitive knowledge.
It’s all about Metacognitive Activities

Computerized Scaffolding of Self-Regulated Learning
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It’s all about Metacognitive Activities

Computerized Scaffolding of Self-Regulated Learning
**Promotores:**
Prof. dr. P. J. C. Sleegers
Prof. dr. C. A. M. van Boxtel

**Overige leden:**
Dr. W.F. Admiraal
Prof. dr. R. Azevedo
Prof. dr. B.H.A.M. van Hout-Wolters
Prof. dr. W. R. van Joolingen
Dr. T. T.D. Peetsma
Prof. dr. M.M.L. Volman

**Faculteit der maatschappij en gedragwetenschappen**
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**Example 1. A group of students unable to regulate their learning**

Example 1 nicely shows how small groups of students collaborating in a complex computer-based learning environment struggle with the regulation of their learning. Students in elementary education often learn in small groups in open learning environments, such as the Internet, e-learning and CSCL environments and games. This is important because learners will be working and learning in small groups with computers throughout their lives (Simons, van der Linden & Duffy, 2000). Students need to be able to regulate their learning in multiple settings as successful life-long learners in the global knowledge society (Simons et al., 2000). Unfortunately, as illustrated by example 1, students fail to sufficiently control and monitor their learning in these environments and research needs to address this issue. Open computer-based learning environments demand more regulation than traditional learning environments (Kalyuga, Chandler & Sweller, 2001; Kirschner, Sweller & Clark, 2006). Learners are asked to set learning goals, apply strategies and select activities to pursue these goals and to monitor and control their own progress (Azevedo & Hadwin, 2005). In more traditional learning environments the task description and linear structure directs learners’ activities almost completely. The teacher’s external control or structure embedded in the learning assignments does not stimulate learners to practice and develop skills to “learn how to learn” (Simons et al., 2000). Open learning environments do provide this opportunity, but there is abundant research evidence showing that students are unable to control and monitor their learning without additional help (Azevedo & Cromley, 2004; Azevedo, Moos, Johnson & Chauncey, 2010; Bannert, 2006).

Scaffolding can support learners in tasks they are unable to fulfill successfully themselves (Hmelo-Silver & Azevedo, 2006; Sharma & Hannafin, 2007; Wood Bruner & Ross, 1976). It is defined as providing assistance to students when needed and fading the support as the learners competences increase (Wood, Bruner & Ross, 1976). Scaffolding supports self-regulated learning in open learning environments, improving learning and motivation (Azevedo & Cromley, 2004; Azevedo, 2010; Bannert, 2006; Land & Greene, 2000; Veenman, Kok & Blote, 2005). Up till now, most scaffolding research has been directed at individual learners in college and high schools. There is some evidence that
scaffolding is also helpful in small group settings (Azevedo, Cromley, Winters, Moos & Greene, 2005; Winters & Alexander, 2011), but this has never been examined with young learners in elementary schools. Moreover, human tutors are not widely available in elementary schools. Computerized solutions could make scaffolding of self-regulated learning more available and applicable in the school context. However, until now few personalized scaffolding systems have been designed for complex open learning environments, because interpreting students’ activities automatically is difficult (Woolf, 2009). The Atgentive project\(^1\) aimed to seek a solution for this issue. A computerized scaffolding system was developed to provide dynamic scaffolds that adjusted to the collaborative learners’ progress. In this dissertation we discuss the conceptual framework that supported the development of this system. Our main goal was to evaluate the effects of the system’s scaffolding on learning. The research question addressed was: What are the effects of computerized scaffolding of self-regulated learning on learning of collaborating students?

On a theoretical level, the goal was to specify the effects of computerized scaffolding of self-regulated learning on learning in collaborative settings. Our computer scaffolding system was designed based on theoretical constructs from educational psychology, namely scaffolding and self-regulated learning. The socio-cognitive perspective on collaborative learning from learning sciences was used to frame the effects on learning of collaborating students. The scientific value of this work lay in our in-depth analysis of the effects of scaffolding on learning in a social setting and the explanation of these effects through elaborated exploration of the students’ learning activities. On a practical level, we aimed to find a solution for the problems students face while learning collaboratively in computer-based learning environment in elementary education. Additionally, this research could offer teachers evidence-based methods to support students’ self-regulated learning in small groups. In order to answer the main question, seven sub-questions were formulated based on the theoretical constructs and perspectives used in this thesis. Before we introduce the sub-questions, we briefly introduce scaffolding, self-regulated learning and the socio-cognitive perspective on collaborative learning.

**Scaffolding**

The design of our computer-based system was based on the construct of scaffolding. Scaffolding comes from the Vygotskian principle of zone of proximal development (Pea, 2004; Vygotsky, 1978). Consequently, scaffolding is defined as providing assistance to a student on an as-needed basis, fading the assistance as the competence of the student increases (Wood, Bruner, & Ross, 1976). Research indicates that scaffolding facilitates learning as it supports learners in activities they are unable to accomplish successfully by

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\(^1\) The Atgentive project was an European STREP under the sixth Framework program. Atgentive stands for “Attentive Agents for Collaborative Learners”. The objective was to investigate the use of artificial agents for supporting the management of the attention of young or adult learners in the context of individual and collaborative learning environments.
themselves and develops knowledge and skills needed to perform future tasks (Hmelo-Silver & Azevedo, 2006; Pea, 2004; Sharma & Hannafin, 2007). The essential elements in the process of scaffolding are diagnosis, calibration and fading (Puntambekar & Hübscher, 2005). The abilities of the learner must be diagnosed continuously in order to define appropriate scaffolds. This diagnosis supports careful selection, or calibration, of the appropriate scaffolds to support the student and a successive reduction of support, fading, when the learner masters all aspects of the task (Molenaar & Roda, 2008). Effective human tutors select their scaffolds with careful diagnosis of a student's behavior and reduce their support when the student's competences increase (Wood et al., 1976, Chi, 2009). However, as briefly mentioned above, automatic diagnosis of students’ behavior to adjust support to their current understanding is problematic, which is why, in contrast to human scaffolding, most computerized scaffolding systems use static scaffolding. Static scaffolding is the same for all students and does not adjust to the individual student's progress; for example a pre-set list of instructions that helps learners to perform a learning assignment. Dynamic scaffolding, on the other hand, analyses the student’s behavior to select an appropriate scaffold (i.e. one can monitor the progress of the student and provide scaffolds when needed during learning). In this thesis, we evaluate the effect of dynamic computerized scaffolding of self-regulated learning. The next section elaborates on the construct of self-regulated learning.

Self-regulated learning and metacognition

In educational research, students’ ability to steer and regulate their learning is considered important for learning in a knowledge society (Azevedo & Green, 2010; Winne & Hadwin, 2010; Zimmerman, 2002). Moreover, it has been shown that students that use more metacognitive activities gain higher learning achievements (Veenman, 2005; 2011). Nevertheless, there are unclear boundaries between the constructs of self-regulated learning and metacognition, which causes confusion and debate among researchers (Alexander, 2008; Dinsmore, Alexander & Loughlin, 2008; Kaplan, 2008). Without professing an ambition to end this debate, we briefly present the definitions used in this thesis. Self-regulated learning was originally defined as an integrated theory of learning (Corno & Mandinach, 1983; Dinsmore et al., 2008), focusing on the interaction of cognitive, motivational and contextual factors to explain learning. Today, we picture self-regulating learners as those who successfully use cognitive activities (read, process, elaborate) to study a topic, control and monitor their learning with metacognitive activities (orientate, plan, monitor and evaluate their actions) and who are able to motivate themselves (Zimmerman, 2002, Azevedo et al., 2008, Winne & Hadwin, 2010). Different theoretical models have specified the relation between these different components (Boekarts, 1999). We used the model of Zimmerman (2002) as the starting point for designing our scaffolding system. Important in this model is the cyclical explanation of the interaction between cognitive, metacognitive and motivational activities. There are three phases in this model, forethought, performance, and reflection, that inform the positioning
of different learning activities. We evaluate the effect of scaffolding on learning in this thesis and our focus is mostly on cognitive and metacognitive activities.

The construct of metacognition originates from cognitive information processing theory (Flavell, 1979). It was originally defined as “cognition over cognition” or “knowledge about knowing”, which a learner needs to control and monitor his learning. A distinction is made between metacognitive knowledge, i.e. the knowledge students have about the interaction between person, task and strategy characteristics (Flavell, 1979) and metacognitive skills, i.e. the skills students have to apply metacognitive activities to control and monitor cognitive activities (Veenman, 2005). In order to distinguish clearly between cognitive and metacognitive activities, Nelson (1996) defined the object-level and the meta-level of learning. Cognitive activities are those activities dealing with the content of the task (the object-level) and metacognitive activities are those activities dealing with controlling and monitoring cognitive activities (the meta-level), such as orientation, planning, monitoring, evaluation and reflection (Meijer, Veenman, Van Hout-Wolters, 2006).

In this thesis, we follow Veenman (2011) in viewing self-regulated learning as a broad theoretical construct and metacognitive activities as one of its components. We assume that metacognitive activities are a manifestation of the students’ metacognitive knowledge and skills. As discussed above, we investigated the role of metacognitive activities in the context of a computer-based learning environment in which students were learning collaboratively. Until now, researchers have hardly applied the constructs of self-regulated learning (or socially regulated learning) and metacognitive activities in collaborative learning (Iiskalla, Vauras, Lehtinen & Salonen, 2011; Dillenbourg, Jarvala & Fischer, 2009). Evidently, learners in small groups need to regulate their own and the group’s learning (Hadwin & Oshige, 2007). This means that groups need to use the appropriate cognitive activities to attain their goals and apply metacognitive activities to control and monitor their learning (Hadwin & Oshige, 2007, Iiskalla et al., 2011; Volet, Vauras & Salonen, 2009). Even though the need for metacognition in group settings is recognized, there is little knowledge about metacognitive activities in social settings. In order to further our understanding of how metacognitive activities and scaffolding of these activities influence students’ learning in groups, we need to look at perspectives that explain learning in collaborative settings.

**Perspectives on collaborative learning**

Collaborative learning is defined as learning that follows from working on a common task under shared responsibility of the group members (van der Linden & Haenen, 1999). Research indicates that under the right circumstances collaboration enhances group performance, individual learning, and individual students' motivation, metacognitive and collaborative skills (Cohen, 1994; Johnson & Johnson, 1999; Lou, 2001; Slavin, 1996; Dillenbourg et al., 2009). There are different explanations for the learning effects of collaborative learning from motivational theories (Slavin, 1996), neurological research
(Chase, Ching, Opperzo & Schwartz, in press; Okita, Bailerson & Schwartz, submitted) and cognitive and socio-constructive perspectives on learning (Dillenbourg et al., 2009; Volet et al., 2009). In this thesis, we draw on the socio-cognitive perspective on collaborative learning. This perspective offers a framework to analyze how individuals learn in interaction with others, emphasizing the student’s individual development as well as the group development as a result of the interaction (Hadwin & Oshige, 2007; liskala, Vauras, & Lehtinen, 2004; Vauras, liskala, Kajamies, Kinnunen, & Lehtinen, 2003; Volet, Vauras, & Salonen, 2009). Learning is considered to take place through reciprocal activities between the students. Consequently, peers are expected to play a mediating role in the learning of others (Vygosky, 1978; Salomon, 1993; Volet et al., 2009). Elaboration on each other's contributions, such as giving feedback, asking questions and receiving answers, discussing and exchanging ideas, is expected to enhance students' learning (Chi, 2009; Webb 2009). Learners contribute knowledge and skills to the social system, which elicits new activities from the other group members. As a result group members influence each other in a spiral-like fashion. This offers individual students the opportunity to practice skills and appropriate knowledge and consequently develops group and individual skills and knowledge (Salomon, 1993; Volet et al., 2009).

The research question addressed in sub-questions

The constructs of scaffolding, self-regulated learning and the socio-cognitive perspective on collaborative learning supported the formulation of seven sub-questions that contributed to answering our main research question: What are the effects of computerized scaffolding of self-regulated learning on the learning of collaborating students? Knowledge about scaffolding and Zimmerman’s model of self-regulated learning were the basis for the conceptual framework that guided the development of a computer-based scaffolding system. The effect of this computerized scaffolding on learning of students in small groups was examined, drawing on the socio-cognitive perspective of collaborative learning, which was also instrumental for our exploration of these studies to find out how students learn from computerized scaffolding. The seven sub-questions are introduced below.

Sub-question 1. How can an attention management system enable dynamic scaffolding of self-regulated learning?

The first sub-question was a design-related question using existing theoretical knowledge about scaffolding and self-regulated learning to design a computer system that supports dynamic scaffolding based on attention management. Attention management systems register the student’s attentional focus (Roda & Nabeth, 2007). As indicated earlier, there are few computerized scaffolding systems that adjust scaffolding to the activities of the learner in open learning environments. This is mainly due to difficulties with automatically interpreting a student’s activities, which makes it difficult to adequately scaffold by means of diagnosis, calibration and fading. Yet, as indicated in Zimmerman’s model (2002) of self-regulated learning, it is important to support cognitive, metacognitive and motivational
activities at the right time during learning. Students not only need to learn how to regulate their learning, but also when to regulate their learning. Consequently, a computer system that enables dynamic scaffolding of self-regulated learning needs to diagnose current behavior and select appropriate scaffolds to foster self-regulated learning. To answer this question, we examined whether an attention management system could be used for this purpose.

Sub-question 2. What are the effects of computerized scaffolding of self-regulated learning on learning outcomes of collaborating students?

The second sub-question is important as until now scaffolding research has mainly focused on investigating the effect of scaffolding self-regulated learning in individual settings. There are few examples of scaffolding self-regulated learning in collaborative settings, especially not with learners in elementary education. In general the goal of scaffolding is to support learners in activities they are unable to accomplish successfully by themselves to enhance learning and to develop knowledge and skills needed to perform future tasks (Hmelo-Silver & Azevedo, 2006; Pea, 2004; Sharma & Hannafin, 2007). Consequently, scaffolding of self-regulation in a small group needs to stimulate cognitive and metacognitive activities to enhance the group performance and individual students' domain and metacognitive knowledge for future learning in complex open learning environments. Most scaffolding studies examine the effects on students' performance and domain knowledge, but effects on metacognitive knowledge, which is important for future learning, are largely ignored. This question was designed to contribute to knowledge about the effects of dynamically scaffolding self-regulated learning with a computer-based system in elementary education and it aimed to address effects on the group’s performance and individual students' domain and metacognitive knowledge for future learning.

Sub-question 3. What are the effects of different forms of metacognitive scaffolds on learning outcomes of collaborating students?

The third sub-question addressed the effects of different forms of scaffolds on learning. This question was designed to build on our understanding of how scaffolding influences learning. Reiser (2004) specified two mechanisms to explain students' learning from scaffolding. Structuring simplifies the learning assignment by reducing its complexity, clarifying the underlying components and supporting performance (i.e. providing the students with an example of a plan for the assignment). Problematizing increases the complexity of the learning assignment by emphasizing certain aspects of the assignment and asking learners to clarify the underlying components and perform actions to construct their own strategies (i.e. asking students to make their own plan for the assignment). These different mechanisms support the formation of different forms of scaffolds that either structure or problematize aspects of the learning assignment. This should allow further insight into how scaffolding supports learning and differentiation between the effects of different forms of scaffolds on learning.
Sub-question 4. Does metacognitive scaffolding stimulate metacognitive activities and develop metacognitive skills in small groups?

After establishing the effects of scaffolding and different forms of scaffolds on learning outcomes, a new question emerged to further explain these effects and to elaborate on existing assumptions in scaffolding research. The assumption in many scaffolding studies is that effects on learning are explained by the activities the scaffolds stimulate. However, most studies only address the effects on learning outcomes, leaving the effects of scaffolding on students’ activities during learning out of the picture. This question investigated the effect of scaffolding on the groups’ activities during learning. Another assumption often made in scaffolding research is that it leads to lasting changes in behavior, i.e. development of knowledge and skills. This assumption was examined by exploring the groups' activities during and after scaffolding. This provided insights into the effects of scaffolding and different forms of scaffolds on stimulating the groups’ metacognitive activities and the development of metacognitive skills.

Sub-question 5. How does metacognitive scaffolding affect individual learning in small groups?

This question aimed to further understanding of how students in small groups learn from scaffolding. This is important for our theoretical understanding of how scaffolding during collaborative learning influences learning and for the practical purpose of optimizing future scaffolding approaches. Moreover, differential effects of problematizing and structuring scaffolds on learning could possibly be explained this way. Research mostly assumes that students learn from scaffolding through the metacognitive activities that are stimulated by the scaffolds (Veenman, Kok & Blote, 2006). This question investigated this assumption, analyzing the relationship between scaffolding and individual learning and the extent to which metacognitive activities mediated this effect. This question further elaborated how students learn from different forms of scaffolds in small groups.

Sub-question 6. How are metacognitive activities embedded in interaction among the group members?

Contrary to the rest of this thesis, this question did not deal with the effects of scaffolding on learning. It focused on understanding how metacognitive activities are embedded in the interaction between group members. As mentioned above, metacognitive activities have been largely ignored in computer-supported collaborative learning as an explanatory factor for learning (Dillenbourgh, Jarvala & Fischer, 2009). Moreover, the treatment of metacognitive activities in the literature does not adequately attend to the social nature of collaborative learning. Until now there have been few empirical examples of metacognitive activities embedded in interaction. Existing examples primarily show reciprocal interaction between the group members, which is the most effective but also the least frequent form of interaction in small groups (Iiskale et al. 2011). We specified different ways in which
metacognitive activities were embedded in interaction among the group members and how this influenced the quality of their metacognitive activities.

Sub-question 7. What is the effect of metacognitive scaffolding on the way metacognitive activities are embedded in interaction?

This question was driven by the proposition that effects of scaffolding and different scaffolds on learning could be partially explained by the way metacognitive activities are embedded in the interaction among the group members. Successful collaboration, in which students exchange, share and co-construct knowledge, enhances learning (Chi, 2009; Webb, 2009). Thus transactive interaction in which students relate to and engage in each other’s metacognitive activities was expected to support the group process and the development of metacognitive knowledge. Hitherto the effects of metacognitive scaffolding on the way metacognitive activities are embedded in the interaction among students have been largely ignored. This question addressed this issue, which could also open up a new line of thinking about the combination of scaffolding and collaboration.

This thesis

We developed a computerized scaffolding system called AtgentSchool and performed two experimental studies to answer our research question. The chapters are guided by the sub-questions and shift from a design perspective to specifying the effects of scaffolding self-regulated learning in part one. We focus on understanding how scaffolding and different scaffolds supported learning in part two. Finally in part three, we elaborate on how metacognitive activities were embedded in interaction between the group members and how scaffolding influenced this (see Figure 1 for an overview). Hence, the goal was not only to establish the effects of our scaffolding system, but also to understand what caused these effects. We hope that this understanding will enable future adjustments to our system and enhance our theoretical understanding of scaffolding self-regulated learning and metacognitive activities in small groups.

Part I. Computer-based scaffolding of self-regulated learning

In part I, we outline the conceptual framework that supported the development of the scaffolding system AtgentSchool and the results of our first study of scaffolding self-regulated learning. Chapter 1 describes the theoretical foundation and rationale for the design of our scaffolding system addressing our first sub-question. Chapter 2 discusses our first study that assessed the effectiveness of scaffolding of self-regulated learning on the group's performance, perception of the learning environment and students' acquisition of domain knowledge.
Introduction

![Diagram of theoretical constructs and sub-questions]

**Part II. Effects of metacognitive scaffolding and different forms of scaffolds**

Part II focuses on the effects of metacognitive scaffolding and different forms of scaffolds (structuring and problematizing scaffolds) on learning. In chapter 3, we discuss the effects of metacognitive scaffolding and different forms of scaffolds on the groups' performance and on individual students' domain and metacognitive knowledge. In order to explain the differential results of different forms of scaffolds, we investigated the effect of scaffolds on the groups' metacognitive activities and report on this in chapter 4. The stimulation and development hypotheses were examined to find evidence for two widely held assumptions in scaffolding research. Finally, in chapter 5 we connect the findings of the previous two chapters in a mediation analysis which investigated the relation between different forms of scaffolds, metacognitive activities and student learning.

**Part III. Metacognitive activities and scaffolding embedded in interaction**

Part III focuses on how students collaboratively regulated their learning and investigates the effects of scaffolding on students' metacognitive activities embedded in interaction. Chapter 6 discusses how metacognitive activities were embedded in interaction between the group members and how that facilitated the group process. In chapter 7, we further analyze the role of scaffolding on the students’ interaction around metacognitive activities to understand how scaffolding influenced this.
Part I. Computer-Based Scaffolding of Self-Regulated Learning
1 Attention Management for Self-Regulated Learning: AtgentSchool

Abstract This chapter addresses how an attention management system can support dynamic scaffolding for self-regulated learning. An attention management system captures information from the students’ environment about the students’ attentional focus. In this chapter we propose a conceptual framework to interpret this information to provide dynamic scaffolds to the learner. The essential elements to select appropriate scaffolds are diagnosing, calibrating and fading. Our intervention model defines how to support self-regulated learning with different scaffolds. The three component processes of self-regulated learning are supported, namely cognition, metacognition and motivation. This chapter is concluded with a short description of the testing procedure that assured the proper functioning of the software.

Chapter 1

Introduction

E-learning has incrementally changed education in recent decades. Many new tools and instruments have been introduced to support existing educational practices. Yet only on a small scale have we seen transformative processes in schools (Mioduser, Nachmias, Tubin, & Forkosh-Baruch, 2003; Woolf, 2009). The large changes which have taken place in other sectors have not yet been achieved in education. This can partially be explained by the fact that e-learning solutions are not yet flexible enough to cater to learner’s individual needs and demands. We see personalization in many sectors today, but education still seems to hold on to the ‘one size fits all’ paradigm even though we know that personalized education is more effective than standardized education (Bloom, 1984).

Artificial intelligence has provided personalized solutions, but these programs are mainly applicable in structured domains (Woolf, 2009). Often artificial intelligence programs construct a model of the student’s knowledge based on the student’s answers to questions. The comparison of the student’s knowledge model to a domain knowledge model supports the selection of new assignments and/or support messages for the student. In ill-structured domains, it is difficult to build knowledge models of the student’s knowledge because answers are difficult to interpret (Lynch, Ashley, Pinkwart & Aleven, 2009). Therefore, few personalized solutions are available in ill-structured domains.

Attention management addresses the quest for personalization on a different level. Instead of building models of the domain knowledge and comparing this to the student’s knowledge model, it focuses on capturing the user’s attentional focus (Roda & Nabeth, 2007). This attentional focus can be built upon to provide personalized instruction and allowing for dynamic support of learning. Attention management systems integrated with electronic learning environments can provide learners with the help they need to direct and sustain attention to appropriate tools and information. This support can evolve with the student's knowledge and skills and is often referred to in the literature as scaffolding (Wood, Bruner & Ross, 1976). Although scholars stress the importance of scaffolding self-regulated learning, especially in open electronic learning environments (Azevedo & Hadwin, 2005), research into the role and effectiveness of computerized scaffolding in supporting self-regulated learning is scarce.

This chapter addresses a design-related question: how can an attention management system enable personalized support, or dynamic scaffolding, of self-regulated learning? In order to answer this question, we describe the theoretical construct of scaffolding and its related dimensions. We will explain how attention management is related to the scaffolding theory and elaborate on the relation between self-regulated learning and scaffolding.
**Scaffolding**

Scaffolding provides assistance to a student on an as-needed basis, fading the assistance as the student’s competence increases (e.g. Wood et al., 1976). The scaffolder can be either a human tutor or a tool embedded in the computer environment. Three important elements in scaffolding are diagnosis, calibration and fading (Puntambekar & Hübscher, 2005). The abilities of the learner must be diagnosed continuously in order to define appropriate scaffolding. This diagnosis supports careful selection, or calibration, of the right scaffolds to support the student and a reduction of support, fading, when the learner masters all aspects of the task.

Within the scaffolding paradigm, there is a distinction between static and dynamic scaffolding (Puntambekar & Hübscher, 2005; Molenaar & Roda, 2008). Static scaffolding is defined at one moment, constant over time and the same for all students; for instance, one may provide a list of instructions to help users perform a learning activity. Dynamic scaffolding entails pedagogical agents which diagnose, calibrate and fade their support in an individualized manner such that one can monitor the student’s progress and provide scaffolds when needed during learning. Static scaffolding can support learners to increase performance. Dynamic scaffolding has the additional benefit that it can help students learn when to apply certain knowledge or skills during learning. The term scaffolding is often used in cases where static scaffolding is applied: the amount and type of support is fixed and not adjusted based on a diagnosis of the student’s learning (Puntambeker and Hübscher, 2005). There is no calibration of the scaffolds to the changing needs of the individual student nor fading of the scaffolding; the scaffolds are permanent and unchanged. We propose using attention management to support dynamic scaffolding, applying diagnosis, calibration and fading based on the students’ attentional focus and information from their environment.

Next to the distinction between static and dynamic scaffolding, another important issue for the design of scaffolds is the focus of the support. As mentioned above, scaffolding plays a crucial role for learning in largely unguided and open learning environments (Kalyuga, Chandler & Sweller, 2001; Kirschner, Sweller & Clark, 2006). In these learning environments scaffolding should be directed at self-regulated learning and support students to successfully learn in these environments (Azevedo & Hadwin, 2005). Self-regulated learning is defined as self-generated thoughts, feelings and behaviors directed at attaining learning goals; it deals with the component processes: cognition, metacognition and regulation of motivation (Ainley & Patrick, 2005). Cognitive activities are directed at the acquisition of knowledge while metacognitive activities are directed at monitoring and controlling these processes. Motivation strongly influences learning activities (Boekaerts, 1999) and regulation of motivation plays an important role in the attainment of learning goals (Ainley & Patrick, 2005; Boekaerts, 1999; Mayor, 1998, Zimmerman, 2002). In order to scaffold all three component processes we developed an intervention model from which scaffolds for each one of the processes are selected. Before
we turn to an explanation of the scaffolding system, we will briefly introduce the reader to some fundamental concepts in human attention that has guided our research.

**Attention**

Attention can be defined as the collection of processes regulating the allocation of a human’s limited cognitive resources. Attention allows us to select some perceptual input for further processing out of the wide variety of stimuli we continuously receive from the environment. Attention also controls the allocation of cognitive resources to the processing of multiple tasks, enabling task monitoring and error detection. Finally attention allows us to create expectations that guide the selection of perceptual stimuli, as when we recognize a person we were waiting for in a crowd. Attention, or the allocation of cognitive resources, may be controlled either endogenously by volition or exogenously when temporarily directed by external stimuli (Posner, 1980; Yantis, 1998). For example, when reading this document, you are applying endogenous attention because you choose to pay attention to the document; however, a sudden noise may exogenously control your attention and temporarily redirect it to the source of the noise.

In general, attention allocation can be observed at several levels of granularity; that is, we may say that a subject is paying attention to a vertical bar on a screen, to a letter ‘t’, to a word ‘table’, to a sentence ‘the glass is on the table’, to a document describing a room layout, to the task of verifying if the description of a room layout corresponds to the room the subject is in, etc. The literature often distinguishes between two granularity levels, the perceptual level and the task level. We can distinguish several different forms of attention. Focused attention is directed to an individual task or input channel. If the focus is prolonged, then we have sustained attention. Because by focusing on a certain target one excludes others, focused attention implies selective attention (Chun & Wolfe, 2001; Driver, 2001; Posner, 1982). An attention switch is the process by which attention is moved from one target to another. There is always a cost involved in attention switches (Jersild, 1927; Monsell, 2003) due both to the uncertainty associated to the task to be performed in response to a stimulus (Spector & Biederman, 1976) and to the cost of reconfiguring the current task set (Monsell, 2003). Often, rather than switching attention, we are able to allocate attention to multiple tasks or channels at the same time. In this case we talk about divided attention; for example, we can easily drink a cup of coffee while reading a book.

The fact that attention plays a fundamental role in learning has been demonstrated in the context of several types of learning processes. Single-task versus dual-task experiments, for example, have demonstrated that implicit learning, the ‘no episodic learning of complex information in an incidental manner, without awareness of what has been learned’ (Seger, 1994 p. 163), requires attention, and it is penalized under dual-task conditions (Shanks et al., 2005). Similar results (Toro et al., 2005) have been obtained for statistical learning (Saffran et al., 1996). Several experiments (e.g. Ahissar & Hochstein, 1993) have also demonstrated the need for focused attention in learning task-relevant
information in perceptual learning, that is, the improvement of perceptual abilities after training. Task-related focused attention in perceptual learning generates an alerting process that may also explain the unexpected effect of task-irrelevant learning (Seitz & Watanabe, 2005). Finally, attention also affects higher-level learning, e.g. the learning of written language or mathematics (Lok, Jin & Sweller, 2011).

Given the role that attention plays in learning processes, attention management systems i.e. systems capable of adapting to and supporting human attention processes (Roda & Thomas, 2006), promise to play an essential role in supporting technology-enhanced learning environments. The attentive system research aims at defining the factors and determining the likely utility of given information for a given user in a given context and the costs associated with presenting the information in a certain way (Roda & Nabeth, 2007). The utility of attentive systems for learning, such as the one introduced in the next sections, is to detect the attentional focus of the student and interpret this information to support learning.

Scaffolding with an attention management system

For a detailed technical description of the AtgentSchool system we refer the reader to Molenaar & Roda (2008). In this chapter we will describe the system’s functioning from an educational perspective, which oversimplifies its technical functioning. First, we will explain how the system is related to the scaffolding theory incorporating diagnosis, calibration and fading. Secondly, we elaborate on the relation between the self-regulated learning and the interventions the system uses to scaffold learning.

AtgentSchool

The AtgentSchool system is an e-learning environment combined with an attention management system. The e-learning environment incorporated with AtgentSchool is called Ontdeknet, and is focused on supporting students in their collaboration with experts (Molenaar, 2003). Ontdeknet is an open learning environment in which assignments are structured in ‘projects’. A project consists of a broad overall assignment which is connected to an external expert who will provide the students with specialized information. The assignment is divided into smaller sub-assignments to support the collaboration with the expert; students are asked to introduce themselves to the expert, write a goal statement and specify topics of interest on a concept map.

AtgentSchool’s attention management system monitors the students’ attentional focus and based on that information supplies them with support to enhance their learning. The system’s technical design consists of three levels, the input level, the reasoning level and the intervention level. The input level collects the attentional information from the students’ environment. Currently, input is based on keyboard strokes, mouse movements and information about the students’ activities in the e-learning environment which is captured by the log file. The reasoning level selects a scaffold that is sent to the learner.
Different software agents assess the attention information to select the appropriate scaffold. The intervention level determines how the scaffold is communicated to the learner. AtgentSchool uses a three-dimensional animated pedagogical agent powered by Living Actor technology (Benoit & Ach, 2011) for the delivery of scaffolds via text balloons and spoken messages accompanied by the agent’s animations and emotions. The student has four icons in the interface to communicate with the agent, a question mark to indicate a need for help and three emotional icons indicating a happy, neutral or sad user. This information from the user is used as additional input. In the section below, we explain how diagnosis, calibration and fading are performed with the AtgentSchool system.

**Diagnosis**

Diagnosis is defined as the ongoing measurement of the students’ current level of understanding to select the appropriate scaffolding (Wood et al., 1976). This entails the evaluation of the users’ progress during learning activities. Progress is evaluated based on the students’ performance on the learning assignment and/or the students’ development of knowledge in the learning domain (Wood et al., 1976). Diagnosis in AtgentSchool is based on the attention information acquired in the students’ environment. The system registers the students’ progress based on his performance in the learning environment. For example, when the learner browses through a text, the system registers both the viewing of the particular text as well as the browsing behavior of the student. The information from the electronic learning environment is particularly important because it provides a real-time description of activity on the learning assignment. Based on this information, the learners’ progress and experience is registered. For example, if a learner is using the concept map tool in the learning environment and proceeding quickly, filling-in different fields, this information is stored with an indication that the learner is capable of appropriately using the concept map tool. Both the current behavior of the student as well as the experience and progress are incorporated in the diagnosis.

Additionally, keyboard strokes and mouse movements provide information beyond the level of involvement in the specific learning task by also measuring the students’ activities in the overall environment. For example, no keyboard strokes or mouse movement registration in a certain time frame can indicate that the student is idle. The students’ current attentional focus is evaluated on the basis on this input-level information (data related to the performance, progress, experience, keyboard strokes and mouse movement) and it constitutes the diagnostic component of AtgentSchool.

**Calibration**

Following diagnosis, calibration is the careful selection of the best scaffold for the student’s activity (Wood et al., 1976). The system assembles a logical attentional focus based on the learning assignment at hand and creates a list of all possible scaffolds that can support the learner at this instant. The learner’s current attentional focus is compared to the logical attentional focus based on the learning assignment. When current and logical
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attentional focus match, a scaffold is selected to support the learner with his current activities. For example, if a student should introduce himself and is at the screen prompting him to enter the introduction then, if the system detects that the student is idle, it may support the student by suggesting that he starts planning the introduction assignment. In case of a discrepancy between the current and the logical attentional focus, the system is triggered to select a scaffold that can overcome the discrepancy. For example, if the student has an assignment to introduce himself and the system establishes that he is not on the correct screen, then a focus discrepancy is diagnosed and a scaffold is selected to direct the attention of the learner to the introduction assignment, yet the system will wait to provide the scaffold until it registers that the student is idle. Calibration has the function of determining the most appropriate scaffold based on the diagnostic information. Scaffolds either support or alter the attentional focus of the student.

**Fading**

The final element of scaffolding is fading. Fading is the gradual reduction of scaffolds leading to full transfer of tasks and control to the learner (Wood et al., 1976). The nature and amount of fading is highly dependent on the experience of the user: when the student masters all aspects of the tasks, no scaffolds are needed to support self-regulated learning. In AtgentSchool the learners’ progress and experience is registered. This information is used to determine whether the scaffold selected in the calibration process should be forwarded to the student. If the system determines that scaffolding is not needed for a student, fading ensures that the scaffold is not sent. For example, when the system registers the students’ focus on the introduction assignment, it will send a scaffold only if the student has not worked at the introduction previously. Thus fading, in the AtgentSchool system, is achieved by selecting appropriate scaffolds based on an assessment of the learners’ progress and previous experiences. If the diagnostics of the system and the registered user information contradict each other, fading will be reduced. For example, if the learner model indicates that the user is an experienced user and the diagnostics of the system show that the user does not perform the task correctly; the system will reduce the fading and show the supporting scaffold to the user.

To summarize, the attention management system derives information from the students’ environment. Based on this information an assessment of the attentional focus of the student is made (diagnosis), which is compared to a logical attentional focus based on the learning assignment. This comparison is the basis for the selection of the scaffold (calibration), which is only sent when the student needs support (fading). Now that we have defined how scaffolds are selected in relation to the attentional focus of the students, we identify which learning activities the scaffolds are supporting.
The intervention model

An important aspect for dynamic scaffolding to become effective is the focus of the scaffolds. The scaffolds are directed toward three different but related components of self-regulated learning, cognition, metacognition and motivation. In order to design scaffolds that are focused on these processes, the AtgentSchool system uses a standardized intervention model (Molenaar & Roda, 2008) from which the scaffolds are selected. There is an important difference between interventions and scaffolds. Interventions are the messages that can be shown to the learner to support learning, but they only become scaffolds when they are presented in the right learning context. The intervention model consists of three intervention categories, metacognitive interventions, cognitive interventions and motivational interventions. The intervention categories are further organized by intervention types (see Table 1 for an overview). The intervention types are general and transformed in task-related scaffolds depending on the students’ context. The different intervention categories are described below; the function of each intervention is discussed followed by an explanation of how the intervention is used during learning and relates to the attentional focus of the student.

Metacognitive interventions

Metacognition is defined as the knowledge about and regulation of one’s cognitive activities (Flavell, 1979). Metacognitive activities are categorized as preparatory activities such as orientation and planning, executive activities such as monitoring and evaluation and closing activities such as reflection (Zimmerman, 2002; Veenman, Aftenbach, van Hout-Wolters, 2006). Orientation on a learning assignment supports a detailed view of the task at hand and the activation of prior knowledge relevant to the task. Planning a learning assignment entails dividing it into subtasks and deciding on the strategies to be followed to complete the sub-tasks. Through monitoring, students check the correctness of their learning. Evaluation enables students to react to failures and misunderstandings. Reflection about the learning procedures and strategies provides grounds for future enhancement.

Metacognitive interventions are directed at supporting and triggering metacognitive activities. These interventions can support learning when they are shown to the learner at times when metacognitive activities are beneficial for learning. AtgentSchool supports three forms of metacognitive scaffolds, orientation, planning and monitoring scaffolds. Orientation is best performed just before task selection; thus when the attentional focus of the students is about to change towards a new assignment, students are shown a scaffold with which to focus on the assignment. An example of an orientation scaffold for the ‘goal statement’ assignment is: ‘Your expert would like to know what your learning goal is; could you tell him? Please click here to write your learning goal.’ Planning is done just before starting a learning assignment; therefore, planning interventions are implemented just after the attentional focus of the student shifts from one assignment to another. The following sentence is an example of a planning scaffold for the ‘goal statement’ assignment (see figure 2): ‘Here you will write your learning goal; for example, I like to
learn everything about David. Just kidding, good luck.’ Finally, monitoring should be performed during and after execution of the assignment, just before the attentional focus of the student moves away from the assignment. The following sentence is an example of a monitoring scaffold for the ‘goal statement’ assignment: ‘I’ll go directly to your expert and explain what you would like to learn.’

Figure 2. Example of metacognitive planning intervention

Cognitive interventions

Cognitive activities are directed toward the acquisition of knowledge (Nelson, 1996). Cognitive interventions can provide the knowledge and skills necessary to perform an assignment and are best shown to learners when there is an indication that they are experiencing problems. Indications of problems could be an idle user, when there are no keyboard strokes or mouse movements, or when the user indicates he needs help via a question mark icon in the interface. The selection of the cognitive interventions is determined by the attentional focus of the learner. Two different types of cognitive interventions are distinguished, cognitive support interventions and cognitive resource interventions. Cognitive support interventions are directed toward helping the learner with the current learning activity whereas cognitive resource interventions provide students with links to resources in the learning environment that can help them perform the task. For example, a message to the user saying ‘What do you already know about the subject you are going to study?’ is a cognitive support scaffold for the assignment ‘write a concept map’: an example of a cognitive resource scaffold for the same learning task would be: ‘Need some ideas? You can read the introduction diary of the expert’.

Motivational interventions

Motivation strongly influences students’ learning activities (Boekaerts, 1999), and motivational support can increase learners’ motivation. Motivational interventions are directed at increasing learners’ motivation to work on the learning assignment. They are best shown when there is an indication that the user is having problems to keep up his motivation. An indication of motivational problems occurs when users indicate their motivation to the agent. Also motivational interventions are triggered when the user is idle and there are no new cognitive interventions available for this user. The selection of the
motivational support intervention is determined based on the attentional focus of the learner. General motivational interventions are implemented in the system. An example is: ‘You can do it! Just start writing’. Additionally, when the user indicates his current emotional state with happy, neutral or sad smiley’s, the agent mirrors the state of the user by showing an animation and expression that resemble the user’s state. The three forms of emotional feedback lead to three emotional support interventions where the embodied agent responds to a user’s notification of a happy, neutral or sad emotional state. The intervention categories and intervention types are summarized in table 1.

<table>
<thead>
<tr>
<th>Intervention Category</th>
<th>Intervention Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacognitive</td>
<td>MC orientation</td>
<td>Introduces the learning assignment to the learner</td>
</tr>
<tr>
<td>Metacognitive</td>
<td>MC planning</td>
<td>Asks the learner to plan the learning assignment</td>
</tr>
<tr>
<td>Metacognitive</td>
<td>MC monitoring</td>
<td>Provides feedback to the learner about the learning activity performed</td>
</tr>
<tr>
<td>Cognitive</td>
<td>Cognitive support</td>
<td>Provides additional explanation to the learner</td>
</tr>
<tr>
<td>Cognitive</td>
<td>Cognitive resources</td>
<td>Provides additional explanation by redirecting the learner to another learning resource containing additional information</td>
</tr>
<tr>
<td>Motivation</td>
<td>Motivation support</td>
<td>Provides a motivational incentive to the learner</td>
</tr>
<tr>
<td>Motivation</td>
<td>ES Happy</td>
<td>Reacts to a happy learner</td>
</tr>
<tr>
<td>Motivation</td>
<td>ES sad</td>
<td>Reacts to a sad learner</td>
</tr>
<tr>
<td>Motivation</td>
<td>ES neutral</td>
<td>Reacts to a neutral learner</td>
</tr>
</tbody>
</table>

Relationships are established between the attentional focus of the learner, the learning assignment and the scaffolds selected. Both the cognitive and motivational scaffolds are selected based on the assignment that is currently in the attentional focus of the learner. They can also be triggered by the ‘user reaction’ icons, the question mark and emotional icons. Metacognitive scaffolds, on the other hand, do not have a direct relation with the assignment currently in the attentional focus of the students. Metacognitive interventions provide pre-task, on-task or post-task support; they are presented to the learner when he/she changes focus. Thus when the learner is about to select a sub-assignment, the metacognitive orientation intervention could be shown. At the start of the assignment a metacognitive planning intervention could be shown, whilst metacognitive monitoring interventions may appear while working on a task. Thus the positioning of metacognitive scaffolds is connected to the registered changes in the learners’ attentional focus. This allows for dynamic support of the students’ metacognitive activities.

It is more difficult to effectively position cognitive interventions in relation to the information about attentional focus the system currently retrieves. Input to the AgentSchool system currently only provides information allowing limited inferences about the cognitive activities of the student. The system knows which activity the student is working on but has no information about the students’ knowledge-building process. This
means that AtgentSchool can position the adequate cognitive support in relation to the current task and the progress of the student, but it is unable to align the cognitive interventions with the students’ knowledge acquisition. The question mark icon in the interface is currently the most important indicator that the students need additional support. Thus AtgentSchool can provide cognitive interventions to support the cognitive activities, but cannot adjust the support given to the students’ knowledge. Also the trigger of cognitive support is dependent on the students’ ability to monitor their own cognitive activities. This means that the positioning of cognitive interventions based on the current registration of attentional focus in AtgentSchool is limited.

Motivational interventions are similarly difficult to position in relation to current information about the students’ attentional focus. The input in AtgentSchool provides no information about the students’ motivational state other than the information students provide voluntarily via the icons in the interface. Based on this input we can support students on the motivational level, but the trigger of this support is largely dependent on the students’ ability to monitor their own motivational states. For the motivational interventions as well, we can conclude that the current registration of the attentional focus in AtgentSchool only supports motivational scaffolding to a limited degree.

So far, we have addressed the question: how can an attention management enable personalized support, or dynamic scaffolding, of self-regulated learning? We have discussed how the AtgentSchool system uses the information from the students’ environment to interpret the students’ attentional focus. Based on this attentional focus, scaffolds that can support self-regulated learning are selected using the diagnosis, calibration and fading. Thus in AtgentSchool, the attention management system allows for dynamic scaffolding to support the learners. We predict that the AtgentSchool system in its current form is particularly capable of scaffolding the metacognitive activities of the students, whereas it will only be effective at scaffolding cognitive activities and motivation when students are capable of indicating their need for help themselves.

In practice: test-runs

The sections above explained how our attention aware system is enabling dynamic scaffolding. In order to test the stability and functioning of AtgentSchool before the study in the Czech Republic, pre-tests were done in six schools in the Netherlands. The main purpose of these tests was to ensure the proper functioning of the system with real users and a representative user load, as well as collecting preliminary results on how learners perceived working with the system. The test runs were one hour sessions in which students were asked to work on the project ‘Where do you want to live?’ in which they researched another country based on information provided by an expert who lives in that country. Students worked on the project for 45 minutes performing the following learning activities: 1. introducing themselves to the expert, 2. setting a learning goal, 3. filling in a concept map, 4. reading a diary of the expert and 5. asking a question. This was a shorter version of the project later used in the studies. Six test runs were performed with 108 students aged
between 9 and 12. Students received a 5 to 10 minute introduction to the task as testers of AtgentSchool and to the project ‘where do you want to live?’ During the sessions they were asked to use the smileys in the screen (happy, neutral, sad) to indicate how they felt about the agent. After their session they filled out a questionnaire about their perception of the agent and a short interview was conducted to further assess their perception of different scaffolds. In three test runs students were also shown interventions on a digital school board and they were asked to rate the interventions and to write down any comment they had.

**Results**

We analyzed the logs of the sessions to confirm that all scaffolds were selected according to the conceptual framework. A few interventions were studied in more detail and some debugging was done in relation to these findings. The children were asked to indicate how they felt about the scaffolds with the smiley buttons. Unfortunately, these were used very infrequent, because students were not able to attend a new task, read the scaffolds, act accordingly, and also indicate how they felt with the smiles. Based on these findings, the feedback acquisition was redefined and we developed a session with children judging the scaffolds on the smart board in a classroom session after the test run session. The students were asked to rate the scaffolds on a five point Likert scale and to write down their comments. The cognitive and metacognitive scaffolds were judged to be very good; the motivation scaffolds were judged neutral (see table 2).

**Table 2 – Judgement of the students of the scaffolds shown.**

<table>
<thead>
<tr>
<th>Scaffolds</th>
<th>Cumulated average judgment of student</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacognitive scaffolds</td>
<td>4.03 = good</td>
</tr>
<tr>
<td>Cognitive scaffolds</td>
<td>3.71 = good</td>
</tr>
<tr>
<td>Motivational scaffolds</td>
<td>2.70 = not good not bad</td>
</tr>
</tbody>
</table>

The analysis of the questionnaires produced very encouraging results. 90.5% of the children wanted to work with the agent David again; 62% wanted to work with an agent more often; 9.5% would have liked to work with a different agent than David. The agent provided good help according to 90% of the children, and the two students that disliked the agent found that more help could have been provided. Students gave David a 7.5 average grade (girls a 8 and boys a 7)

Based on these test runs we ensured the proper functioning of the software for the first study. We improved the motivation interventions trying to address the users’ feedback. We adjusted aspects of the original configuration of the motivational support, instead of trying to respond the users’ motivational input the agent now just mirrors their motivational state. The configuration of the metacognitive and cognitive support was
judged positively by the users and therefore maintained. The agent David, (see figure 2) which had been developed within the Atgentive project, was well liked by the Dutch students.

Discussion

We began this chapter proposing that attention management could be used to personalize education. We have discussed how AtgentSchool enables dynamic scaffolding during learning with an attention management system. The attention management system derives information from the students’ environment. Based on this information, an assessment or diagnosis of the students’ attentional focus is made and then compared to a logical attentional focus based on the learning assignment. This comparison is the basis for the selection of the scaffold, or calibration, which are only sent when the student needs the support. AtgentSchool uses an intervention model directed at supporting self-regulated learning with metacognitive, cognitive and motivational scaffolds. The different scaffolds are shown to the user based on diagnosis, calibration and fading decisions made by the attention management system.

We expect that the current input into our system is rather limited to support the diagnosis of the students’ cognitive and motivational development. However the test-runs indicated that the students were positive about the cognitive scaffolds. Registering more and different information from the students’ environment would allow us to accumulate a better representation of the learners’ attentional focus. This could enhance our ability to position interventions in relation to the students’ cognitive activities and motivation. For example, the effectiveness of cognitive scaffolds could be enhanced using eye tracking, which would allow a better diagnosis of learners’ current cognitive activities and the use of a webcam to assess the students’ emotional state could help to provide more input for the diagnosis of learners’ motivation.

During calibration the students’ attentional focus is used to select a scaffold; for example, selecting a planning scaffold at the moment the learner starts a new task. Again the system could be enhanced with respect to cognitive scaffolding; for instance, if we know more about the learners’ knowledge, we can adjust the cognitive scaffolds to provide more adjusted scaffolds. Finally, adjustments could be made in the presentation of scaffolds to the user. The form and modality of the scaffolds can be modified. In our studies we have used the virtual agent, but one can think of many other possible modalities that give interventions such as text, agents or robots. The effects of these modalities on learning are largely unknown. Additionally, with respect to the virtual agent, we know very little with respect to the usage of his emotions, appearance, animations and their effects on learning outcomes.

In sum, we specified how an attention management could be used to support learning on a personalized level. Artificial intelligence has traditionally struggled with ill-structured domains resulting in few personalized solutions for these fields. Attention management
systems are domain-independent and thus can also be used in ill-structured domains. This means that learning systems augmented with an attention management system could be an interesting path of exploration that would enhance the availability of personalized learning solutions.

Acknowledgements

This research was supported by a grant from the National Scientific Organization of the Netherlands (NWO) 411-04-102 and from the European Commission under the FP6 Framework project Atgentive IST 4-027529-STP. We acknowledge the contribution of all project partners to the development of the AtgentSchool scaffolding system.
Abstract The aim of this study is to test the effects of dynamically scaffolding self-regulated learning of middle school students working in a computer-based learning environment. Students in the scaffolding condition (N=56) are supported with computer-generated scaffolds and students in the control condition (N=54) do not receive scaffolds. The scaffolds are dynamically adjusted to students’ progress with an attention management system. The scaffolds support students’ metacognitive and cognitive activities. We analyzed the effects of dynamic scaffolding on students’ learning and on their perception of the learning environment. We found that scaffolding has a positive effect on the students’ learning performance, but did not affect students’ domain knowledge. The repeated measurement of perceptions of the learning environment showed that students in the experimental condition were more positive about their teachers and their collaborators than students in the control condition. With respect to their perception of the software and the 3D embodied agent delivering the scaffolds, we found a stronger decrease of perception over time in the scaffolding condition compared to the control condition.

Keywords · Self regulated learning · Dynamic scaffolding · Attention Management Systems · Middle school

Chapter 2

Introduction

Self-regulation is important for learning in complex Computer-Based Learning Environments (CBLE’s), such as hypermedia and computer based learning environments (Azevedo & Hadwin, 2005, Bannert & Mengelkamp, 2008). Students have to define their own learning goals and form a strategy to obtain these goals (Kalyuga, Chandler & Sweller, 2001; Kirschner, Sweller & Clark, 2006). In complex computer-based learning environments students are often incapable of adequately regulating their learning (Azevedo, Moos, Johnson & Chauncey 2010; Azevedo & Hadwin, 2005). Scaffolding can support students in tasks they cannot accomplish by themselves by providing assistance when needed (Hmelo-Silver & Azevedo, 2006; Sharma & Hannafin, 2007; Wood, Bruner, & Ross, 1976). Studies found that scaffolding fosters self-regulated learning and consequently improves students’ learning and motivation (Azevedo & Cromley, 2004; Azevedo & Hadwin, 2005; Land & Greene, 2000).

The effectiveness of scaffolding provided by human tutors has recently stimulated the development of computer-based scaffolding systems supporting self-regulated learning such as Metatutor (Azevedo Johnson, Chauncey, 2010) and Atgentive (Molenaar, Van Boxtel, Sleegers & Roda, 2011). These systems are inspired by effective human tutors who determine scaffolding needs through diagnosis of students’ behavior and appropriately reduce scaffolds when students’ competences increase (Chi, Siler, Jeong, Yamauchi & Hausmann, 2001; Wood, Bruner & Ross, 1976). Most computerized scaffolding systems, however, enact scaffolds at predetermined time intervals. Therefore the scaffolds are not adjusted to the students’ progress, which compromises learning (Azevedo, 2004). A solution to this problem is to automatically monitor students’ behavior and consequently adjust scaffolds accordingly. Therefore, we need a system that tracks and traces students’ activities, diagnoses current behavior, and then selects the scaffolds that foster self-regulated learning (Azevedo et al, 2010, Molenaar & Roda, 2008).

In our study, we used an attention management system to attain dynamic scaffolding (Molenaar et al., 2011). The aim of this study is to assess the effects of dynamic scaffolding on middle school students’ learning and their perception of the learning environment. This analysis allows us to identify how the AgtentSchool system we developed supported students’ self-regulated learning. We will start with a short discussion how an attention management system can support dynamic scaffolding. Then we will elaborate on studies assessing the effects of scaffolding on learning and motivation.

Computerized dynamic scaffolding

Scaffolding is defined as providing assistance to a student as-needed, fading the assistance when the competence of the student increases (Wood, Bruner & Ross, 1976). Within the scaffolding paradigm, a distinction can be made between different types of scaffolding, namely static and dynamic scaffolding (Molenaar & Roda, 2008; Puntambekar & Hübscher, 2005). Static scaffolding is constant over time and the same for all students (e.g.
one may provide a list of instructions that helps users to perform a learning activity). Whereas static scaffolds do not adjust to individual students’ progress, dynamic scaffolds do. Dynamic scaffolding analyzes the students’ behavior after which an appropriate scaffold is selected (i.e. one can monitor the progress of the student and provide scaffolds when needed in the learning process).

The latter form of scaffolding use diagnosis, calibration and fading to select the right scaffold for a particular student in a specific situation. As described above human tutors perform dynamic scaffolding analyzing the students’ behavior and knowledge in relation to the demands of the learning task (diagnosis). Based on their diagnosis, they select the right scaffold for the situation (calibrating). Finally, fading is a consequence of a continuous diagnosis and calibration cycle. As diagnosis and calibration continuously happen, the scaffolds are reduced when the students become more experienced (fading). Computer software has to perform the same processes to dynamically scaffold the learner. Yet, computer systems’ awareness and interpretation of students’ behavior in relation to the learning task is still restricted (Molenaar et al., 2011; Woolf, 2009). We used an attention management system to capture students’ attentional focus and used this information to implement dynamic scaffolding (Molenaar & Roda, 2008). Attention management systems can capture users’ attentional focus and determine costs associated with presenting certain information to learners (Molenaar & Roda, 2008). The utility of attentive systems for educational sciences is therefore related to the ability to detect students’ attentional focus and interpret this information. This enables the continuous assessment of students’ attentional focus, its interpretation (diagnosis) and by the selection of the appropriate scaffold (calibration) when needed (fading) (Molenaar et al., 2011).

Scaffolding self-regulated learning

Cognitive and metacognitive activities are key to self-regulating one’s learning in Computer-Based Learning Environments (CBLE’s) such as the Internet, electronic learning environments and games (Azevedo et al., 2010; Azevedo & Hadwin, 2005). Students who orientate, plan, monitor and evaluate learn more and show higher motivation than students who do not engage in these activities (Azevedo & Jacobson, 2008; Azevedo, Moos, Greene, Winters & Cromely, 2008; Bannert & Mengelkamp, 2008). However research has abundantly shown that students insufficiently regulate their learning in CBLE’s. Students struggle with the regulation of their learning; they do not formulate clear learning goals nor control their cognitive activities according to these goals (McCrudden & Schraw, 2007; Winne & Hadwin, 2010). Successful self-regulating learners use cognitive activities (read, process, elaborate) to study the learning domain, control and monitor their learning with metacognitive activities (orientate, plan, monitor and evaluate their actions) and motivate themselves (Azevedo et al., 2010; Zimmerman, 2002). Therefore, in order to support students’ self-regulated learning, scaffolding should focus on supporting cognitive and metacognitive activities (Molenaar & Roda, 2008). Students’ perception of the learning environment interacts with their motivation to apply cognitive and metacognitive
activities (Zimmerman, 2002). Students’ perception about the software and their teacher can determine students’ investments and consequently influence their performance and learning (Howland & Moore, 2002; Martens, Bastiaans & Kirchner, 2007).

**Effects of scaffolding on learning**

As discussed above, scaffolding differs with respect to the types of scaffolds (static vs. dynamic). Moreover the modality (paper based, computerized or human tutors) and the focus of the scaffolds (cognitive and/or metacognitive activities) can vary. Below we discuss the results of different scaffolding studies on students’ learning. We emphasize the type, modality and focus of scaffolding.

First, we report on static scaffolding studies. Veenman, Kok & Blote (2005) analyzed the effects of a paper list of 6 metacognitive questions on the performance on math’s problems in a study of 12 year old children. Initially the students performed the learning task without the scaffolds and later with the scaffolds. Learning performance was measured by the number of correct answers and the grade for math. Students performed significantly better on problems supported with scaffolds compared to problems not supported with scaffolds. Bannert, Hildebrand & Mengelkamp (2009) assessed the effect of paper-based metacognitive scaffolds on learning outcomes of college students studying ‘psychological theories of using pictures in a multimedia environment’ in a hypermedia learning assignment. The learning outcomes were measured with a recall test, a domain knowledge test and a transfer task. The authors found no effects on the recall and knowledge test; they did found that the students in the experimental condition outperformed the students in the control condition with regard to the transfer task.

Bannert’s (2006) research evaluates static computerized scaffolds directed at cognitive and metacognitive activities. The author investigated the effect on the learning outcomes of college students studying “conditioning” in a hypermedia environment. Students were asked at every node change in a hypermedia environment to specify why they choose this node. The learning outcomes were assessed by a recall test, a domain knowledge test and a transfer task. Scaffolding only affected the outcomes on the transfer task; students in the scaffolding condition outperformed the students in the control condition. There were no differences between the two conditions with respect to recall and domain knowledge. Lin and Lehman (1999) looked at the effect of static computer scaffolds supporting problem solving on the near and far transfer performance on biology tasks. They found increased far transfer on contextually different problems when students were supported with the scaffolds. However, no effects of scaffolding were found on near transfer problems.

There are few studies with computerized dynamic scaffolding of self regulated learning. Metatutor is a computerized scaffolding system for self-regulated learning which has recently been developed to support students learning of the circulatory system (Azevedo et al., 2010). The first studies show that Metatutor successfully fosters student’s
self-regulated learning and facilitates learning of complex science topics (Azevedo et al., 2010). Azevedo and colleagues performed several studies (Azevedo et al, 2008) assessing students learning in a hyper media environment. The scaffolding was dynamic and delivered by a human tutor. They assessed learning outcomes by determining shifts in mental models and acquired domain knowledge (matching task, labeling task, flow diagram task). Students receiving scaffolds developed better mental models and acquired significantly more domain knowledge on the labeling task and the flow diagram task.

In summary, static scaffolding appears to increase problem solving and transfer of domain knowledge. However, no effects were found on the students’ domain knowledge. Dynamic scaffolding by a human tutor and computer-based systems, on the other hand, did affect domain and transfer of domain knowledge.

Our study

The aim of our study is to explore the effects of dynamic scaffolding with an attention management system on students’ learning and their perception of the learning environment. Research has shown effects of static scaffolding on problem solving and transfer of domain knowledge and dynamic scaffolding also improved student’s domain knowledge. However, to our knowledge no studies have been conducted so far into the effects of computerized dynamic scaffolds supporting students in middle school. The aim of our study is to evaluate these effects. Research indicates that students’ perception about the learning environment drives their motivation and consequently their investment in cognitive and metacognitive activities. Therefore we also assesses students’ perception and how this fluctuates during learning. The following research questions are addressed:

1. What are the effects of dynamic scaffolding of self-regulated learning on students’ learning?
2. What are the effects of dynamic scaffolding of self-regulated learning on students’ perceptions about the learning environment and does this fluctuate over the learning sequence?

In an experimental design a scaffolding condition is compared with a control condition. The students in the scaffolding condition are supported with cognitive and metacognitive scaffolds. These scaffolds are dynamically adjusted to the progress of the students. The control condition does not receive any scaffolds of their cognitive or metacognitive activities. Based on earlier scaffolding research the hypothesis is that the system will positively affect learning and perception of the students.

Method

110 students from 4 schools divided over 5 classes in the Czech Republic participated in this study. The students were in 5th grade and on average 11 years old, with ages ranging from 10.5 to 11.4. The teachers grouped students in 55 dyads within their classes based on
the principle of heterogeneity, balancing gender, school performance, and reading and computer abilities. The pairs in all classes were randomly assigned to one of two conditions. The control condition was formed by 27 dyads who received no scaffolds. The experimental group was formed by 28 dyads that were supported by scaffolds. The conditions were equally divided over the different classes. The dyads in the experimental group received scaffolds supporting their metacognitive and cognitive activities as will be described below in the section about the scaffolding system. The scaffolds were provided by a virtual agent (see figure 3). The dyads in the control condition did see the virtual agent but did not receive any form of support from the agent.

The total duration of the experiment was 6 lessons of 45 minutes each. During the lessons, pairs of students worked on an assignment called ‘Would you like to live abroad?’ The goal of the assignment was to learn about New Zealand, write a paper on the findings and decide if they would like to live in this country. The pairs worked on one computer with an electronic learning environment (Ontdeknet) through which students had access to an inhabitant of the country, their expert. Students could consult the expert by asking questions and by reading the information section about the country written by the expert. The final assignment, write a paper about New Zealand, was preceded by three preparation assignments: a self-introduction of the two students, the writing of a goal statement, and the design of a concept map specifying the topics of interest. All assignments were integrated in the working space of the pair where they also wrote their paper. In the first lesson the students were given instructions about the task. All students received the same instructions and spent the same time working on the assignment (4 hours). In the final lesson, students finished the assignment and the domain knowledge of individual students was measured.

**Treatment: The scaffolding system**

The e-learning environment used in this study is called Ontdeknet. It focuses on supporting students in their virtual collaboration with experts (Molenaar, 2003). The experts provide students with information about their subject of expertise, knowledge about their country for this study. The experts’ contributions are edited by the (human) editor of Ontdeknet. The teacher gives the assignment and monitors students’ progress. Collaborative learning is implemented at two levels: students collaborating with an expert in a virtual environment and with each other face-to-face in small groups in front of a computer.

For the purpose of the experiment, the Ontdeknet system was augmented with dynamic scaffolding. We refer to this new system as AtgentSchool (Molenaar & Roda, 2008). AtgentSchool includes an attention management system capable of determining when to send which scaffold to the learners. Attention management systems capture the attention focus of the students (Molenaar et al., 2011). The attentional focus was monitored at three levels: the input level, the reasoning level and the intervention level. The input level collected information about the students’ attention from the students’ environment.
Input information was derived from the keyboard strokes, mouse movements and event information about the students’ activities in the e-learning environment. The reasoning level determined what was in the focus of the students’ attention using the event information and the active task of the student. Based on this diagnosis of the students’ attention, a scaffold was selected that could be useful for the student. Finally, the intervention level determined how the scaffold should be communicated to the learner. AtgentSchool used a three-dimensional virtual agent powered by Living Actor© technology for the delivery of scaffolds (Morel & Ach, 2011). The scaffolds were shown in text balloons and could be heard as spoken messages through the computer’s audio output (see figure 3). The messages were accompanied by the agent’s animations (e.g. movements of the agent’s hands) and emotions (e.g. smile on the face of the agent). The reasoning system was validated in extensive studies ensuring the functioning of this component with a wizard of OZ design and test runs of the systems within schools (Molenaar & Roda, 2008).

Students’ pairs in the scaffolding condition received scaffolds supporting their cognitive and metacognitive learning activities during the first three lessons. The cognitive scaffolds were triggered when students indicated they needed help by clicking on the smiley in the screen or when the system monitored an idle user (prolonged absence of keyboard strokes or mouse movements). We implemented two types of cognitive scaffolds, cognitive support and cognitive resources. Cognitive support helped the learner with the current learning activity, whereas cognitive resource interventions provided students with links to resources in the learning environment that could help them perform the task. For example a cognitive support scaffold for the assignment ‘make a concept map’ would be: ‘What do you already know about the subject you are going to study? ’; and a cognitive resource scaffold for the same task would be: ‘Need some ideas? You can read the introduction diary of the expert’.

The metacognitive scaffolds were delivered at times when metacognitive activities are generally executed in the learning process based on Zimmerman’s model (2002) for self-regulated learning. As mentioned above, the scaffolding system determined the appropriate instance to be sent on the basis of the students’ attention focus. Scaffolds were triggered by the system on the basis of the following changes in the attention focus of the students:

Orientation activities should be performed just before selecting a task; thus students who were recognized as moving their attention to a sub-task received a scaffold to orientate on the sub-task. For example an introduction scaffold for the task of setting a learning goal would be: “You can write a goal statement to explain to the expert why you choice his country and indicate what you hope to learn”. Planning should be performed just before starting a task; therefore planning scaffolds were implemented just before execution of the sub-task. For example a planning scaffold for a learning goal task would be: “A learning goal is what you want to learn. For instance, we would like to learn more about
New Zealand to decide if we would like to live there”. Finally, monitoring should be performed during and after execution of the task therefore, upon saving, the sub-task dyads were shown a scaffold prompting them to monitor (Molenaar & Roda, 2008). For examples a monitoring scaffold for the learning goal task would be: “I will send your learning goal to your expert to explain to him what you want to learn”.

For each sub-task and the main task three types of metacognitive scaffolds were implemented: orientation, planning and monitoring scaffolds. Students in the scaffolding conditions received a minimum of 12 metacognitive scaffolds.

![Figure 3. Example of the embodied agent in the learning environment providing a scaffold to the learner.](image)

**Measurements**

**Learning**

We measured student learning at two different levels: the dyads’ performance and individual student’s knowledge. The dyads’ performance was measured by evaluating their paper “Would you like to live in New Zealand?” The number of questions posed to the expert was also monitored as an indicator of the dyads’ performance. Papers were graded by two researchers who were asked to reach mutual agreement about the number of topics covered by the paper and the percentage text formulated by the students. The paper score was 1 if there were less than 4 topics covered or if the students scored low on self-formulated text. The score was 2 if students discussed between 4 and 8 topics and used a reasonable amount of self-formulated text. The maximum score of 3 points was received when students discussed more than 8 topics in mostly self-formulated texts.
Student’s domain knowledge was measured individually by a curriculum-based knowledge test with 15 true/false items related to New Zealand. Students received 1 point for each correct answer and 0 points for incorrect answers. Cronbach’s alpha, which is an indicator of the reliability of the test (Field, 2005), was 0.76 for knowledge test. The same test was used as pre-test and as post-test with 6 weeks in between the two measurements.

Perception questionnaire
The students’ perception about different aspects of the AgentSchool environment was measured with a questionnaire. The questionnaire was administered twice, once in the middle of the learning sequence (week 3) and once after the students were finished (week 7). The questionnaire was divided in 4 scales; the perception of the agent; the perception of the software; the perception of the teacher and of the collaboration with their peer. The perception of the agent dealt with questions about the 3D agent that provided the scaffolds to the students. This scale consisted of 6 items with a Cronbach’s alfa of 0.72. The perception of the software measured the students’ ideas about the software and consisted of 8 items with a Cronbach’s alfa of 0.67. The perception of the teacher included three questions about the role of the teacher during the experiment and had a Cronbach’s alfa of 0.63. The students’ perception of the collaboration was measured asking questions about the usefulness of collaborating with a peer on this task. This scale also consisted of three items with a Cronbach’s alfa of 0.83. The answer options were 1 through 5 with 5 indicating very good and 1 indicating very bad. See appendix 2A for an overview of the questions. The dyads filled in one questionnaire together, they were asked to come to an agreement about the answers.

Analysis
The data of the group performance measurements and application test data were not normally distributed, thus a Mann-Whitney test was used to analyze the effects on the dyads performance. The domain knowledge test was normally distributed thus a Mixed ANOVA with the scores on pre- and the post test was used as the within subject factor and the conditions (control, scaffolding) as between-subject factor.

The data of the perception questionnaire were normally distributed thus a Mixed ANOVA with the scores on 1st and the 2nd measurements of each scale was used as the within subject factor and the conditions (control, scaffolding) as between-subject factor. Four separate analyses were conducted one for each scale: the agent (Honza), the software, the teacher, and the collaboration. It is important to note that the first measurement was not a pre-test, but was taken in the middle of the learning assignment. The second measurement taken after the learning assignment was finished. The effect sizes are
calculated using the effect size estimate $r$, following Rosenthal (1991) defining 0.1 as a small effect, 0.3 as a medium effect and 0.5 as a large effect.\footnote{We use the effect size $r$ for both the parametric and non-parametric test following Rosenthal (1991) as described in (Field, 2005). The $r$ for non-parametric data is calculated on the basis of the data from the Mann-Whitney test, namely $r = \frac{z}{\sqrt{N}}$. For $r$ for the parametric data is calculated on the basis of the data from the repeated Anova $r = \frac{\sqrt{F(1,dfR)}}{F(1,dfR)+dfR}$}

**Results**

*Dyads’ performance and learning*

We assessed the effect of dynamic scaffolding on the learning performance of the dyads by comparing the control condition with the experimental group. The experimental group ($\text{Mdn}= 2$) significantly outperformed the control condition ($\text{Mdn}=1$) on the quality of their paper, $U = 268.5$, $p < .05$, $r = 0.26$. An effect size of $r = 0.26$, indicates a medium positive effect of scaffolding on group performance on the paper. Also, with respect to the number of questions asked there was a significant effect of scaffolding. The experimental group ($\text{Mdn}= 1$) significantly outperformed the control condition ($\text{Mdn}=0$), $U= 290.5$, $p < .05$, $r = 0.21$. An effect size of $r= 0.21$ shows a small to medium positive effect of scaffolding on the number of questions asked. These findings with respect to group performance confirm our prediction that attention based dynamic scaffolding did significantly affect group performance.

For the analysis of the development of domain knowledge we compared the pre- and post-test scores of students in different conditions. The main effect of time (post vs. pre-test) on domain knowledge was significant, $F(1,55)=137.5$, $p<.001$, $r= 0.85$, the main effect of condition (control vs. experimental) is not significant in this case (not significant $p>.05$) and the interaction between time and condition was not significant, $p>.05$. Thus with regard to domain knowledge, the findings do not confirm our expectations: attention based dynamic scaffolding did not significantly affect domain knowledge. There was a large significant effect for all students between the pre-($m=6.61$) and post -test ($m=10.57$), indicating that all students gained more domain knowledge.

*Perception questionnaire*

We will discuss the effects of time and conditions on the four scales of the perception questionnaire, namely the agent, the software, the teacher and the collaboration. The main effect of time on perception of the agent was significant, $F(1,38)=53.65$, $p<.001$, $r= 0.76$, the main effect of condition was not significant $p>.05$ and the interaction between time and condition was significant, $F(1,38)= 6.38$, $p<.05$, $r=0.38$. In the middle of the learning sequence all students were more positive about the agent compared to the end of the learning sequence. There was no significant difference in perception between students from the experimental group and the control group, but students in the experimental condition did shift their opinion more over time than the students in the control group (see
Overall, all students reported a good perception of the agent, but over time this reduced to a neutral attitude.

**Figure 4.** Perception agent at time 1 and time 2 of the control group and the experimental group

The main effect of time on the scale software was significant, $F(1,38)=7.75, p<.001, r=0.41$, the main effect of condition was not significant $p>.05$ and the interaction between time and condition was significant, $F(1,38)=10.54, p<.01, r=0.47$. Students in both conditions were more positive about the software in the middle of the learning sequence than at the end, but again students in the experimental condition changed their perception about the software more drastically over time than students in the control condition (see figure 5). Students reported a positive to neutral perception of the software and students in the control group remained stable whereas students in the experimental condition dropped their perception to a neutral level.

With respect to the perception of the teacher the main effect of time was not significant, $p>.05$ the main effect of condition was significant $F(1,38)= 12.87, p<.001,$
r=0.50, and the interaction between time and condition was not significant, p>.05 . Thus students in the experimental condition are significantly more positive about their teacher, than the students in the control condition both in the middle as at the end of the learning sequence. Students in the experimental condition were positive about their teachers (m=4.05), whereas students in the control group were more neutral (m=3.30). Finally, the main effect of time on the perception of their collaboration was not significant, p>.05 the main effect of condition was significant, F(1,38)=4.60, p<.05, r=0.33, and the interaction between time and condition was not significant p<.05. The students in the experimental condition (m=4.05) are more positive about their collaboration than students in the control condition (m=3.56) both in the middle as at the end of the learning sequence.

Conclusion and discussion

This study contributes to the existing body of knowledge on scaffolding self-regulated learning by showing the effect of dynamic scaffolding supported by an attention management system on several aspects of the learning processes. Dyads in the scaffolding condition received context specific scaffolds to support their cognitive and metacognitive activities. Dynamic scaffolding, as implemented by AtgentSchool, had a positive effect on dyads’ performance leading to a higher quality of their paper and more questions asked. However, students receiving scaffolds did not gain more domain knowledge. Thus even though students wrote better papers and asked more questions, this did not lead to more domain knowledge. However, the better quality of the papers could be explained by better structuring of their knowledge, a better understanding of the task and what is relevant to compare two countries. The focus of the assignment was on writing the paper comparing the Czech republic with New Zealand and acquiring new information by asking questions. All students had gained significantly more domain knowledge after the learning sequence, indicating that they all learned.

Next we discussed the results of students’ perception during and after the learning assignment. Students in the experimental group reported more positive perceptions of their teacher and were more positive about the collaboration both during and at the end of the learning sequence. However, with respect the perception of the software and of the agent, the scores of students in the control and experimental group did not differ significantly. Yet the students in the experimental group did shift their perception more over time. This requires an explanation as we expected the experimental group to have a more positive perception of the software and the agent compared to the control group. The students give more positive evaluations of the environment at the beginning, probably because they are surprised by its reactivity. However as time passes students become used to it, they probably don’t “see” the system anymore but they concentrate on the learning task. Another explanation for the larger shifts in perception of students in the experimental condition might be that during the first lessons students received mainy metacognitive scaffolds. These scaffolds were faded during the latter lessons. The metacognitive scaffolds were automatically provided by the system based on the cyclical model of
Zimmerman (2002). Cognitive scaffolds could also be sent later in the learning sequence, but must be initiated by help-questions of learners. Thus for the selection of these scaffolds the system was largely dependent on students’ own ability to indicate that they need help. The fact that students received less scaffolds with time could also explain students’ shift in perception.

The students receiving scaffolds had a more positive perception of their teachers. As students were divided equally over the conditions within a class, this effect is not dependent on specific teachers. Also students in the experimental group felt better about their collaboration. We can image two possible explanations. First, students value their teachers and peers more after working with the agent because, compared to the agent, teachers and peers are better collaborative partners. Second, students that received scaffolds were able to formulate better questions for their teachers and peers and therefore had a more satisfactory interaction. In this case the interaction among the students was enhanced by the scaffolding.

Overall, the findings indicate that dynamic scaffolding of self-regulated learning can be given form with an attention management system. Dynamic scaffolding increases dyads’ performance on the learning task. However, the perception questionnaires indicate that the system is perceived more useful at the beginning than at the end as shown by the larger shift in perception of the software and the agent of the experimental group compared to the control group. Naturally, these findings need to be validated in different settings with different students and assignments, but these first results do indicate that dynamic computerized scaffolding with attention management could be a promising method towards dynamic computerized scaffolding.

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Appendix 2A.

*Table 2A. Perception questionnaire items*

<table>
<thead>
<tr>
<th>Question</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Honza helped us a lot</td>
<td>Perception of the agent</td>
</tr>
<tr>
<td>2. Software does what we want it to do</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>3. Software does nothing we want it to do</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>4. Honza looks great</td>
<td>Perception of the agent</td>
</tr>
<tr>
<td>5. Honza is really friendly</td>
<td>Perception of the agent</td>
</tr>
<tr>
<td>6. Honza is very helpful</td>
<td>Perception of the agent</td>
</tr>
<tr>
<td>7. Honza is very annoying</td>
<td>Perception of the agent</td>
</tr>
<tr>
<td>8. I think Honza likes us a lot</td>
<td>Perception of the agent</td>
</tr>
<tr>
<td>9. The software reacts immediately on our actions</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>10. We understand what software tells us</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>11. We like the look of the software</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>12. We know what we are doing with the software</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>13. We feel in control of the software</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>14. Screen instructions were helpful</td>
<td>Perception of the software</td>
</tr>
<tr>
<td>15. We understood our teacher’s instructions</td>
<td>Perception of the teacher</td>
</tr>
<tr>
<td>16. It is good to ask our teacher a question</td>
<td>Perception of the teacher</td>
</tr>
<tr>
<td>17. Our teacher knew all about the software</td>
<td>Perception of the teacher</td>
</tr>
<tr>
<td>18. We really enjoyed the lessons</td>
<td>Motivation</td>
</tr>
<tr>
<td>19. We divided the work equally</td>
<td>Perception of the collaboration</td>
</tr>
<tr>
<td>20. We shared typing equally</td>
<td>Perception of the collaboration</td>
</tr>
<tr>
<td>21. We shared deciding equally</td>
<td>Perception of the collaboration</td>
</tr>
</tbody>
</table>
Part II. The Effects of Metacognitive Scaffolding and Different Forms of Scaffolds
Abstract This study examined the effects of metacognitive scaffolds on learning outcomes of collaborating students in an innovative learning arrangement. The triads were supported by computerized scaffolds, which were dynamically integrated into the learning process and took a structuring or problematizing form. In an experimental design the two experimental groups receiving scaffolds were compared with a control group (n=48). The experimental groups differed in the form of scaffolding used: structuring scaffolds (n=51) vs. problematizing (n=57) scaffolds. We analyzed the effects of metacognitive scaffolding and of different forms of scaffolds on the learning outcomes at group and individual level. The results showed a no effect of scaffolding on group performance, nor on the acquired individual domain knowledge and a small significant effect on acquired individual metacognitive knowledge. With respect to the effects of different forms of scaffolds, we found a small significant effect on group performance, on transfer of individual domain knowledge and on the individual metacognitive knowledge acquired. Problematizing scaffolds gained better learning results then structuring scaffolds.

Keywords Metacognition · Scaffolding · Innovative Learning Arrangements · Virtual Agents · Elementary Education.

Introduction

Many students have difficulties learning successfully in innovative learning arrangements, which in turn have an impact on their performance and achievement (Azevedo & Cromley, 2004; Azevedo & Hadwin, 2005; Bannert & Mengelkamp, 2008; Hannafin & Land, 1997; Land & Greene, 2000). Innovative learning arrangements, such as hypermedia and electronic learning environments, are characterized by constructive learning assignments in a situated environment in which students often work collaboratively in small groups supported by technological tools (Simons, van der Linden & Duffy, 2000). In these learning arrangements students are given the responsibility to specify the topics to be learned and to decide upon the learning strategies to be followed (Kalyuga, Chandler, & Sweller, 2001; Kirschner, Sweller, & Clark, 2006). As a consequence, these environments draw heavily on students’ metacognitive skillfulness to regulate their learning. Research, however, has shown that students lack the metacognitive skillfulness to perform the required regulation and that metacognitive scaffolds can support the regulation of their learning (Veenman, Kok, & Blote, 2005). Findings of studies into the effects of metacognitive scaffolding have shown that scaffolding can improve the learning outcomes of individual learners in innovative learning arrangements (Azevedo & Hadwin, 2005; Azevedo, Moos, Greene, Winters, & Cromley, 2008; Bannert, 2006; Bannert, Hildebrand, & Mengelkamp, 2009; Lin & Lehman, 1999; Veenman et al., 2005).

In innovative learning arrangements, students often work collaboratively in small groups. Small groups have similar problems to those experienced by individual students regulating their learning in innovative learning arrangements (Hadwin & Oshige, 2007; liskala, Vauras, & Lehtinen, 2004; O’Donnell, 2006). As a consequence, metacognitive scaffolds directed at the group members to regulate their collective learning activities might improve the performance and achievement of small groups. Although scholars have stressed the need for research that focuses on the effect of metacognitive scaffolding on the learning outcomes of both the group and individual learners in innovative learning arrangements, systematic research is lacking. This paper extends recent literature by emphasizing the potential of metacognitive scaffolding for students’ performance and achievement and makes a unique contribution by exploring the effects of metacognitive scaffolding on learning outcomes in a collaborative setting. Additionally we investigated the effects of different forms of scaffolding. We present the results of an experimental study into the effects of metacognitive scaffolds in an innovative learning environment on the learning outcomes of 156 students who were randomly assigned to 52 triads in three different experimental conditions.

Our inquiry examined the following general question: What is the effect of metacognitive scaffolding and different forms of scaffolds on learning outcomes of collaborating students in an innovative learning arrangement? We provide a brief overview of the literature on scaffolding in innovative learning arrangements and summarize previous research into the effects of metacognitive scaffolding on the learning outcomes of
individual students. Then we outline the socio-cognitive perspective which provides the conceptual framework of our study to explain the effect of scaffolding on students in a group setting. Next we pose the hypotheses around the effects of metacognitive scaffolding on the learning outcomes, i.e. the quality of the triads’ product and the individual knowledge acquisition.

Scaffolding in innovative learning arrangements

Scaffolding is defined as providing assistance to a student on an as-needed basis, fading the assistance as the competence of the student increases (Wood, Bruner, & Ross, 1976). To determine the effect of scaffolding in an innovative learning arrangement on learning outcomes, different characteristics, which are best explained as the why, what and how of scaffolding, can be distinguished (Azevedo & Hadwin, 2005; Luckin & Boulay, 2002; Pea, 1993). The why of scaffolding refers to the rationale for applying scaffolding in an innovative learning environment; most students are unable to perform a learning assignment or achieve the desired level of learning without getting support from scaffolds. As mentioned above, research findings have shown that in innovative learning arrangements students have problems regulating their learning due to a lack of metacognitive skillfulness (Veenman et al., 2005). In our study, we used an innovative learning arrangement in which students worked collaboratively in a small group (triad) on a learning task. The scaffolding was used in our study to increase the regulation of learning and hence improve performance and achievement.

The what of scaffolding refers to the kind of learning activities scaffolds is mediating to sustain the desired learning outcomes. Scaffolding can be directed at the object or the meta level of learning (Nelson, 1996). The object level deals with cognitive activities, which are directed at the acquisition of knowledge and/or skills. The meta level regulates the object level through monitoring and controlling the cognitive activities. Metacognition is defined as knowledge about and regulation of one’s own cognitive activities (Flavell, 1979) and can be divided into metacognitive knowledge and metacognitive skillfulness (Veenman, Van Hout-Wolters, & Afflerbach, 2006). Metacognitive knowledge is the individual’s declarative knowledge about the interactions between person, task and strategy characteristics (Flavell, 1979), whereas metacognitive skillfulness refers to the individual’s abilities to apply metacognitive activities to regulate his or her own problem-solving and learning activities (Veenman, 2005). Metacognitive activities are categorized into preparatory activities, orientation and planning, executive activities, monitoring and evaluation, and closing activities such as reflection (Veenman et al., 2006; Zimmerman, 2002). In innovative learning arrangements students need scaffolds to support their metacognitive activities to improve the regulation of their cognitive activities, which in turn improves their achievement. In our study, scaffolding was directed at supporting the metacognitive activities of triads.

The next characteristic of scaffolding is the how of scaffolding, which refers to the nature and design of the scaffolds delivered. Several aspects, such as the modality of
delivery, integration into the learning process and the form of the scaffold message, are relevant to determine the effects of scaffolding in an innovative learning arrangement. First, the scaffolds can be delivered to the learner by a human tutor or a virtual agent, on paper or through tools in a computer environment. In innovative learning arrangements scaffolds are often delivered by computers. In our study, scaffolds were delivered by a three-dimensional virtual agent embedded in the electronic learning environment. Second, in computerized scaffolding it is important to determine the way scaffolds are integrated into the learning process; scaffolding can be static or dynamic (Molenaar & Roda, 2008; Puntambekar & Hubscher, 2005). Static scaffolding is defined once; it is constant over time and the same for all students (e.g. a list of instructions that helps users to perform a learning activity). Dynamic scaffolding entails pedagogical agents who diagnose, calibrate, and provide support tailored to the performance on the learning assignment (e.g. monitoring the learning progress of a student and providing scaffolds when needed in the learning process). In innovative learning arrangements, both static and dynamic scaffolding can be used. The scaffolding used in this study is dynamically integrated into the learning process.

A third aspect with regard to the how of scaffolding refers to the form of the scaffold message, often referred to as using a structuring or problematizing mechanism (Reiser, 2004). Structuring simplifies the learning assignment by reducing its complexity, clarifying the underlying components and supporting planning and performance (i.e. providing the students with an example of a plan for the assignment). Problematizing increases the complexity of the learning assignment by emphasizing certain aspects of the assignment and asking learners to clarify the underlying components and perform actions to plan and to construct their own strategies (i.e. asking students to make their own plan for the assignment). The different forms of scaffolds mediate behavior differently; structuring scaffolds tend to support learning activities by providing directive guidelines that perform part of the regulation for the students, whereas problematizing scaffolds are explicitly directed at eliciting their own metacognitive activities through initiating messages or questions. Both forms of scaffolds can be used in innovative learning arrangements. In our study both forms were used in different experimental settings (conditions) to enable the differential effects of the two scaffold forms to be examined.

Research into the effects of metacognitive scaffolds has only occasionally been used to support metacognitive activities of individuals in innovative learning arrangements (Azevedo & Hadwin, 2005; Azevedo et al., 2008; Bannert, 2006; Bannert et al., 2009; Lin & Lehman, 1999; Veenman et al., 2005). The main results from these studies are that scaffolding can increase problem-solving (Veenman et al., 2005), domain knowledge (Azevedo et al., 2008) and transfer of domain knowledge (Bannert, 2006; Bannert et al., 2009; Lin & Lehman, 1999). Scaffolding has consistently been found to support problem-solving. With respect to the domain knowledge acquired, the results have been inconsistent; Bannert (2006 and 2009) did not find an effect on the amount of domain knowledge acquired, whereas Azevedo et al. (2008) did find an effect on domain
knowledge measurements. All studies found an improved transfer of domain knowledge in near transfer tasks (Bannert, 2006; Bannert et al., 2009; Lin & Lehman, 1999). None of the studies measured metacognitive knowledge as a result of the scaffolding. This emphasizes the perspective in scaffolding studies that the function of metacognitive scaffolds is to improve learning outcomes; it is not seen as a method of developing metacognitive knowledge or to train metacognitive skillfulness.

**Scaffolding in a social system**

In an innovative learning arrangement students often work together in small groups supported by technical tools. Scholars assume that small groups have similar problems as individual students in regulating their learning and therefore that scaffolding could improve the regulation and learning outcomes of small groups in innovative learning arrangements (O'Donnell, 2006). As discussed earlier, research has focused on how metacognitive scaffolds affect individual students resulting in better learning outcomes, rather than on how scaffolds influence joint activity leading to enhanced learning outcomes both at the group and individual level. In this study, we aimed to determine the effects of metacognitive scaffolding on the learning outcomes in a collaborative setting.

In order to understand the effects of metacognitive scaffolding on collaborative regulation, we draw on the socio-cognitive perspective of learning (Hadwin & Oshige, 2007; Iiskala et al., 2004; Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen, 2003; Volet, Vauras, & Salonen, 2009). This perspective focuses on how peers play a mediating role in the learning of others through reciprocal activity on the interpersonal plane and emphasizes individual and group learning as the outcome of collaborative learning. Collaborative regulation refers to the metacognitive activities that are shared among the group members regulating their collective cognitive activity (Hadwin & Oshige, 2007). Members of the group are conceptualized as multiple regulating agents who co-regulate each other’s learning and operate as a social system, consisting of two interrelated levels (individual and social) (Volet et al., 2009). From a socio-cognitive perspective, socially shared metacognition is considered as a process taking place on the interpersonal problem plane between two or more individuals affecting more than one individual (Iiskala, et al., 2004). Furthermore, the socio-cognitive perspective emphasizes group and individual learning as the outcome of the collaborative learning process.

In our study the social system consisted of three students (triads) who interacted face to face with each other and with a virtual agent delivering the scaffolds in an e-learning environment. The students and the technological tools influenced each other in a spiral-like fashion; students contributed knowledge and skills to the social system, which altered the state of the interpersonal plane and elicited new activities from the group members and the technological tools. The activities offered the opportunity to practice knowledge and skills at the individual level, which subsequently altered future participation of the students on the interpersonal plane of the small group (triad). Thus the individual students appropriated knowledge provided by the social system and contributed through their participation to the
development of the social system and vice versa (Salomon, 1993; Volet et al., 2009). Accordingly, we distinguished two parallel outcomes of activities on the interpersonal plane: the product of the social system and the individual cognitive residues, which are the effects of the interpersonal plane’s activities on the development of individual’s skills and knowledge. In our study the product of students’ joint activity was the group product and the individual cognitive residues were individuals’ knowledge acquisition.

As mentioned earlier, the scaffolding in our study was used to increase co-regulation of the collective cognitive activity of students working collaboratively in an innovative learning arrangement, which in turn was expected to improve their performance and achievement (the why of scaffolding). The scaffolds in our study were directed at supporting the metacognitive activities on the interpersonal plane to enhance regulation of the collective cognitive activity of the triads (the what of scaffolding). Furthermore, we used computerized scaffolding which was dynamically integrated into the interactive system (the how of scaffolding). The modality of scaffolding in this study was a three-dimensional virtual agent embedded in the e-learning environment. Dynamic scaffolding can influence a social system in two ways, by directly regulating the interpersonal plane or by eliciting individual’s metacognitive activities to contribute to the interpersonal plane. With respect to the form of scaffolds, we used both structuring and problematizing scaffolds in our innovative learning arrangement. The form of scaffolds determines the “route” taken; structuring scaffolds take the direct route, whereas problematizing scaffolds take the indirect route. Structuring scaffolds regulate the interpersonal plane directly by providing a regulative contribution. In our study the agent showed the students an exemplary plan of an assignment to make a mind map. This scaffold provided a planning activity to make the mind map and could be directly applied. Subsequently, the exemplary plan supported the students as they made additional planning contributions themselves. Problematizing scaffolds, on the other hand, trigger metacognitive activities of individuals to regulate the interpersonal plane. For instance, in our study the agent asked the question “how can you plan a mind map assignment?” The scaffold provided no regulation; it only elicited planning activities from the students to plan collectively. The metacognitive activities generated by the problematizing scaffolds could come from more individuals in the group possibly leading to interaction and discussion about the regulation of their collective cognitive activity on the interpersonal plane.

**The present study**

The aim of this study was to assess the effect of dynamic computerized metacognitive scaffolds on learning outcomes of collaborating students in an innovative learning arrangement. In addition to the effects of scaffolding, this study also aimed to assess the effects of two different forms of scaffolds (structuring vs. problematizing) on the learning outcomes of collaborating students. The learning outcomes were specified at group and individual level, taking into account the parallel learning outcomes resulting from the reciprocal interaction on the interpersonal plane. At the group level the product was the
group paper and at the individual level we distinguished between the effect of scaffolding on the individual students’ domain knowledge and on their metacognitive knowledge. Our research was designed to address two research questions:

1. What is the effect of metacognitive scaffolds on the learning outcomes of collaborating students in an innovative learning arrangement?
2. What is the effect of different forms of scaffolds (structuring vs. problematizing) supporting metacognition on learning outcomes of collaborating students in an innovative learning arrangement?

Drawing on the socio-cognitive perspective, we discussed the role of metacognitive scaffolding in supporting co-regulation of collective cognitive activity of a small group. We assumed that groups supported by metacognitive scaffolds would increase co-regulation on the interpersonal plane, leading to improved group performance and achievement. Although research on the effects of metacognitive scaffolding on collaborating students’ learning outcomes is lacking, earlier studies have shown that metacognitive scaffolds improve learning outcomes through improving individuals’ regulation of their cognitive activities. We therefore expected that groups supported by metacognitive scaffolds would outperform groups who were not supported by metacognitive scaffolds on the quality of the group product (hypothesis 1a).

As discussed above, scaffolding in a social system influences not only the quality of a group product, but also the individual cognitive residues, such as knowledge and skills. An individual’s knowledge is affected through the reciprocal interaction between the social system (social level) and individual cognition (individual level). Scaffolds focused on the group level will therefore also affect learning outcomes on an individual level. Groups that receive scaffolds are expected to co-regulate their collective cognitive activity more than groups that do not receive scaffolds. We therefore predicted that students in groups receiving scaffolds would also acquire more domain knowledge (hypothesis 1b).

Scaffolds increase co-regulation on the interpersonal plane, which models metacognitive activities and/or provides opportunities to practice metacognitive activities. As a consequence, individuals increase their understanding of how to use metacognitive activities to regulate cognitive activity. Thus we expected students working in triads and receiving metacognitive scaffolds to acquire more metacognitive knowledge than students in the groups that did not receive scaffolds (hypothesis 1c).

As discussed above, the form of the scaffold determines the “route” through which the scaffold affects the social system. This has implications for the way we expect the forms of the scaffolds to influence the parallel learning outcomes. Structuring scaffolds provide a regulative contribution to the interpersonal plane; this could trigger metacognitive contributions of the individuals in the system but does not necessarily do so. The problematizing scaffolds offered in our study initiated the individual student’s
metacognitive activities. Each individual in the group could contribute metacognitive activities, which could lead to regulative interaction and discussion on the interpersonal plane. We therefore expected more regulation of the collective cognitive activity in groups supported by problematizing scaffolds than in groups with structuring scaffolds. As specified above, more regulation of collective cognitive activities was expected to lead to a better quality of the group product, thus we expected groups supported by problematizing scaffolds to outperform groups supported by structuring scaffolds (hypothesis 2a).

Based on the same reasoning as for hypothesis 1b, we assumed that the individual student’s knowledge development is influenced through the interaction between the social system (social level) and the individual cognition (individual level). The form of scaffolds would therefore also influence the learning outcomes at the individual level. Groups that received problematizing scaffolds were expected to regulate their collective cognitive activity more than groups receiving structuring scaffolds. We therefore predicted that students in groups receiving problematizing scaffolds would also acquire more domain knowledge about the topic of the group product, than students receiving structuring scaffolds (hypothesis 2b).

Structuring scaffolds directly regulate the interpersonal plane; the virtual agent’s metacognitive modeling was likely to affect the development of metacognitive knowledge. Problematizing scaffolds elicited metacognitive activities from the individual students, affecting the development of the metacognitive knowledge through practice. Both modeling and practicing positively influence the development of metacognitive knowledge, but practicing is expected to have a stronger effect on student’s knowledge development as it is more actively involving than modeling. We therefore expected that students who were in groups supported by problematizing scaffolds would outperform students who were in groups receiving structuring scaffolds on metacognitive knowledge acquisition (hypothesis 2c).

This chapter reports an experiment on the effects of metacognitive scaffolding and different forms of scaffolds (structuring vs. problematizing) on learning outcomes of collaborating students. Triads in the scaffolding conditions received scaffolds to support their co-regulation; triads in the control condition did not receive scaffolds. Triads in the structuring condition received scaffolds directly regulating the interpersonal plane and triads in the problematizing condition received scaffolds to elicit metacognitive activities of the students participating on the interpersonal plane. Scaffolds were integrated dynamically into the e-learning environment supporting regulation at the appropriate instances in the collaborative learning process (see section on scaffolding in the method for an explanation). If the first hypothesis holds, we would expect triads who received scaffolds to outperform the triads in the control condition with respect to their group performance, the amount of individual domain knowledge and metacognitive knowledge acquisition. If the second hypothesis holds, we would expect students in the problematizing condition to outperform the students in the structuring condition with respect to their group
performance, the amount of individual domain knowledge and metacognitive knowledge acquisition.

Method

Sample and design
156 students in three schools divided over 6 classes participated in the study. The students were in Grade 4 (27), Grade 5 (82) or Grade 6 (47) of elementary education. This spread across 3 grades was chosen to assess the effect of scaffolds on learning outcomes over different levels of metacognitive skillfulness. The teachers assigned the students to triads (52) within their class based on the principle of heterogeneity. Each triad consisted of male and female students. Students were rated on their school performance as low, medium and high achievers and every triad had one participant of each level. Finally each triad had to include at least one student with good reading abilities and one student with good computer abilities. The triads were randomly assigned to the three conditions: 1. no scaffolds (control group, 16 triads); 2. structuring scaffolds (experimental group 1, 17 triads); and 3. problematizing scaffolds (experimental group 2, 19 triads). The conditions were equally divided over the classes.

The e-learning environment used in this study is called Ontdeknet. It focuses on supporting students in their collaboration with experts (Molenaar, 2003). Ontdeknet is an open learning environment in which assignments are described as ‘projects’. A project consists of a broad overall assignment which is connected to an external expert who will provide students with specialized information. The assignment is divided into smaller sub-assignments to support students’ collaboration with the experts. Ontdeknet embeds the design elements of innovative learning arrangements in three aspects: constructive learning assignments, a situated environment and collaborative learning. Constructive learning assignments come to the fore in the self-initiating role the students play with respect to the learning strategies and topics to be learned. Students select their own learning goals and select the learning strategies to pursue these goals. The role of the experts is to support the students in acquiring their goals through providing information and expertise. Situated environment is related to this role of the expert, the information given by the experts concerns their professional or personal knowledge and experiences. It is edited for its value and relevance for students by the editor of Ontdeknet. The vocabulary used by the experts is related to the socio-cultural environment of their expertise, and their examples, reasoning and explanations reflect their thinking as an expert about the topic (Ericsson & Charness, 1994). Collaborative learning is implemented at two levels: students collaborating with an expert in a virtual environment and with each other in small groups behind the computer.

The total duration of the experiment was 8 lessons of 1 hour. In the first lesson, the students were given instructions about the assignment and the electronic learning environment. All students received the same instructions and all triads spent the same time
working on the assignment (6 hours). In 6 lessons the triads worked on an assignment called “Would you like to live abroad?” The goal of the assignment was to explore a country of choice (New Zealand or Iceland), write a paper on the findings and decide if they would like to live in this country. The triads worked on one computer and had access to an inhabitant of the country. They could consult the expert by asking questions and requesting information about different topics about the country that they were interested in. In the expert section, the requested information about the country was written by the expert and questions were answered in a forum. The assignment to write a paper about the country was preceded by 4 sub-assignments: introducing the group, writing a goal statement, selecting a country and specifying topics of interest in a mind map to further support the collaboration with the expert. All tasks were integrated into the working space of the triads, where they also wrote the paper. The performance of the triads was stored in the learning environment. All lessons were supervised by the same researcher. The 8th hour was used for the measurement of individual domain and metacognitive knowledge.

The scaffolding system and the conditions

The computerized scaffolds were dynamically integrated into the learning environment. An attention management system was used to determine when to send which scaffold to the learners. This system monitored students’ attention focus and based on this information supplied the scaffolds. The system’s technical design consisted of three levels: the input level, the reasoning level and the intervention level. The input level collected information about students’ attention from students’ environment. Currently, input information is derived from the keyboard strokes, mouse movements and event information about students’ activities in the e-learning environment. The reasoning level selected the scaffold that is sent to the learner. Different software agents assessed students’ attention information to select the appropriate scaffold. The intervention level determined how the scaffold was communicated to the learner. AtgentSchool used a three-dimensional virtual agent powered by Living Actor technology for the delivery of scaffolds. The scaffolds were shown in text balloons and could be heard as spoken messages through the computer’s audio output. The messages were accompanied by the agent’s animations (e.g. movements of the agent’s hands) and emotions (e.g. smile on the face of the agent). The students had four icons in the interface by which to communicate with the agent, a question mark to indicate a need for help and three emotional icons indicating a happy, neutral or sad user. This information from the user was used as additional input.

The triads in the scaffolding conditions received scaffolds supporting their metacognitive activities during the first two lessons. The scaffolds were dynamically timed in the learning process, and the triads in both conditions received the scaffolds at the same instance in the learning process. The scaffolds were delivered at times when metacognitive activities are generally executed in the learning process based on Zimmerman’s model for self-regulated learning (Zimmerman, 2002). The scaffolding system determined the appropriate instance to send a scaffold based on students’ attention focus. This attention
focus was established based on the input information that the system acquired from students’ environment. The scaffolds were triggered by the system in relation to the following changes in the attention focus of the students. Orientation activities should be performed just before selecting a task; thus at sub-assignment selection triads received a scaffold to orientate on the sub-assignment. Planning should be done just before starting a task; therefore planning scaffolds were implemented just before execution of the sub-assignment. Finally, monitoring should be performed during and after execution of the task, upon saving the sub-assignment triads were shown a scaffold prompting them to monitor (Molenaar, van Boxtel, Sleegers & Roda, 2011). For each sub-assignment three types of scaffolds were implemented: orientation, planning and monitoring scaffolds. Students in the scaffolding conditions received a minimum of 12 scaffolds (see Appendix 4A for an overview of all scaffolding messages).

![Figure 6. An example of a structuring and problematizing scaffold.](image)

The triads in the structuring condition (experimental group 1) received scaffolds in the structuring form, which consisted of direct support to their regulation. The triads in the problematizing condition (experimental group 2) received scaffolds in the problematizing form which were designed to elicit individual student’s metacognitive activities. The triads in the problematizing condition were obliged to answer the agent’s questions in an answer box on the screen, (see figure 6) for an example of both forms of scaffold. Screenshots in Appendix 4A figure 4A shows how the messages are integrated into the electronic learning environment.

Table 3 shows the messages of the orientation, planning and monitoring scaffolds in structuring and in problematizing form for the introduction assignment (In appendix A, table 4A contains all scaffolding messages). Finally, the triads in the control group did see the virtual agent, but did not receive any form of metacognitive support from the agent. The agent was included in the interface to prevent a Hawthorne effect (Franke & Kaul, 1978).
Table 3. Example of structuring and problematizing scaffolds for the assignment introduction.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Structuring scaffold</th>
<th>Problematizing scaffold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation on introduction</td>
<td>Before we start, I would like to know who you are, please introduce yourselves.</td>
<td>Why are you going to introduce yourselves?</td>
</tr>
<tr>
<td>Planning of Introduction</td>
<td>I am going to show you an example of how to introduce yourselves: I am David, I am 12 years old and like to play games on the internet.</td>
<td>How are you going to introduce yourselves?</td>
</tr>
<tr>
<td>Monitoring of introduction</td>
<td>Thank you, I will send your introduction to the expert.</td>
<td>Did you introduce yourselves as planned?</td>
</tr>
</tbody>
</table>

Measures
The measurement for the product of the social system was the group performance on the assignment as measured by the quality of the group paper. The measurements of the individual cognitive residues were the individual domain knowledge acquired measured by recall, a knowledge test and a transfer test and metacognitive knowledge was measured.

Group performance was measured by scoring the triad’s paper that they wrote as a collaborative product of the learning assignment. The quality of the paper was defined by the richness of the text and the amount of processing of the information. The number of different topics about the country covered was an indication of the richness of the paper (Janssen, 2008). The percentage of self-formulated text was an indication of the amount of processing the students had done in relation to the information provided (Igo, Bruning, & McCrudden, 2005). The students received information given by the inhabitant which was used to determine the level of processing, indicated by the percentage of copying. This was measured by comparing the given information to the students’ finished text using WinCopyfind 2.6. This percentage was turned into a processing score: less copying resulted in a higher processing score. The richness of the text was evaluated by two independent researchers who counted the number of topics covered in the paper. 28% of the papers were scored by two independent researchers (Cohen’s kappa =0.75). The quality of the paper was calculated by adding the richness of the paper score to the processing score. The maximum paper score was 6 points.

Students’ domain knowledge was measured individually on three different levels: recall, knowledge test and a near transfer task following Bannert (2006, 2009). Recall was measured by asking students to make a mind map in 5 minutes with as many issues as they knew about the country they had investigated. For each correct proposition one point was assigned. Knowledge was measured by a curriculum-based knowledge test with 40 questions (true/false/question mark) related to the country the students had studied. Students received 1 point for each correct answer, 0 points for a question mark or an incorrect answer. The question mark option was included to prevent gambling, we told the
students they would receive -1 point for each incorrect answer. Cronbach’s alpha was 0.93 for the New Zealand test and 0.88 for the Iceland test. The near transfer task was to see if students could relate the domain knowledge on the country to a more general classification of topics that are important to consider when moving to a different country. We asked them to make a mind map with as many topics as possible that you need to consider when moving to another country. For each correct proposition one point was assigned.

Finally, students’ metacognitive knowledge was measured by asking them to imagine that they were going to do the same assignment again. They were asked to write down how they would proceed on this assignment in steps to be taken. The answers were scored against a full procedural overview made by the researchers. The full procedural overview consisted of 18 steps; examples of steps were “plan the learning task”, “activate prior knowledge” and “monitor the activity of the group”. The maximum score was 18 points. 10% of the tests were scored by two independent researchers (kappa =0.83). An overview of all measurements is given in table 4.

Table 4: Overview of measurements.

<table>
<thead>
<tr>
<th>Learning Outcome</th>
<th>Group measurement</th>
<th>Individual measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Quality of the paper</td>
<td>Free recall</td>
</tr>
<tr>
<td>Domain knowledge</td>
<td></td>
<td>Knowledge test</td>
</tr>
<tr>
<td>Metacognitive knowledge</td>
<td></td>
<td>Near transfer test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metacognitive knowledge test</td>
</tr>
</tbody>
</table>

Analysis

The first hypothesis predicted that students in both experimental conditions would perform better than students in the control condition on the learning outcome variables. The second hypothesis predicted that the students in the problematizing condition would outperform the students in the structuring condition on the learning outcome variables. We treated the different learning outcome variables (group performance, individual domain knowledge and individual metacognitive knowledge) as separate dependent variables, because they differed conceptually. As a consequence, we conducted ANOVA’s with planned contrasts to test the two hypotheses. The effect sizes were calculated using the effect size estimate $r$, following Rosenthal (1991) defining 0.1 as a small effect, 0.3 as a medium effect and 0.5 as a large effect. Analyzing the data, we found that a number of students ($n = 27$) were unable to answer the questions about metacognitive knowledge. These students were equally distributed over the conditions. We therefore excluded these students from the data analysis of metacognitive knowledge.
Chapter 3

Results

The effects of scaffolding: the experimental conditions versus the control group

Planned comparisons of the control group with the two experimental groups revealed that scaffolding did not have a significant effect on group performance, \( t(49) = 1.39; p > 0.05 \) (one tailed). The effect size \( r = 0.19 \), however, indicated a small to medium positive effect of scaffolding on group performance. This finding on group performance did not therefore confirm our first hypothesis: scaffolding did not significantly affect the quality of the group product, but it did have a small to medium positive effect on the quality of the group product.

Planned comparisons of the control group with the two experimental groups revealed that scaffolding did not have a significant effect on the domain knowledge of the individual students. Specifically, we did not find a significant effect of scaffolding on free recall (t(144)=0.42; p > 0.05; r=0.03), the knowledge test on New Zealand (t (89)=-0.17; p > 0.05; r=0.01) the knowledge test on Iceland (t (61)=0.79; p > 0.05; r=0.08), nor the transfer of knowledge (t (147)=-0.37; p >0.05; r=0.03). All the effects sizes were very low (close to zero). This suggests that metacognitive scaffolds had little to no effect on the domain knowledge construction. So, also with regard to domain knowledge, the findings did not confirm our first hypothesis.

Table 5. The effect of scaffolding on learning outcomes; comparing the control group to the two scaffolding conditions.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Control</th>
<th>Scaffolding</th>
<th>t</th>
<th>p &lt;</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of group paper</td>
<td>3.31(1.35)</td>
<td>3.98(1.41)</td>
<td>1.39</td>
<td>0.08</td>
<td>0.19</td>
</tr>
<tr>
<td>Recall domain knowledge</td>
<td>8.89(3.37)</td>
<td>9.15(3.59)</td>
<td>0.42</td>
<td>0.34</td>
<td>0.03</td>
</tr>
<tr>
<td>Domain knowledge New Zealand</td>
<td>19.56(5.70)</td>
<td>19.25(9.14)</td>
<td>-0.17</td>
<td>0.43</td>
<td>0.01</td>
</tr>
<tr>
<td>Domain knowledge Iceland</td>
<td>15.78(6.39)</td>
<td>17.06(5.39)</td>
<td>0.79</td>
<td>0.22</td>
<td>0.08</td>
</tr>
<tr>
<td>Transfer of domain knowledge</td>
<td>6.42(2.32)</td>
<td>6.27(2.23)</td>
<td>-0.37</td>
<td>0.35</td>
<td>0.03</td>
</tr>
<tr>
<td>Metacognitive knowledge</td>
<td>4.51(1.96)</td>
<td>5.21(2.15)</td>
<td>1.63</td>
<td>0.05*</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Planned comparisons of the control group with the two experimental groups revealed that scaffolding did significantly affect metacognitive knowledge, \( t (108) = 1.63; p < 0.05 \) (one tailed). The effect size \( r = 0.16 \) indicated a small positive effect of scaffolding on the amount of metacognitive knowledge acquired. These findings thus confirmed our first hypothesis: scaffolding did have positive effects on the amount of metacognitive knowledge the individual students acquired. See table 5 for an overview.
The form of the scaffolding: the problematizing condition versus the structuring condition

The comparison of the problematizing condition with the structuring condition revealed that the form of the scaffolds had a significant effect on group performance as measured by the quality of the group paper, \( t(49) = 2.07; p < 0.05 \) (one tailed). The effect size \( (r = 0.28) \) indicated a medium positive effect of the form of scaffolding on the quality of the paper. This finding on group performance did therefore confirm our second hypothesis: problematizing scaffolds did result in a significant higher quality of the group product.

Planned comparisons of the problematizing condition with the structuring condition revealed that scaffolding did not have a significant effect on the domain knowledge of the individual students. We did not find a significant effect of the form of the scaffolding given on the recall of knowledge \( (t(144) = -0.28; p > 0.05; r = 0.02) \), the knowledge test on New Zealand \( (t(89) = -0.35; p > 0.05; r = 0.03) \), or the knowledge test on Iceland \( (t(61)= -0.83; p >0.05; r=0.11) \). Furthermore, all effects found were negative, indicating that problematizing actually reduces the domain knowledge compared to structuring. With regard to one aspect of domain knowledge, however, we did find a significant effect. Students who worked in triads which received problematizing scaffolds scored significantly higher on the transfer test than students who worked in triads receiving structuring scaffolds \( (t(147)=1.64; p <0.05) \). The effect size \( (r =0.13) \) indicated a small positive effect of the form of scaffolding on the transfer of knowledge.

Table 6. The effect of the form of scaffolds on learning outcomes; comparing the structuring condition to the problematizing condition.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Structuring</th>
<th>Problematizing</th>
<th>( t )</th>
<th>( p &lt; )</th>
<th>( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of group paper</td>
<td>3.41(1.46)</td>
<td>4.37(1.34)</td>
<td>2.07</td>
<td>0.02*</td>
<td>0.28</td>
</tr>
<tr>
<td>Recall domain knowledge</td>
<td>9.25(3.53)</td>
<td>9.05(3.62)</td>
<td>-0.28</td>
<td>0.39</td>
<td>0.02</td>
</tr>
<tr>
<td>Domain knowledge New Zealand</td>
<td>19.61(9.03)</td>
<td>18.88(9.23)</td>
<td>-0.35</td>
<td>0.37</td>
<td>0.03</td>
</tr>
<tr>
<td>Domain knowledge Iceland</td>
<td>17.77(5.99)</td>
<td>16.35(4.80)</td>
<td>-0.83</td>
<td>0.21</td>
<td>0.11</td>
</tr>
<tr>
<td>Transfer of domain knowledge</td>
<td>5.90(2.05)</td>
<td>6.65(2.41)</td>
<td>1.64</td>
<td>0.05*</td>
<td>0.13</td>
</tr>
<tr>
<td>Metacognitive knowledge</td>
<td>4.81(2.31)</td>
<td>5.61(1.99)</td>
<td>1.67</td>
<td>0.05*</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Planned comparisons of the problematizing condition with the structuring condition revealed that the form of scaffolding did significantly affect the metacognitive knowledge of the individual students \( t(108) = 1.67; p < 0.05 \) (one tailed). The effect size \( (r = 0.16) \) indicated a small positive effect of the form of scaffolding on the amount of metacognitive knowledge acquired. These findings did confirm our second hypothesis: problematizing scaffolds did positively affect the amount of metacognitive knowledge the students acquired compared to structuring scaffolds. See table 6 for an overview.
Conclusion and discussion

In this study we investigated the effect of computerized dynamic metacognitive scaffolding on learning outcomes of collaborating students in an innovative learning arrangement. Although some research has been conducted on the effect of metacognitive scaffolding on learning outcomes in an individual setting, no research has been performed in a small group setting. Based on the socio-cognitive perspective, we expected that metacognitive scaffolds would enhance the learning outcomes of collaborating students at individual and group level. We hypothesized that dynamic scaffolding would result in higher learning outcomes in general and that different forms of scaffolds would have different effects on learning outcomes; namely that problematizing scaffolds would result in higher learning outcomes than structuring scaffolds. To test our hypotheses, we first compared the learning outcomes of both scaffolding conditions with the control condition, followed by a comparison of the learning outcomes of the problematizing versus the structuring condition.

The results showed that metacognitive scaffolding in triads had a small positive effect on group performance that was not significant and had no effect on the domain knowledge students acquired. We did find a small significant positive effect of dynamic scaffolding on the metacognitive knowledge students acquired. These findings therefore partly confirmed our first hypothesis: dynamic scaffolding did support learners to acquire more individual metacognitive knowledge, but did not lead to better group performance nor to the acquisition of more domain knowledge. These results concur with findings of other studies. In another study, we found a small to medium effect of scaffolding on the quality of group papers (Molenaar & Roda, 2008; submitted), which had a similar magnitude to the effect found in this study. The absence of effects of metacognitive scaffolding on students’ domain knowledge is in line with other scaffolding studies, which also failed to find an effect of scaffolding on the quantity of domain knowledge (Bannert, 2006; Bannert et al., 2009; Lin & Lehman, 1999). An argument provided for these findings is that metacognitive scaffolding does not affect the quantity, but could only lead to enhanced quality of the domain knowledge (Bannert, 2006; Bannert et al., 2009).

With respect to the form of scaffolds, there was a significant medium positive effect of problematizing scaffolds compared to structuring scaffolds on group performance and a significant small positive effect on the metacognitive knowledge acquired and the transfer of domain knowledge. These results show how the form of the scaffold influenced the interaction between the social and individual level of the group learning process. Different forms of scaffolds affected the group learning outcomes differently from the individual learning outcomes; problematizing scaffolds affected the group product as well as individual knowledge construction, whereas structuring scaffolds only influenced individual knowledge construction. This means that scaffolds taking the indirect route eliciting regulative activities were more effective in altering the group product than scaffolds regulating the groups’ collective cognitive activity directly. This can be explained by the students’ active participation in the problematizing condition compared to the more
passive participation in the structuring condition. We also found that problematizing scaffolds resulted in more individual metacognitive knowledge than structuring scaffolds. This is in line with our assumption that problematizing scaffolds would increase the opportunity to practice metacognitive activities, which enhance individual metacognitive knowledge. Scaffolding in general increased metacognitive knowledge, which supports the hypothesis of the modeling effect of the structuring scaffolds.

Interestingly the quantity of domain knowledge was the same in all conditions, whereas the quality of the group product as well as the transfer of individual domain knowledge was positively affected by the problematizing scaffolds. Even though the students’ group product was enhanced by the scaffolds resulting in a richer and better processed paper, this did not result in more knowledge about the researched country at the individual level. However, the acquired domain knowledge was applied better in a transfer assignment, so even though students did not acquire more knowledge, they were better able to transfer it to new assignments. This is in line with Bannert’s argument (2006, 2008) that metacognitive scaffolds do not affect the quantity of acquired domain knowledge, but do affect its quality.

As mentioned in the theoretical section, research looking at metacognitive scaffolds is directed at improving learning outcomes and is not concerned with the effect on metacognitive knowledge. In this study, we did analyze the effect of the scaffolding on metacognitive knowledge and found that scaffolding positively influenced this type of knowledge. This indicates that metacognitive scaffolding could be applied to increase metacognitive knowledge as an alternative method to training metacognition. We would encourage future studies to look at metacognitive scaffolds, to incorporate measurements to assess the development of metacognitive skillfulness, and to explore this idea of scaffolding as training for metacognition further.

The results of this experimental study confirmed that metacognitive scaffolds can be functional in a collaborative setting to increase learning outcomes and deserve further inquiry in the quest for better learning results in innovative learning arrangements. We found that all students supported by scaffolds acquired more metacognitive knowledge to regulate future learning, and that triads in the problematizing condition also had better group products and transfer of domain knowledge. This provides reasons to assume that if learners are supported to overcome problems with respect to metacognitive skillfulness, innovative learning arrangements might live up to their anticipated promise to enhance learning performance and achievement.

The results encourage us to further explore the nature and quality of the triads’ metacognitive activities used for the co-regulation of their collective cognitive activities. Interesting questions are: how do metacognitive activities occur and develop on the interpersonal plane; how do the individuals contribute to and interact with metacognitive activities on the interpersonal plane; and how does co-regulation influence the collective cognitive activities? Finally, we would like to empirically establish how different forms of
scaffolds influence the social system and how the routes consequently influence individual cognition. Insights into this process would allow us to develop scaffolding methods that are more tuned towards the social system and thus more effective at enhancing the learning outcomes at the group and individual level.

Acknowledgements

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Appendix 4A.

Figure 4a. Structuring condition with structuring scaffolds and the problematizing condition with problematizing scaffolds.
Table 4a. All scaffolding messages

<table>
<thead>
<tr>
<th>Situation</th>
<th>Structuring scaffold</th>
<th>Problematizing scaffold</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction of the group</strong></td>
<td><strong>Before we start, I would like to know who you are, please introduce yourselves.</strong></td>
<td><strong>Why are you going to introduce yourselves?</strong></td>
</tr>
<tr>
<td>Orientation on introduction</td>
<td><strong>I am going to show you an example of how to introduce yourselves:</strong> I am David, I am 12 years old and like to play games on the internet.</td>
<td><strong>How are you going to introduce yourselves?</strong></td>
</tr>
<tr>
<td>Planning of Introduction</td>
<td><strong>Thank you, I will send your introduction to the expert.</strong></td>
<td><strong>Did you introduce yourselves as planned?</strong></td>
</tr>
<tr>
<td>Monitoring of introduction</td>
<td><strong>I would like to know what you want to learn, please explain that in your goal statement</strong></td>
<td><strong>Why are you going to write a goal statement?</strong></td>
</tr>
<tr>
<td><strong>Writing the goal statement</strong></td>
<td><strong>A learning goal is what you want to learn. For instance, we would like to learn more about New Zealand to decide if we would like to live there.</strong></td>
<td><strong>How are you going to write a goal statement?</strong></td>
</tr>
<tr>
<td>Orientation on goal statement</td>
<td><strong>I will send your learning goal to your expert to explain to him what you want to learn.</strong></td>
<td><strong>Did you write your goal statement as planned?</strong></td>
</tr>
<tr>
<td>Planning of goal statement</td>
<td><strong>Please explore the environments of the experts to decide which country you would like to learn more about.</strong></td>
<td><strong>How are you going to choose the country?</strong></td>
</tr>
<tr>
<td>Monitoring of goal statement</td>
<td><strong>You have now selected the country to learn more about.</strong></td>
<td><strong>Did you make your choice as planned?</strong></td>
</tr>
<tr>
<td><strong>Selecting the country</strong></td>
<td><strong>The expert would like to know what you want to learn; let’s make a mind map.</strong></td>
<td><strong>Why are you going to make a mind map?</strong></td>
</tr>
<tr>
<td>Orientation on mind map</td>
<td><strong>Please explore the environments of the experts to decide which country you would like to learn more about.</strong></td>
<td><strong>How are you going to make a mind map?</strong></td>
</tr>
<tr>
<td>Planning of mind map</td>
<td><strong>I will send the topics you would like to learn more about to the expert.</strong></td>
<td><strong>Did you make your mind map as planned?</strong></td>
</tr>
<tr>
<td>Monitoring of mind map</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Effects Scaffolding Metacognitive Activities in Small Groups

Abstract This study examined the effects of scaffolds on groups’ metacognitive activities in complex computer-based learning environment. In an experimental design, two experimental groups receiving scaffolds were compared with a control group (n=18). The experimental groups differed in the form of scaffolds used: structuring scaffolds (n= 18) vs. problematizing scaffolds (n=18). We analyzed the effects of scaffolding and the different forms of scaffolds on the amount of metacognitive activities of triads on the interpersonal plane. The results show that scaffolding has a significant effect on metacognitive activities; triads receiving scaffolds performed significantly more metacognitive activities on the interpersonal plane. Additionally, scaffolding also has a significant development effect; triads continue to show more metacognitive activities after the scaffolding is ceased. Finally, no significant differences between the two forms of scaffolding were found: triads receiving problematizing scaffolds did not show more metacognitive activities during or after the scaffolding compared to triads receiving structuring scaffolds.

Keywords Metacognitive activities · Scaffolding · Complex open learning environments · Virtual Agents · Elementary Education.

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Introduction

Students collaborating in small groups often have problems controlling and monitoring their learning in complex open learning environments such as electronic learning environments (Jacobson & Azevedo, 2008). Students find it difficult to set clear goals to guide their learning, recognize and repair deviations from goals and develop sufficient plans to structure the group process. This indicates that students collaborating in small groups often lack the metacognitive skills to regulate their individual and collective learning in complex open learning environments (Azevedo & Hadwin, 2005; Bannert & Mengelkamp, 2008). During collaborative learning, group members can build on each others’ knowledge and provide feedback on each others’ activities (van Boxtel 2004, Webb, 2009), also on each others’ metacognitive activities (Lin & Sullivan, 2008). Consequently a lack of metacognitive activities does not only hamper the group learning process, but also reduces the development of students’ metacognitive skills in collaboration. Therefore, small groups will continue to face problems regulating their learning.

Scaffolding, providing assistance to a student on as-needed basis, (Wood, Bruner, & Ross, 1976) can support students in tasks they cannot accomplish by themselves (Hmelo-Silver & Azevedo, 2006; Sharma & Hannafin, 2007). Studies found that scaffolding promotes metacognitive activities (Azevedo, Moos, Greene, Winters, & Cromley, 2008; Veenman, Kok, & Blote, 2005) and consequently improves learning achievements, metacognitive knowledge and motivation in individual learning settings (Azevedo & Cromley, 2004; Azevedo & Hadwin, 2005; Land & Green, 2000). The main question addressed in this article is: does scaffolding metacognition in small groups stimulate metacognitive activities and develop metacognitive skills in small groups? This paper extends recent literature by emphasizing the effects of scaffolding on triads’ metacognitive activities. We present the results of an experimental study into the effects of metacognitive scaffolding in an electronic learning environment. First, we elaborate on the role of metacognition in a small group; formulating the mechanisms by which metacognition on the interpersonal plane stimulates metacognitive skills influencing the groups’ metacognitive activities. Next, we discuss how a small group setting influences scaffolding emphasizing the role of peer interaction that amplifies the effects of scaffolding; both of the stimulation of metacognitive activities and consequently enlarging the development of metacognitive skills in group settings. Finally, we explicate how different forms of scaffolds stimulate the groups’ metacognition and enhance metacognitive skills of students in small groups.

Socially shared metacognition

The role of metacognition in small groups is to structure the cognitive processes and the co-construction of knowledge in the activity between individuals and to monitor and control the learning processes of the individual group members. Social metacognition is the process taking place on the interpersonal plane regulating the collective cognitive
activity (Iiskala, Vauras, Lehtinen, & Salonen, 2011). Different metacognitive activities such as orientation, planning, monitoring, evaluation and reflection regulate the small groups’ collaborate learning (Veenman, Van Hout-Wolters, & Afflerbach, 2006; Zimmerman, 2002). Group dynamics play an important role in both the performance and the development of metacognition in groups (Lin & Sullivan, 2008).

In order to understand how metacognitive activities in small groups develop students’ metacognitive skills; we draw on the socio-cognitive perspective on learning. This perspective offers a framework to analyze how individuals learn in interaction with others emphasizing the individual developments of the students as well as the group development as a result of the interaction on the interpersonal plane (Hadwin & Oshige, 2007; Iiskala, Vauras, & Lehtinen, 2004; Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen, 2003; Volet, Vauras, & Salonen, 2009). From a socio-cognitive perspective collaborative learning is considered to take place through reciprocal activities between the students on the interpersonal plane (Volet et al., 2009). Consequently, peers play a mediating role in learning of others (Salomon, 1993). The students influence each other in a spiral-like fashion; students contribute knowledge and skills to the social system, which alters the state of the interpersonal plane and elicits new activities from the group members. The activities offer the opportunity to practice skills at the individual level, which subsequently develops the skills and alters the students’ future participation on the small groups’ interpersonal plane. Therefore, individual students appropriate knowledge provided by the social system and in turn contribute with their enhanced participation to the development of the social system (Salomon, 1993; Volet et al., 2009).

In an example, we apply the above described mechanism of development of metacognitive skills in small groups. One student performs a metacognitive activity giving him an opportunity to practice. Additionally, this provides an example for the other group members, which supports the development of their metacognitive skills. The group members can provide feedback and advice on the student’s metacognitive activity. For example, one student monitors the group’s learning activity by stating that he thinks the calculation the group is performing is wrong. Another group member can ask the student why the calculation is wrong, asking the first student to further elaborate on his monitoring. Naturally a prerequisite for this mechanism to be effective is that learners must pay attention to the feedback and perceive it as relevant. Therefore, in case when the group members engage in an interaction around metacognitive discourse in which students co-construct their metacognitive activities, this supports the development of metacognitive skills consequently affecting future collective practices of socially shared metacognition. Accordingly, researchers using a socio-cognitive perspective on learning emphasize the regulating effects of metacognitive interaction on the group’s performance, which develops metacognitive skills and consequently shapes future metacognitive activities in the group.

As mentioned earlier, most students collaborating in small groups have problems to perform metacognitive activities regulating the group learning process. This also hampers the development of students’ metacognitive skills for future participation in collaborative
cognitive activities on the interpersonal plane. Scaffolding can stimulate metacognitive activities in the groups’ interaction and consequently enhance the metacognitive skills within small groups. In the next paragraph we discuss the functioning of scaffolding in small group settings.

**Scaffolding metacognition in social settings**

Scaffolding is defined as providing assistance to a student on as-needed basis, fading the assistance as the competence of the student increases (Wood et al., 1976). The purpose of scaffolding is two-folded: 1) to support learners in activities they are unable to accomplish successfully by themselves and 2) to develop knowledge and skills needed to perform future tasks (Hmelo-Silver & Azevedo, 2006; Pea, 2004; Sharma & Hannafin, 2007). The purpose of scaffolding metacognition in a social setting is thus to stimulate metacognitive activities on the interpersonal plane and develop metacognitive skills of students needed for future learning during collaboration. Research has mainly focused on how metacognitive scaffolds affect individual students, rather than on how scaffolds influence joint activity. The findings of studies evaluating the use of metacognitive scaffolds showed that scaffolds can support metacognitive activities of individual students (Davis & Linn, 2000; Ge & Land, 2003; Reiser, 2004; Saye & Brush, 2002) and increase the amount of metacognitive activities performed (Azevedo et al., 2008; Veenman et al., 2005). In addition, research also showed that well designed scaffolds can help students to appropriate knowledge and skills sustaining successful application in new situations (Hogan & Pressley, 1999).

In order to be effective, scaffolds in social settings need to stimulate metacognitive activities to regulate the cognitive activity of the group. The group’s activities on the interpersonal plane guide the selection of scaffolding messages (Molenaar & Roda, 2008). Zimmerman’s model (2002) offers a useful theoretical model to determine which scaffolding message can regulate the group’s current learning activities. Metacognitive activities are categorized in preparatory activities (orientation and planning) which are effective at the beginning of an task; executive activities (monitoring and evaluation) effective while working on a task and closing activities (reflection) useful after task completion. For example, when a group starts a learning activity a planning scaffold is appropriate to support the group’s metacognitive activities.

Subsequently, to stimulate planning activities in the group, the scaffold message also has to influence the social interaction between group members (Ge & Land, 2003). Scaffolds focus the collective attention of the group members. Shared attention shapes reciprocal interaction stimulating productive group activities (Barron, 2000, 2003). For example, a planning message focuses the group’s attention on planning of the learning task influencing the activities of the group members and their interaction. Peer interaction is advantageous for learning in a number of ways by providing and receiving explanations, co-constructing ideas, reproving conflicts and negotiating meaning (Ge & Land, 2003). As a result, metacognitive interaction can stimulate the development of metacognitive skills.
Applied on our example; scaffolds focusing on the group’s interaction around planning issues, can support the development of students’ appropriate planning skills to be applied in future learning settings.

To conclude, scaffolding can be applied to social settings to overcome the group’s lack of regulation in complex open learning environments stimulating metacognitive activities on the interpersonal plane. The group setting amplifies the effect of scaffolding facilitating additional interaction around metacognition. Both scaffolding as well as the peer interaction contributes to the development of metacognitive skills equipping students to continue to perform metacognitive activities in the group setting without the support of scaffolding. To further specify how scaffolding stimulates metacognition in a group setting, we need to elaborate on the mechanisms behind scaffolding. In the next section, we describe how structuring and problematizing scaffolds influence students’ metacognitive skills in social settings.

**Different forms of scaffolds**

Reiser (2004) specified two mechanisms of scaffolding to explain how scaffolding functions in detail, namely structuring and problematizing. Scaffolds can simply show examples of regulation, performing part of the groups’ metacognitive activities. These scaffolds structure the groups’ metacognitive activities and stimulate students to elaborate on these issues. An example of a structuring scaffold is to show students an exemplary plan of a task ‘I am going to show you how to introduce yourselves; I am David and I am 12 years old’. Students can consequently elaborate and reformulate the specifications of their group planning activities. Alternatively, scaffolds can problematize metacognitive aspects of the task, posing questions that elicit metacognitive activities. Research shows that problematizing scaffolds such as question prompts elicit individual students’ explanations supporting articulation of their thinking (Chi, Siler, Jeong, Yamuachi, & Hausmann, 2001; Davis & Linn, 2000; King, 1998, 2002). Consequently, problematizing scaffolds trigger students’ metacognitive contributions to the interpersonal plane generating explanations and articulation of their thinking. An example of a problematizing scaffold is asking students ‘How can you plan this task?’ This scaffold elicits planning activities from the students stimulating the group to discuss their collaborative approach to planning the learning task. Thus, the mechanism of scaffolding which is explicated through the form of the scaffolds influences the ways in which metacognition is stimulated.

The different forms of scaffolds additionally address different levels of the social system; resulting in different ways by which the students learn from the scaffolding. Structuring scaffolds contribute metacognitive activities to the interpersonal plane. The examples provided by structuring scaffolds can be appropriated by students and the subsequent students’ interaction discussing their collaborative approach can support further development of metacognitive skills. Referring back to the example of the structuring planning scaffold, students both learn from the planning example in the scaffolding message and elaborate on this example towards the group’s planning strategy.
Problematizing scaffolds address individual students directly stimulating students to form their own metacognitive activities and the question form elicits group discussion. Performing activities as well as giving and receiving explanations results in higher-level thinking and learning (Chi et al., 2001; King, 2002). Applied to the example above, students learn from performing the planning actions and discussing the planning approach followed.

Summarizing the above, different forms of scaffolds stimulate metacognitive activities differently. Structuring scaffolds structure metacognitive activities stimulating metacognition on the interpersonal plane; problematizing scaffolds elicit metacognitive activities of individual student and in turn support group discussion on the interpersonal plane. Thus different forms stimulate metacognitive activities differently, which are intertwined with differently shaping the groups’ interaction consequently influencing the development of metacognitive skills in a different way.

The present study

The purpose of this study is to determine the effect of metacognitive scaffolding and the different forms of scaffolding on the groups’ metacognitive activities. To our knowledge there are no studies that systematically researched the effect of scaffolding and specifically of different forms of scaffolds on metacognitive activities in social settings. The main question addressed in this article is: Does scaffolding metacognition in small groups stimulate metacognitive activities and develop metacognitive skills? We report an experiment on the effects of scaffolding and different forms of scaffolds on metacognitive activities of triads in elementary schools. Triads in the scaffolding conditions received scaffolds to support their metacognitive activities; triads in the control condition did not receive scaffolds. Furthermore, two experimental groups received different forms of scaffolds; namely problematizing scaffolds versus structuring scaffolds. Triads in the structuring condition received scaffolds to stimulate metacognitive activities on the interpersonal plane (see examples in appendix 4A, previous chapter) and triads in the problematizing condition received scaffolds addressing individuals to perform metacognitive activities.

Based on the findings of individual studies and on the framework of scaffolding in social settings described above, we expect more metacognitive activities in groups receiving scaffolds than in groups receiving no scaffolds (Hypothesis 1a: stimulation hypothesis). Different forms of scaffolds stimulate metacognition and interaction among the students differently. Structuring scaffolds structure metacognition on the interpersonal plane stimulating group interaction, whereas problematizing scaffolds elicit individual students’ metacognitive activities, providing seeds for social interaction and group discussion. Both types of scaffolds positively stimulate metacognitive activities, yet, we expect problematizing scaffolds to have a stronger effect as they explicitly elicit both metacognitive activities and interaction among the group members. Therefore, consistent with the stimulation hypothesis as formulated above, we expect more metacognitive
activities in groups supported by problematizing scaffolds than in groups with structuring scaffolds (*Hypothesis 1b: stimulation hypothesis*).

Students in small groups receiving scaffolds will learn from the scaffolds and engage in more metacognitive social interaction, which develops metacognitive skills which can be used for future learning in small group settings. Therefore, we expect a lasting effect on the performance of metacognitive activities, assuming small groups in the scaffolding conditions to continue to show more metacognitive activities after scaffolding is ceased (*Hypothesis 2a: development hypothesis*). Here we refer to short term development within the small groups in the same learning environment.

Structuring scaffolds show examples of metacognitive activities and support interaction resulting in learners to appropriate metacognitive skills. Problematizing scaffolds elicit metacognitive activities and support interaction and discussion affecting the metacognitive skills. Although both types of scaffolds positively influence the development of metacognitive skills, we expect problematizing scaffolds to lead to more metacognitive interaction and thus have a stronger and sustained impact on metacognitive activities in the groups. Consistent with the development hypothesis as formulated above, we therefore expect that groups supported by problematizing scaffolds continue to perform more metacognitive activities when scaffolding is ceased than groups who are receiving structuring scaffolds (*Hypothesis 2b: Development hypothesis*).

The quantity of the metacognitive activities on the interpersonal plane will be measured during learning analyzing the dialogue of the triads. If the stimulation hypothesis holds, we expect triads who receive scaffolds to perform more metacognitive activities, and the triads in the problematizing condition to outperform the triads in the structuring condition on this aspect. If the development hypothesis holds, we expect groups who receive scaffolds to continue to perform more metacognitive activities after scaffolding is ceased and groups in the problematizing condition to uphold this metacognitive behavior more than groups in the structuring condition.

**Participants**

For this study, we randomly selected 18 triads from 52 triads that participated in a previous study (Molenaar, Van Boxtel & Sleegers, in press). In the original study, 156 students in three schools divided over 6 classes participated. The teachers assigned students to triads (52) based on the principle of heterogeneity; this means that we asked teachers to rate the students as low, middle and high achievers based on their (reading, writing and computer) abilities. Teachers created triads containing one low, one middle and one high achiever. Finally, we randomly assigned the triads to the three experimental conditions, equally divided over the classes: 1. no scaffolds (control group, 16 triads); 2. structuring scaffolds (experimental group 1, 17 triads); and 3. problematizing scaffolds (experimental group 2, 19 triads). The conditions were equally divided over the classes by randomly assigning triads to the conditions within a class, we blocked for effects of classes (Howard, 2006).
For this study, we have randomly drawn three triads (one in each condition) from the original sample from every class. The sample thus consists of 54 students (23 boys and 31 girls) assigned in 6 control triads, 6 triads in the structuring condition and 6 triads in the problematizing condition. The students of this sample were in Grade 4 (9), Grade 5 (27) or Grade 6 (18) of 3 schools for elementary education. With respect to school characteristics; the three schools that participated in our study were comparable; all situated in outer city suburban areas with a white middle class population. As mentioned above we blocked for class effects by ensuring that within every class equal numbers of triads were assigned to the different conditions. This also ensures an equal division of the triads in the different conditions over the different schools. We tested if the number of metacognitive activities in the triad was dependent on the school by calculating the intraclass correlation between the schools. We found an intraclass correlation of 0. Additionally, there was no teacher effect because all classes were taught by the same researcher outside their own classroom in the computer lab. Students were working in triads they had never worked in the exact same combination before. Because all triads performed the same task, there were no deviations in task characteristics among the triads.

Finally, we did not measure the metacognitive knowledge or skills of the individual students to create the triads, because offline measures of metacognition are not or low correlated with actual metacognitive performance (Veenman, Wolters & Alferbach, 2006). This is due to two problems with offline measurements, first they ask students to make a judgment of their metacognitive activities without providing a contextual reference and second off line measures ask students to make a general judgment about their abilities.

**Treatment: The scaffolding system and the conditions**

The e-learning environment used in this study is called *Ontdeknet*. It focuses on supporting students in their collaboration with experts (Molenaar, 2003). *Ontdeknet* embeds the design elements of complex open learning environments in three aspects: constructive learning assignments, a situated environment and collaborative learning. *Constructive learning assignments* come to the fore in the self-initiating role the students play with respect to the learning strategies and topics to be learned. Teachers only provide the overall assignment and students select their own learning goals and their learning strategies to pursue these goals. Students thus have much control over their own learning and are encouraged to self-regulated learning.

The role of the experts is to support the students in acquiring their goals through providing information and expertise. *Situated environment* is related to this role of the experts. The information given by the experts concerns their professional or personal knowledge and experiences. The language used by the experts is related to their expertise, and their examples, reasoning and explanations reflect their thinking as an expert about the topic (Ericsson & Charness, 1994). The experts’ contributions are edited for its value and relevance for students by the editor of *Ontdeknet*. *Collaborative learning* is implemented at
two levels: students collaborating with an expert in a virtual environment and with each other in small groups behind the computer.

The computerized scaffolds were dynamically integrated into the learning environment. An attention management system was used to determine when to send which scaffold to the learners. Attention management systems capture the attention focus of the students (Roda & Thomas, 2006). The attentive system research aims at defining the factors and determining the likely utility of given information for a given user in a given context and the costs associated with presenting the information in a certain way (Roda & Nabeth, 2007). The utility of attentive systems for learning is to detect the attentional focus of the student and interpret this information to support the learning process (Molenaar & Roda, 2008). Our system monitored the students’ attention focus and based on this information supplies the scaffolds. The attentional focus was monitored at three levels: the input level, the reasoning level and the intervention level. The input level collected information about the students’ attention from the students’ environment. Currently, input information was derived from the keyboard strokes, mouse movements and event information about the students’ activities in the e-learning environment. The reasoning level determined what was in the focus of the student based on the event information and the active task of the student. Based on this diagnosis of the students’ attention information a scaffold was selected that can be useful for the learner. Finally, the intervention level determined how the scaffold is communicated to the learner. Ontdeknet used a three-dimensional virtual agent powered by Living Actor technology for the delivery of scaffolds. The scaffolds were shown in text balloons and could be heard as spoken messages through the computer’s audio output. The messages were accompanied by the agent’s animations (e.g. movements of the agent’s hands) and emotions (e.g. smile on the face of the agent). The systems reasoning system was validated in extensive studies ensuring the functioning of this component with a wizard of OZ design and test runs of the systems within schools (Molenaar & Roda, 2008).

The total duration of the experiment was 8 lessons of 1 hour. In the first lesson, the students were given instructions about the task and the electronic learning environment and the last lessons was to fill in questionnaires. All students received the same instructions and all triads spent the same time working on the task (6 hours). In 6 lessons the triads worked on a task called “Would you like to live abroad?” The goal of the task was to explore a country of choice (New Zealand or Iceland), write a paper on the findings and decide if they would like to live in this country. The triads worked on one computer and had access to an inhabitant of the country. They could consult the expert by asking questions and requesting information about different topics about the country that they were interested in. In the expert section, the requested information about the country was written by the expert and questions were answered in a forum.

The task to write a paper about the country was preceded by 4 sub-tasks: introducing the group, writing a goal statement, selecting a country and specifying topics of interest in a mind map to further support the collaboration with the expert. All tasks were integrated.
into the working space of the triads, where they also wrote the paper. The performance of the triads was stored in the learning environment. All lessons were supervised by the same researcher.

The triads in both experimental scaffolding conditions received scaffolds supporting their metacognitive activities at the same instance in their learning process during the first two lessons. The scaffolds were delivered at times when metacognitive activities are generally executed in the learning process based on Zimmerman’s model for self-regulated learning (Zimmerman, 2002). As mentioned above, the scaffolding system determined the appropriate instance to send a scaffold based on the students’ attention focus. The scaffolds were triggered by the system in relation to the following changes in the attention focus of the students. Orientation activities should be performed just before selecting a task; thus at sub-task selection triads received a scaffold to orientate on the sub-task. Planning should be done just before starting a task; therefore planning scaffolds were implemented just before execution of the sub-task. Finally, monitoring should be performed during and after execution of the task, upon saving the sub-task triads were shown a scaffold prompting them to monitor (Molenaar, van Boxtel, Sleegers & Roda, 2011). For each sub-task three types of scaffolds were implemented: orientation, planning and monitoring scaffolds. Students in the scaffolding conditions received a minimum of 12 scaffolds in each condition (see Appendix 4A for an overview of all scaffolding messages).

Figure 7. An example of a structuring and problematizing scaffold.

The triads in the structuring condition (experimental group 1) received scaffolds in the structuring form, which consisted of direct support to their metacognitive activities on the interpersonal plane. The triads in the problematizing condition (experimental group 2) received scaffolds in the problematizing form which were designed to elicit individual students’ metacognitive activities and explanations. The triads in the problematizing condition were obliged to answer the agent’s questions in an answer box on the screen (see figure 7) for an example of both forms of scaffold. Screenshots in 4A show how the messages are integrated into the electronic learning environment. Table 7 shows the messages of the orientation, planning and monitoring scaffolds in structuring and in problematizing form for the introduction task (Appendix 4A contains all scaffolding messages).
Table 7. Examples of structuring and problematizing scaffolds for the introduction task.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Structuring scaffold</th>
<th>Problematizing scaffold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation on introduction</td>
<td>Before we start, I would like to know who you are, please introduce yourselves.</td>
<td>Why are you going to introduce yourselves?</td>
</tr>
<tr>
<td>Planning of introduction</td>
<td>I am going to show you an example of how to introduce yourselves: I am David, I am 12 years old and like to play games on the internet.</td>
<td>How are you going to introduce yourselves?</td>
</tr>
<tr>
<td>Monitoring of introduction</td>
<td>Thank you, I will send your introduction to the expert.</td>
<td>Did you introduce yourselves as planned?</td>
</tr>
</tbody>
</table>

Finally, the triads in the control group did see the virtual agent, but did not receive any form of metacognitive support from the agent. The agent was included in the interface to prevent a Hawthorne effect, implicating that the sole presence of the agent could influence the student activities without the actual scaffolding (Franke & Kaul, 1978).

**Measurements**

The discourse of all triads was audio-taped using voice-recorders. We coded the transcribed protocols of each lesson. The unit of analysis was the speakers’ turn. Mutually exclusive and exhaustive categories were used, which entails that every turn was coded and coded with only one main category code and one subcategory code. Table 8 shows an overview of the main categories. The categories cognitive activities, metacognitive activities, off task activities, not codable activities and teacher activities were derived from the coding scheme of Veldhuis-Diermanse (2002). Additionally, two types of activities were added; relational activities specific for the group setting and procedural activities specific for our learning environment.

Table 8. Main categories of our coding scheme.

<table>
<thead>
<tr>
<th>Main category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacognitive activity</td>
<td>Turns about monitoring and controlling the cognitive activities during learning</td>
</tr>
<tr>
<td>Cognitive activity</td>
<td>Turns about the content of the task and the elaboration of this content</td>
</tr>
<tr>
<td>Relational activity</td>
<td>Turns regarding the social interaction between the students in the triad</td>
</tr>
<tr>
<td>Procedural activity</td>
<td>Turns regarding the procedures to use the learning environment</td>
</tr>
<tr>
<td>Teacher/researcher</td>
<td>Turns that are made by the teacher or the researcher.</td>
</tr>
<tr>
<td>Off task</td>
<td>Turns that are not relevant to the task.</td>
</tr>
<tr>
<td>Not codable</td>
<td>Turns that are too short or unclear to interpret</td>
</tr>
</tbody>
</table>

The category metacognitive activities includes turns that deal with the regulation of cognitive activities, thus the controlling and monitoring of these activities on the interpersonal plane. The category cognition contains turns about the content of the task and
elaboration on this content. Relational turns deal with social interaction between students in the triad. Procedural turns support procedures using the electronic learning environment. The main subcategory metacognitive activity was coded further for six different subcategories: orientation, planning, monitoring, evaluation and reflection which were derived from the coding scheme of Meijer, Veenman, & van Hout-Wolters (2006) for metacognitive subcategories. Previously reported low numbers of execution activities lead to the removal of this subcategory in our coding schema.

Within each subcategory, different activities are combined as specified in Table 9. Orientation utterances include turns about orientation on prior knowledge, task demands and feelings about the task. Planning utterances deal with planning of the learning strategies used for a particular task. Monitoring of the learning process deals with turns related to checking the progress and the comprehension of the task. Evaluation utterances deal with the evaluation of the learning process and content and finally reflection elaborates on the learning process.

**Table 9. Subcategories of metacognitive activities**

<table>
<thead>
<tr>
<th>Subcategory</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>Orientation on prior knowledge, task demands and feelings about the task</td>
<td>What do we need to do?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do you know what a learning goal is?</td>
</tr>
<tr>
<td>Planning</td>
<td>Planning of the learning process, for instance, sequencing of activities or choice of strategies</td>
<td>How are we going to do this?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Now we are going to ask questions.</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Monitoring of the learning process: checking progress and comprehension of the task.</td>
<td>I do not understand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>You are doing it wrong</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wait, please just leave it like that</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Evaluation of the learning process; checking of the content of the learning activities.</td>
<td>We posted a good question</td>
</tr>
<tr>
<td>Reflection</td>
<td>Reflection on the learning process and strategies through elaboration on the learning activities.</td>
<td>Let me think, this is more difficult than I thought.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why do we have the most difficult task?</td>
</tr>
</tbody>
</table>

For each group and for each lesson we calculated the quantity of metacognitive activities and of the sub-activities orientation, planning, monitoring, evaluation, and reflection. We cumulated these numbers to the total quantity over all the lessons. To determine the reliability, two raters independently coded two randomly selected protocols (2500 turns). We used Cohen’s Kappa to determine the inter-rater agreement. There was an excellent (Fleiss, 1981) agreement for the main categories: the kappa was K=0. 92. The kappa was highest for the category metacognitive activities K=0.94 and lowest for category non-codable K=0.82. There also was an excellent agreement within the sub-metacognitive scale with an overall kappa of K=0.92. The kappa was the highest for orientation K=0.94 and lowest for planning K=0.77.
Analysis

As mentioned earlier, the purpose of our study is to determine the effect of metacognitive scaffolding and the different forms of scaffolding on the groups’ metacognitive activities. The focus of our study is thus on the stimulation and development of metacognition in small groups through scaffolding. As a consequence all analyses were done at the triad level and we therefore did not pay attention to individual differences between students or effects of metacognitive group activities on individual performances.

To assess the metacognitive activities of triads, we used discourse analysis. The total dataset entails 108 hours of lessons and 51,339 utterances. To test the stimulation hypothesis, we examined the effects of scaffolding on the quantity of metacognitive activities performed by triads. The development hypothesis was tested by examining the quantity of metacognitive activities performed after scaffolding has been ceased (lessons 3 until 6). There was no significant difference in total utterances between the control condition (mdn= 2633) and the scaffolding conditions (mdn = 3122; U= 32; p = 0.75 n.s.) nor between the problematizing condition (mdn= 3223) and the structuring conditions (mdn = 3122; U= 16; p = 0.82 n.s.). We therefore used in our analysis frequencies of metacognitive activities. Although the distributions of the conditions were similar, but the sample was not normally distributed, we used a Mann-Whitney test to evaluate the hypotheses.

The first test was between the control condition and the scaffolding conditions to assess the effect of scaffolding. The second test was between the problematizing condition and the structuring condition to assess the effect of the form of scaffolding. The effect sizes are calculated using the effect size estimate r, following Rosenthal (1991) defining 0.1 as a small effect, 0.3 as a medium effect and 0.5 as a large effect. To further determine the effects on subcategories we followed the same procedure. There were too few reflection turns (0.08% of all metacognitive turns) to include them in the analysis.

Results

Stimulation of metacognitive skills: the activation of metacognitive activities during scaffolding

The Mann-Whitney test showed an effect of scaffolding on the frequency of metacognitive activities on the interpersonal plane: the experimental group (mdn= 687) outperformed the control group (mdn = 400) significantly (U=17; p<0.05 (one sided); r=0.40). These findings suggest that scaffolding had a medium to large effect on the quantity of metacognitive activities.

With regard to the effects of scaffolding on the separate metacognitive sub-activities (orientation, planning, monitoring and evaluation), the results revealed that there is a significant difference between the triads in the experimental and the triads in the control condition with respect to the quantity of the metacognitive sub-activities they perform. The
Chapter 4

triads supported by scaffolds performed more orientation activities (mdn = 22) compared to the control group (mdn = 14; U = 17; p = 0.04 (one sided), r = 0.42). Also more monitoring activities occurred in the dialogue of the triads supported by scaffolds (mdn = 312) compared to the control group (mdn = 210; U = 14; p < 0.05 (one sided), r = 0.49). Furthermore the results indicated a trend in the expected direction; the triads in the experimental condition performed more planning activities (mdn = 238) than the triads in the control group (mdn = 117; U = 20.5; p > 0.05 (one sided), r = 0.34) and more evaluation activities (mdn = 77) compared to the triads in the control condition (mdn = 55); (U = 23; p > 0.05; r = 0.28). Figure 8 shows an overview of the mean frequencies for the separate metacognitive sub-activities.

Figure 8. The mean frequency of metacognitive sub-activities comparing the control group and the scaffolding conditions.

In addition to examining the effect of scaffolding on metacognitive activities between the experimental condition and control condition, we also examined the effect of different forms of scaffolding on the amount of metacognitive activities triads performed. In order to assess this effect, a Mann-Whitney test was performed comparing the differences between the problematizing condition and the structuring condition. The results showed that student dialogues in the problematizing condition (mdn = 766) did not contain significantly more metacognitive activities than dialogues of the structuring group (mdn = 624; U = 14; p > 0.05, r = 0.19). We also did not find significant effects of forms of scaffolding on the metacognitive sub-activities performed by triads in the different experimental groups. Figure 9 provides more information and shows an overview of the different metacognitive activities performed by the different conditions. All trends are in the expected direction.
The effects of scaffolding on the development of metacognitive activities found comparing the control condition and the experimental condition, could not be found when comparing the structuring condition to the problematizing condition. The results of the Mann-Whitney test between these two experimental conditions showed that student’s dialogues in the problematizing condition (mdn=417) did not contain significantly more metacognitive activities than the student’s dialogues of the structuring group (mdn = 321; U=15; p>0.05, r= 0.14) when scaffolding has ceased.

Development of metacognitive skills; activation of metacognitive activities after scaffolding ceased

The effects of scaffolding on the development of the metacognitive activities on the triads’ interpersonal plane after scaffolding ceased were analyzed with a Mann-Whitney test. The results showed a significant lasting effect of scaffolding on the frequency of metacognitive activities on the interpersonal plane. The triads in the experimental condition who received scaffolds showed significantly more metacognitive activities when scaffolding has ceased (mdn 369) than the triads in the control group (mdn = 241; U=15.5; p<0.05 (one sided), r=0.45). These findings suggest that scaffolding can have a medium to large effect on the development of metacognitive activities even when scaffolding has been ceased.
Some illustrations

In order to better understand the effect of scaffolding on the development of metacognitive activities in the triads, figure 10 illustrates the mean frequencies of the different metacognitive activities in the different conditions over time. This figure shows that orientation only occurs more frequently in the problematizing condition when students received orientation scaffolds. After the scaffolding ceases the orientation activities immediately fall back, seemingly not yielding any learning effects.
With respect to planning and monitoring, both problematizing and structuring scaffolds stimulated the occurrence of these activities. The problematizing conditions continue to show more planning and monitoring activities in lesson 3 compared to the structuring and control conditions after which the patterns become comparable. Thus during the third lesson there seems to be a stronger learning effect of problematizing scaffolds compared to structuring scaffolds. Finally, we did see an effect of scaffolding on the evaluation activities even though students did not receive scaffolds directed at evaluation activities.

Figure 10. The usage over time of orientation, planning, monitoring and evaluation activities shown in the three conditions.
Triads in the structuring condition show an increase during lesson 2. Triads in the problematizing condition show a higher frequency throughout all the lessons. This could be explained by the high interdependency between the different metacognitive activities (Veenman & Spaans, 2005). For example, a detailed learning plan supports the students to effectively monitor the learning progress, checking their proceedings and supports evaluative actions to correct failures and misunderstandings. This interdependency could entail that scaffolding particular metacognitive activities on the interpersonal plane (i.e. orientation, planning and monitoring) can also influence metacognitive activities that are not supported by scaffolds (evaluation and reflection).

Conclusion and discussion

Research has shown that students collaborating in small groups have difficulties with regulating their learning in a complex open learning environment, due to a lack of metacognitive activities. In order to stimulate metacognitive activities to enhance the collective cognitive activity and develop metacognitive skills for future learning, scaffolding of metacognitive activities is needed. In this study an experiment was performed comparing a control group to the experimental group that received scaffolds. Our first goal was to understand the effects of metacognitive scaffolding on the quantity of metacognitive activities in small groups. In addition, the effects of different forms of scaffolds on the metacognition activities in small groups were tested comparing the experimental triads in two different experimental conditions: triads receiving structuring scaffolds versus triads receiving problematizing scaffolds. Our second goal was to determine the lasting effects of scaffolding on metacognitive activities in small groups after scaffolding is ceased and to establish the differential effects of problematizing versus structuring scaffolds on the groups’ metacognitive activities. We tested the hypotheses by analyzing the discourses of triads’ aged 10 to 12 in three different schools in the Netherlands.

The results of the discourse analysis showed that metacognitive scaffolding had a significant positive effect on the quantity of metacognitive activities performed by triads on the interpersonal plane. The analysis of the sub-activities also showed a significant effect for orientation and monitoring activities and a trend in the expected direction for planning and evaluation. These findings confirmed our stimulation hypothesis: scaffolding supported triads to engage in more metacognitive activities. With respect to the effect of different forms of scaffolds on the metacognitive activities; we predicted that problematizing scaffolds elicit more metacognitive activities than structuring scaffolds. This expectation was based on the combination of two aspects; the direct activation of students’ metacognitive activities and the anticipated stronger effect on the interaction in the group of problematizing scaffolds. This hypothesis was not confirmed, yet the direction of the results was as expected. These results suggest that scaffolding can increase metacognitive activities on the interpersonal plan, yet we did not find differentiating effects of the different forms of scaffolds.
The development hypothesis predicted that scaffolds have a positive effect on the metacognitive skills revealed by the amount of metacognitive activity performed after the scaffolding was ceased. This hypothesis was also confirmed; the triads receiving scaffolds remained to perform more metacognitive activities after the scaffolding had stopped than the triads in the control group. This supports the expectation that metacognitive activities on the interpersonal plane contribute to the development of the individual metacognitive skills of students leading to a lasting effect on metacognitive activities. These findings co-collide with findings from another study we conducted on the effect of scaffolding on learning outcomes; students receiving scaffolds scored significantly higher on individual metacognitive knowledge than students that did not receive scaffolds (Molenaar, van Boxtel & Sleegers, 2011). This thus confirms the following mechanism; the scaffolds stimulate metacognition which leads to an increase in metacognitive activities in interaction between the group members which supports the development of individual metacognitive skills resulting in more metacognitive activity in the triad. The form of the scaffolds, however, did not affect the performance of metacognitive activities after scaffolding was ceased, but again the trend was in the anticipated direction.

A possible explanation for the lack of a significant difference between the two different forms of scaffolds could or might be the limited intensity of scaffolding, the students only received 12 different scaffolds during the first two hours on the task. This intensity is enough to make the distinction between no scaffolding and scaffolding but not to make the more subtle distinction between the different forms of scaffolding. Additionally, it is possible that the form of the scaffold made no difference with respect to triggering metacognitive activities and had no differential influence of the groups’ interaction. However, our previous findings with respect to the effects of different forms of scaffolding on individual learning outcomes did show that students gained more metacognitive knowledge on an individual test taken after the study (Molenaar et al. 2011). We anticipated that these results could be explained by the quantity of metacognitive activities performed in the triads; however this analysis shows this is not the case. To complicate this case, we also found that the groups supported with problematizing scaffolds wrote papers with significantly higher quality and scored significantly higher on the transfer of domain knowledge than students in the structuring condition (Molenaar et al., 2011). These results demand for an explanation; why do problematizing scaffolds yield more metacognitive knowledge than structuring scaffolds even though they do not stimulate more metacognitive activities? There are a number of viable explanations; first, the qualitative differences in metacognitive activities indicating that some metacognitive activities are better than others and thus have more effect on the development of metacognitive skills. Second, the interaction around metacognitive activities caused by the different forms of scaffolds could lead to different learning results; more transactive interaction in which learners build more on each other’s contributions are known to increase cognitive learning results (Teasley, 1997, Weinberger & Fischer, 2006) and might also increase the development of metacognitive knowledge in small groups. Third; in line with the interdependence of metacognitive activities the answer could be sought in
different combinations of the metacognitive activities (the optimal mix) and the positioning of the metacognitive activities over time. In future work these directions will be further explored. Finally, the problematizing scaffolds could have been more successful at capturing students’ attention, because students were requested to fill in the answer box.

The main limitation of this study was the small sample size; which should caution the reader in generalizing the result presented. Furthermore, there could be metacognitive activities occurring in the group which are not verbalized by the group members. This can occur if there is non-verbal communication among the group members or if one group member is working individually not verbalizing nor sharing his process with the other group members. Additionally, it could be argued that some metacognitive activities are not explicit, but implicit in the occurrence of higher cognition (Veenman et al., 2006). For these reasons the measurement of metacognitive activities is not exhaustive for all metacognitive activities occurring within the triads. Another limitation is the specific group of participants, namely students from elementary schools, that was used in the experiment. We should be careful in generalizing the results to older students due to the developmental differences in metacognitive knowledge and skills. Finally, the positive effect found may also be caused by the fact that the scaffolding agents were new and interesting for the students participating in the study. However, we do think that this possible short-term additional effect will not sustain over time, thereby reducing the effect of scaffolding during and after the experiment.

Despite these limitations, our main conclusion is that metacognitive scaffolding of small groups in complex open learning environments is successfully in stimulating metacognitive activities and supporting the development of metacognitive skills in the triads. The form of scaffolds does not significantly influence activation of metacognitive activities on the interpersonal plane, however earlier results did show significantly more individual metacognitive knowledge resulting from problematizing scaffolds. This leaves a puzzle to be unraveled in future work. This study contributes to the scientific body of knowledge about the effects of metacognitive scaffolding in small group settings. On a practical level the results can help teachers understand how to support the regulation of small groups of students in complex open learning environments.

Acknowledgements

This research was supported by grants from the National Scientific Organization of the Netherlands (NWO) 411-04-102 and from the European Commission under the FP6 Framework project Atgentive IST 4-027529-STP.
Scaffolding of Small Groups’ Metacognitive Activities with an Avatar

Abstract Metacognitive scaffolding in a computer-supported learning environment can influence students’ metacognitive activities, metacognitive knowledge and domain knowledge. In this study we analyze how metacognitive activities mediate the relationships between different avatar scaffolds on students’ learning. Multivariate, multilevel analysis of the 51,339 conversation turns by 54 elementary school students working in triads showed that scaffolding has an effect on students’ learning. Students receiving structuring or problematizing metacognitive scaffolds displayed more metacognitive knowledge than students in the control group. We found that metacognitive activities mediate the effects of scaffolding and that increased metacognitive activities support students’ metacognitive knowledge. Moreover students who were engaged in proportionately more cognitive activities or fewer off-task activities also outperformed other students on the metacognitive knowledge test. Only problematizing scaffolds lead to more domain knowledge and again metacognitive activities mediate the effects of the problematizing scaffolds. Moreover students in the problematizing condition who were engaged in more cognitive activities or whose group mates used more relational activities had greater domain knowledge acquisition than other students.

Keywords Scaffolding * Metacognition * Embodied Agents * Elementary Education.

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Introduction

Students collaborating in computer-based learning environments often have problems regulating their learning (Azevedo & Hadwin, 2005; Manlove, Lazonder, de Jong, 2006). They often do not engage in sufficient metacognitive activities to control and monitor their learning. Metacognitive scaffolding can support student’s metacognitive activities and learning (Azevedo, Moos, Greene, Winters, & Cromley, 2008; Land & Greene, 2000; Veenman, Kok, & Blote, 2005). However, previous scaffolding studies only examined the effects of scaffolding on student’s learning (Molenaar, van Boxtel & Sleegers, 2010; Veenman, 2011). Therefore, there is little in-depth knowledge of how metacognitive activities are related to types of scaffolding (structuring vs. problematizing) and learning.

Unlike past studies on a data set that examine whether the post-intervention outcomes or the group’s metacognitive activities simply differ across the control and experimental conditions (Molenaar, van Boxtel & Sleegers, 2011), this study uses multivariate, multilevel methods on a subset of the data to test an explanatory model of the relationships among the scaffolds, student activities (metacognitive and others), group mate activities, and individual learning outcomes.

Moreover, most research into scaffolding focuses on the effects of metacognitive scaffolds in individual settings (Azevedo et al. 2008, Veenman et al, 2005). Although these results can be used to understand the role of metacognitive scaffolding on student learning in collaborative learning settings, some important issues related to the nature of collaborative learning need further exploration. In small groups, students elaborate, discuss and give feedback on each other’s contributions, which supports learning (Chi, 2009; van Boxtel, 2004; Webb, 2009). Furthermore, student’s involvement is important, student’s constructive activities affect learning more than active activities attending to other student’s contributions (Chi, 2009). Consequently, to understand the effect of scaffolding in collaborative settings, it is crucial to understand how scaffolds influence student’s involvement embedded in the group’s interaction. In addition, the underlying assumption of constructivist theories is that the nature of learning activities (e.g. cognitive, metacognitive activities) influences student learning (Duffy & Jonassen, 1992; Janssen, Erkens, Kirschner, & Kanselaar, 2010). During collaborative learning, many activities beyond metacognitive activities (such as cognitive, relational and off task activities) support students’ learning (Jansen, et al, 2010). Therefore, we will argue that a comprehensive analysis of how metacognitive scaffolding affects learning requires that the other learning activities are taken into account to assess the unique effects of metacognitive activities.

This chapter examines the question: to what extent do metacognitive activities mediate the effects of scaffolding and different scaffolds on students’ learning? We argue that different forms of metacognitive scaffolds foster metacognitive activities differently and, in turn, will have differential effects on student learning, i.e students’ metacognitive knowledge and domain knowledge. We expect that metacognitive activities mediate this
relationship between scaffolding and individual learning. The activities of 54 students during their 51,339 conversation turns across 108 hours were analyzed as they collaborated face-to-face in triads in a computer supported learning environment. There were three metacognitive scaffolding conditions (none, structuring, and problematizing). We used mixed methods, namely discourse analysis and multi-level statistical analysis. As such, this paper not only contributes to our understanding of how different metacognitive scaffolds affect students’ metacognitive activities and learning, it also offers practical insights on how to create scaffolds that support students’ engagement in activities that aid learning.

**The effect of metacognitive scaffolding on metacognitive activities and learning**

Scaffolding is defined as providing assistance to a student when needed and fading the assistance as the competence of the student increases (Wood, Bruner, & Ross, 1976). Research indicates that scaffolding facilitates learning as it supports learners in tasks they are unable to accomplish successfully by themselves, as well as developing knowledge for future learning (Hmelo-Silver & Azevedo, 2006; Pea, 2004; Sharma & Hannafin, 2007). Metacognition is defined as knowledge about and regulation of cognitive activities (Flavell, 1979). Metacognitive scaffolding aims to help students to adequately control and monitor their learning (Azevedo et al., 2008; Molenaar et al., 2010; Veenman et al., 2005). Students in small groups are supported to engage in metacognitive activities, such as orientation, planning, monitoring, evaluation and reflection (Meijer, Veenman & Van Hout-Wolters, 2006). Research showed that metacognitive scaffolds in small groups stimulate metacognitive activities and enhance students’ learning (Azevedo & Cromley, 2004; Land & Greene, 2000). Researchers often assume that metacognitive activities mediated the effect of scaffolding on learning, but there is little empirical evidence for this assumption (Veenman, Kok & Blote, 2005). Moreover, scaffolding and metacognitive activities are often embedded in interaction between the group members. To understand how metacognitive scaffolding affects students’ learning during collaboration, we must look at perspectives on collaborative learning.

Collaboration can aid student’s learning when students modify their knowledge through interactions with their group members. Various collaborative learning perspectives, e.g., cognitive elaboration (Chi, 2009; Mercer, 1996; Webb, 2009; van Boxtel, 2004; socio-cognitive conflict, Piaget, 1932; Doise, 1990; Doise & Mugny, 1984; co-construction, (Hatano, 1993; van Boxtel, 2004) stress different mechanisms that cause learning during collaboration, e.g., giving, receiving and using explanations; resolving conflicts; co-construction. They all emphasize that students’ elaborations on one another’s contributions support learning. Thus, a side effect of metacognitive scaffolding in small groups is that the interaction among the group members can stimulate reflection, provide feedback and elicit discussion of metacognitive activities, which in turn enhances individual learning (Chi, 2009, Webb, 2009).
Another important issue influencing learning in collaborative settings is a student’s involvement in learning activities. Active vs. constructive vs. interactive learning activities are each related to different cognitive processes (Chi, 2009). Active activities entail attending to ongoing actions through activating prior knowledge, assimilating new knowledge and storing it (Chi, 2009). Stronger involvement is found in constructive activities, in which a student goes beyond the presented information through self-explaining, inferring new knowledge, organizing or restructuring existing knowledge (Mayer & Wittrock, 1996; Chi, 2009). Finally, in interactive activities, students build on their group members’ contributions through elaboration, feedback, agreeing and challenging ideas (Chi, 2009; Webb, 2009). For example, studies have shown that even collaboration with an ignorant partner generates better learning achievements than learning alone (Chi, 2009). Ignorant partners pose questions that elicited their partner’s constructive activity. Furthermore, in pairs of students with similar past achievement, in which each student perform an “explainer” or a “listener” role, the explainers learn more than the listeners (Coleman, Brown, Rivkin, 1997; Housmann, Chi & Roy, 2004; Schwartz & Bransford, 1998). By engaging in more constructive activities than the listeners, the explainers benefit more from their participation in collaborative activity. This indicates that even though interaction among group members supports learning during collaboration, the student’s involvement in these activities influences how he or she learns. Thus students who engage in more constructive activities due to scaffolding might benefit more than students who engage only in active activities.

Based on the above research, it can be argued that scaffolding in a collaborative setting may foster student’s involvement embedded in interaction between the group members, which in turn, affects student’s learning. Reiser (2004) specified two mechanisms to explain student’s learning from scaffolding. Structuring simplifies the learning assignment by reducing its complexity, clarifying the underlying components and supporting performance (i.e., providing the students with an example of a plan for the assignment). Problematizing increases the complexity of the learning assignment by emphasizing certain aspects of the assignment and asking learners to clarify the underlying components and perform actions to construct their own strategies (i.e. asking students to make their own plan for the assignment). These different mechanisms support the formation of different scaffolds that either structure or problematize metacognitive aspects of the learning assignment.

Structuring scaffolds give context suitable examples of metacognitive activities to the group (e.g., showing students an exemplary plan for their mind mapping task when they start this task “What would you like to learn; let’s make a mind map with important topics to learn, for instance the climate”). Structuring scaffolds encourage students’ attention to the information in the scaffold, but do not invite them to construct their own metacognitive activities. On the other hand, problematizing scaffolds pose context suitable questions that elicit students’ metacognitive activities (e.g., asking students to plan their mind mapping task when they start this task “How are you going to make the mind
map?”). Past studies showed that problematizing scaffolds, such as question prompts elicit students’ explanations and support articulation of students’ thinking (Chi, Siler, Jeong, Yamuachi, & Hausmann, 2001; Davis & Linn, 2000; King, 1998, 2002). Thus, problematizing scaffolds are likely to encourage students’ constructive activities. Different scaffolds could influence student involvement differently. Scaffolds that drive students’ interaction could stimulate metacognitive activities beyond the direct impact of the scaffolding. Interaction among the group members can further stimulate metacognitive activities when students start to elaborate, discuss and reflect on each other’s contributions. Referring back to the example of the structuring planning scaffold, students can elaborate on this example, adjusting and shaping the group’s plan for the mind map task. In response to the problematizing scaffolds, students can have discussions about (conflicting) views, exchange, share, or co-construct metacognitive activities together.

To conclude, metacognitive scaffolding can influence student learning through supporting and stimulating metacognitive activities that monitor and control the group’s cognitive activities. Different scaffolds provide different support for metacognitive activities, possibly stimulating student’s involvement embedded in the interaction between the group members differently. Unlike scaffolding in an individual setting, scaffolding in a collaborative setting also modifies student’s involvement and supports additional metacognitive activities which can influence learning. The next section elaborates on the effect of metacognitive activities on learning in collaborative settings.

Effects of metacognitive activities on learning during collaboration

In the section above, we argued that metacognitive scaffolding can stimulate metacognitive activities, which in turn aids student learning of domain and metacognitive knowledge (Veenman, 2005; 2011). Metacognitive activities monitor and control cognitive activities, which directly address the task content; for example, students read, elaborate and process information in discussions. Students who engage in more cognitive activities acquire more domain knowledge (Chinn, O’Donnell & Jinks, 2000; Howe et al, 2007). Metacognitive activities support the development of domain knowledge through activating prior knowledge, planning the use of effective strategies to obtain learning goals, integrating new knowledge with existing knowledge, monitoring the group’s activities in relation to the learning goals and evaluating understanding. As such metacognitive activities optimize the cognitive activities, which aids student learning of domain knowledge.

Metacognitive activities support student’s metacognitive knowledge through showing examples, providing room for practice and receiving feedback (Veenman, 2011). Group members construct metacognitive activities in reciprocal interaction (Iiskala, Vauras & Lehtinen, 2004; Iiskala, et al., 2011). Moreover, metacognitive activities embedded in intensive interaction among the group members support productive metacognitive decisions (Goos, Galbraith and Renshaw, 2002). These interactions are likely to also help develop student’s metacognitive knowledge (Salamon, 1993; Veenman, 2011; Molenaar et
al., 2011). Students in groups can share existing metacognitive knowledge and build on one another’s metacognitive contributions to co-construct new metacognitive knowledge (Lin & Sullivan, 2008; Iiskala et al., 2011). Their metacognitive activities can elicit new activities from the other group members. These activities offer opportunities for further metacognitive activities and allow students to appropriate knowledge from other group members. Subsequently, these activities can aid students’ developing knowledge and alter their future participation, which in turn can contribute to the knowledge development of other group members (Salamon, 1993; Volet, Vauras & Salonen, 2009). As noted above, student’s involvement varies across activities (Chi, 2009). Student’s own activities are often constructive in nature; whereas attending to other group members’ contributions often only requires their attention (Chi, 2009). Thus we argue that student’s own metacognitive activities are more likely than attention to other group members’ metacognitive activities to influence his or her metacognitive knowledge.

Apart from cognitive and metacognitive activities in the problem content space, students in small groups engage in activities in the social relational space (i.e., motivating one another, engaging one another and managing allocation of tasks, (Jansen et all, 2010; McGrath, 1991). The group’s activities in the relational space can enhance group members’ social relationships, aid their collaboration and facilitate their learning. These relational activities foster a positive group climate, increase group cohesion, and aid task completion (Kreijns, et all 2003; Massey et al, 2003; McGrath 1999; Jehn & Shah, 1997; Wilson et, 2006). Likewise, negative socio-emotional processes such as rudeness, insults or domination reduce the quality of group solutions (Chiu & Koo, 2003; Webb, Bremer & Zuniga, 2002). Off-task activities (e.g., discussing weekend plans) in the social relational space can improve relationships among group members, but they also tend to reduce learning and achievement (Chiu, 2004). Accordingly, cognitive activities and metacognitive activities support the development of knowledge, while relational activities foster a positive group climate which can support learning. In contrast, off-task behaviors often hinder learning. Hence, multiple activities must be modeled when analyzing the effects of scaffolding and metacognitive activities on learning.

The present study

The purpose of this study is to examine the relationships among different scaffolds, metacognitive activities and students’ learning in a collaborative learning setting. To our knowledge, there are few empirical studies available on the effects of scaffolding on learning in a group setting that also account for both the learning activities and the learning outcomes. We report an experiment with three metacognitive scaffolding conditions (none, structuring, and problematizing). The main question addressed in this study is: To what extent do metacognitive activities mediate the effects of metacognitive scaffolding and different scaffolds (structuring vs. problematizing) on students’ domain and metacognitive knowledge? This question entails three hypotheses (see figure 11):
Hypothesis 1. Scaffolding and different scaffolds support students’ domain and metacognitive knowledge

Previous studies have shown that scaffolding improves student learning. Therefore, we expect that students supported by scaffolding will outperform students in the control group on both domain and metacognitive knowledge. As problematizing scaffolds are more likely than structuring scaffolds to foster constructive metacognitive activities, we expect students supported with problematizing scaffolds to outperform those supported with structuring scaffolds on both domain and metacognitive knowledge.

Hypothesis 2. Scaffolding and different scaffolds support students’ metacognitive activities

Previous studies have shown that scaffolding stimulates metacognitive activities. Thus, we expect more metacognitive activities from students receiving scaffolding than those who do not. As problematizing scaffolds explicitly elicit students’ metacognitive activities and stimulate interaction among students, we expect more metacognitive activities from students who receive problematizing scaffolds than those who receive structuring scaffolds.

Hypothesis 3. Metacognitive activities support students’ domain and metacognitive knowledge

Finally, we argued that metacognitive activities support student’s domain knowledge and metacognitive knowledge. As outlined above, student involvement in learning activities influence their effect on learning. Student’s own activities are likely to aid learning more as they are often more constructive than simply attending to other group members’ contributions. Therefore, we expect that student’s own metacognitive activities are more important than group members’ metacognitive activities in mediating the relationship between metacognitive scaffolding and individual learning.

Methods

For this study, we analyzed the learning activities of students. Due to the labor intensive nature of discourse analysis, we could not analyze all triads that participated in a full study (Molenaar et al., 2010). In the full study, 156 students in three schools divided over six classes participated. The teachers assigned students to triads (52) to maximize
heterogeneity. Teachers rated students as low, middle or high achievers based on their reading, writing and computer abilities and then created triads containing one low, one middle and one high achiever, with at least one boy and one girl. We randomly assigned the triads to the three experimental conditions: (a) no scaffolds (control group, 16 triads); (b) structuring scaffolds (experimental group 1, 17 triads); and (c) problematizing scaffolds (experimental group 2, 19 triads). The conditions were equally divided over the classes. By randomly assigning triads to the conditions within a class, we blocked for effects of classes (Howard, 2006).

As coding all conversation turns from all triads requires enormous time, labor and resources, we randomly drew a smaller sample of 18 triads (one in each scaffolding condition from each class) for this study. The sample consists of 54 students (23 boys and 31 girls) assigned in 6 control triads, 6 triads in the structuring condition and 6 triads in the problematizing condition. The students of this sample were in Grade 4 (9), Grade 5 (27) or Grade 6 (18) across 6 classes in 3 elementary schools. These three schools were comparable, all in outer city suburban areas with a white middle class population. Within each class, equal numbers of triads were assigned to the different conditions, resulting in an equal allocation of triads in each scaffolding condition across schools. For a sample size of 54, an effect size of 0.4 and a significance level of p = .05, the statistical power is 0.86. Hence, non-significant results at the individual level must be interpreted cautiously.

Virtual learning environment and assignment

The e-learning environment in this study, Ontdeknet, supports students in their virtual collaboration with experts (Molenaar, 2003). The experts shared information about their country with students, which was edited by the editor of Ontdeknet. The teacher gives the assignment and monitors students’ progress. Collaborative learning is implemented at two levels: students collaborating with each other face-to-face in small groups with a computer and with an expert in a virtual environment. The study consisted of eight lessons, each lasting one hour. In the first lesson, the students completed a pre-test, and then received instructions about the assignment and the virtual environment. In the last lesson, the students completed several post-tests. All students received the same instructions, and all triads spent the same time working on the assignment (six hours). During these 6 lessons, the triads worked on an assignment called “Would you like to live abroad?” The goal of the assignment was to explore a country of choice (New Zealand or Iceland), write a paper on their findings and decide if they would like to live in this country. The triads worked on one computer and had access to an expert, namely an inhabitant of the country. They could consult the expert by asking questions and requesting information about different topics in the country. In a separate expert window in the computer environment, the expert provided the requested information, and questions were answered in a forum. Four sub-tasks preceded the task to write a paper about the country: (a) introducing the group to the expert, (b) writing a goal statement, (c) selecting a country and (d) specifying topics of interest on a mind map. All tasks were integrated into the working space of the triads,
where they also wrote the paper. The performance of each triad was stored in the learning environment. All lessons were supervised by the same researcher.

The scaffolding system and the conditions

Scaffolds are messages that support the learner in task that they cannot successfully perform without help (Wood et al., 1976). Both forms of metacognitive scaffolds were dynamically integrated into the computer environment. The triads of students in both experimental scaffolding conditions received computerized scaffolds supporting their metacognitive activities during the first two lessons at the same instance in the learning process (Molenaar & Roda, 2008). These scaffolds were given when metacognitive activities are typically executed in the learning process. The timing was based on Zimmerman’s model for self-regulated learning (Zimmerman, 2002). The computerized scaffolding system determined the appropriate instance to send a scaffold based on the students’ attention focus. Students in the scaffolding conditions received a minimum of 12 scaffolds in each condition. The triads in the structuring condition (experimental group 1) received direct support for their metacognitive activities; for example, the computer avatar David showed the students an exemplary plan of a task “The expert would like to know what you want to learn. Please write all the topics about New Zealand that you would like to learn more about in this mind map” (see figure 12). In response, students can elaborate and reformulate the specifications to the planning activities of the group (see 12). The triads in the problematizing condition (experimental group 2) received scaffolds designed to elicit students’ metacognitive activities and explanations; for example, the computer avatar David asks, “How are you going to make a mind map?” The triads in the problematizing condition were obliged to answer the avatar’s questions in an answer box on the screen (see figure 12). In response, students can construct a plan of how to make a mind map. Lastly, the control group triads saw the avatar David, but did not receive any metacognitive scaffolds (to control for a Hawthorne effect, in which the avatar’s mere presence could influence the student activities, Franke & Kaul, 1978).

Figure 12. Example of structuring (left) and problematizing (right) scaffolds
Measurements

The learning activities

The conversations within each triad of students were audio-taped with voice-recorders. We coded the transcribed protocols of each lesson. The unit of analysis was the conversation turn of each speaker. Each conversation turn was coded with one main category code, (see table 10 for an overview) and one subcategory code (see appendix 6A tables 6a1-3). All main categories were mutually exclusive and exhaustive categories, as were all subcategories within a main category.

Table 10. Main categories of our coding scheme.

<table>
<thead>
<tr>
<th>Main category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacognitive activity</td>
<td>Turns about monitoring and controlling the cognitive activities during learning</td>
</tr>
<tr>
<td>Cognitive activity</td>
<td>Turns about the content of the task and the elaboration of this content</td>
</tr>
<tr>
<td>Relational activity</td>
<td>Turns regarding the social interaction between the students in the triad</td>
</tr>
<tr>
<td>Procedural activity</td>
<td>Turns regarding the procedures to use the learning environment</td>
</tr>
<tr>
<td>Teacher/researcher</td>
<td>Turns that are made by the teacher or the researcher.</td>
</tr>
<tr>
<td>Off task</td>
<td>Turns that are not relevant to the task.</td>
</tr>
<tr>
<td>Not codable</td>
<td>Turns that are too short or unclear to interpret</td>
</tr>
</tbody>
</table>

Several categories (cognitive activities, metacognitive activities, off task activities, not codable activities and teacher activities) were derived from the coding scheme of Veldhuis-Diermanse (2002). Additionally, two types of activities were added; relational activities specific for the group setting and procedural activities specific for our learning environment. In this analysis, we focus on cognitive, metacognitive, relational and off-task activities. The cognitive activity category contains turns regarding the content of the task and elaboration of this content (e.g., reading the material, asking a question about the domain, discussing the learning task, elaborating specific issues and summarizing previous contributions of group members, see appendix 6A table 6a1). Metacognitive activity includes turns that monitor or control cognitive activities, and includes Meijer, Veenman and van Hout-Wolters’s (2006) subcategories: orientation, planning, monitoring, evaluation and reflection (see Appendix 6A table 6a2). Relational activity includes turns regarding the social interaction between the students, such as engaging other group members, discussing the division of labor among the group members, and supporting other group members (see Appendix 6A table 6a3). Off task refers to activities that are not related to both the learning task at hand and the task domain, and teacher activities are contributions made by the teacher.

To determine the inter-coder reliability, two raters independently coded two randomly selected protocols (2500 turns). There was an excellent agreement for the main categories (Fleiss, 1981): Cohen’s kappa $K = 0.92$. The kappa was highest for the metacognitive activities, $K = 0.94$, and lowest for the non-codable category, $K = 0.82$. The
dataset consists of 51,339 activities at the conversation turn level across 108 hours of discourse.

Using these codes, we computed individuals and group mates’ proportions of turns; for example,

\[
\% \text{My cognitive activities} = \frac{\text{person’s cognitive turns}}{\text{total turns of group}}
\]
\[
\% \text{Group mates’ cognitive activities} = \frac{\text{group mates’ cognition turns}}{\text{total turns of group}}
\]

We computed parallel pairs of variables for each main category. Furthermore, we analyzed all the responses of the triads to the scaffolds to select representative excerpts illustrating how the triads generally responded to the scaffolds.

**Individual learning achievements**

The individual learning achievements were assessed by measuring each student’s domain and metacognitive knowledge on separate tests. *Domain knowledge* was measured by a curriculum-based knowledge test with 40 questions (true/false/question mark) about the country the students had studied. Students received 1 point for each correct answer, and 0 points for a question mark or an incorrect answer. The question mark option was included to reduce guessing, as we told the students that for each incorrect answer, 1 point would be subtracted from their test score. Cronbach’s alpha was 0.93 for the New Zealand test and 0.88 for the Iceland test. This test was also used as pre-test before students engaged in the learning assignment. The time between pre-test and post-test was eight weeks.

The *metacognitive knowledge* was measured by asking them to imagine that they were going to do the same assignment again. They were asked to write down the steps that they would take to do this assignment. The answers were scored against a full procedural overview made by the researchers. The full procedural overview consisted of 18 steps; examples of steps were “plan the learning task”, “activate prior knowledge” and “monitor the activity of the group.” The maximum score was 18 points. 10% of the tests were scored by two independent researchers (kappa = 0.83). We did not conduct a pre-test of metacognitive knowledge as the test was not suitable for that purpose.

**Analysis**

We used mixed methods to analyze the conversations of students in the different conditions. To understand how different scaffolds stimulate metacognitive activities among students, we used discourse analysis (Gee, 2005). We selected representative excerpts of conversations in which students responded to different forms of metacognitive scaffolds, illustrating how they stimulate students’ metacognitive activities, how students respond (active, constructive or interactive activities) and how they influence students’ interactions.

To test our hypotheses, we must address analytical difficulties involving the outcome variables and explanatory variables (see Table 11). There are two outcome variables, and
they differ across groups and across individuals. To analyze the two outcome variables simultaneously (domain and metacognitive knowledge), we used a multivariate outcome model to account for contemporaneous correlation in the errors across equations (Goldstein, 1995). To model differences across groups and across individuals simultaneously, we used a multilevel analysis (also known as: Hierarchical linear modeling, Bryk & Raudenbush, 1992; Goldstein, 1995) to account for heteroskedasticity.

Table 11. Addressing each analytical difficulty with a statistic strategy

<table>
<thead>
<tr>
<th>Analytical difficulty</th>
<th>Statistics strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcome variables</td>
<td></td>
</tr>
<tr>
<td>• Multiple dependent variables</td>
<td>• Multivariate outcome models (Goldstein, 1995)</td>
</tr>
<tr>
<td>• Differences across groups and across individuals</td>
<td>• Multilevel analysis (aka Hierarchical linear modeling, Bryk &amp; Raudenbush, 1992; Goldstein, 1995)</td>
</tr>
<tr>
<td>Explanatory variables</td>
<td></td>
</tr>
<tr>
<td>• Indirect, mediation effects</td>
<td>• Multilevel mediation tests (Krull &amp; MacKinnon, 2001)</td>
</tr>
<tr>
<td>• False positives (Type I errors)</td>
<td>• Two-stage linear step-up procedure (Benjamini, Krieger &amp; Yekutieli, 2006)</td>
</tr>
</tbody>
</table>

The explanatory variables may show indirect, mediation effects or false positives. To test for multilevel, mediation effects, we use a multilevel, mediation test (Krull & MacKinnon, 2001). Testing many hypotheses increases the likelihood that at least one of them incorrectly rejects a null hypothesis (false positive). To control for this false discovery rate, we used the two-stage linear step-up procedure, which outperformed 13 other methods in computer simulations (Benjamini, Krieger & Yekutieli, 2006). The hypotheses were tested through a three-step process. First, we studied the influence of the control variables on test scores. Second, we conducted regression analyses to test the direct effect of different forms of metacognitive scaffolds on test scores and metacognitive activities. Finally, we tested the mediating influence of metacognitive activities on the relationship between metacognitive scaffolding and test scores with multi-level mediation tests (Krull & MacKinnon, 2001). We estimated a multivariate, multi-level regression of the following form:

\[ \text{Test}_{igy} = \beta_{00y} + f_{0gy} + e_{igy} \] (1)

\( \beta_{00y} \) are the grand mean intercepts of \( \text{Test}_{igy} \), a vector of \( y \) outcome variables (domain knowledge test score and metacognitive knowledge test score) for student \( i \) in group \( g \). The group- and student-level residuals are \( f_{igy} \) and \( e_{igy} \) respectively.

This study design seeks to control for students’ abilities and gender influences. Specifically, each triad includes a student with high abilities, one with medium abilities and one with low abilities. Furthermore, each triad includes at least one girl. Regressions confirmed that neither domain knowledge test score nor metacognitive knowledge test score were associated with means or distributions of ability or gender.
To examine the link between scaffolding interventions and test scores, we entered a vector of $u$ scaffolding conditions: structuring and problematizing (Scaffold) with the control group as the baseline. Each set of predictors was tested for significance with a nested hypothesis test ($\chi^2$ log likelihood, Kennedy, 2004).

$$\text{Test}_{igy} = \beta_{00y} + e_{igy} + f_{0gy} + \beta_{gy}\text{Scaffold}_{igy} + \beta_{gy}\text{Turn}_{igy} \quad (2)$$

Then, we entered a vector of $x$ variables indicating specific conversation turn characteristics: total group turns, percentage of conversation turns in which a student engaged in each activity in their triad (total individual turns, cognitive activities, relational activities, procedural activities, and off-task activities, Turn), and percentages of the above activities of other group members.

Next, we tested whether the metacognitive scaffolding conditions were linked to the percentage of conversation turns in which a student engaged in metacognitive activities in a triad.

$$\text{Metacognition}_{igy} = \beta_{00y} + e_{igy} + f_{0gy} + \beta_{gy}\text{Scaffold}_{igy} + \beta_{gy}\text{Turn}_{igy} \quad (3)$$

Lastly, we added the percentage of conversation turns in which a student engaged in metacognitive activities in a triad (Metacognition) to equation (2). By doing this we can test our third hypothesis.

$$\text{Test}_{igy} = \beta_{00y} + e_{igy} + f_{0gy} + \beta_{gy}\text{Scaffold}_{igy} + \beta_{gy}\text{Turn}_{igy} + \beta_{1gy}\text{Metacognition}_{igy} \quad (4)$$

We used multi-level mediation tests across the above vectors (Krull & MacKinnon, 2001). For significant mediators, the proportional change was $1 - (b'/b)$, where $b'$ and $b$ were the regression coefficients of the explanatory variable, with and without the mediator in the model, respectively.

We reported how a ten percent increase in each continuous variable above its mean was linked to each outcome variable. As percent increase is not linearly related to standard deviation, scaling is not warranted.

An alpha level of .05 was used. Testing many hypotheses increases the likelihood that at least one of them incorrectly rejects a null hypothesis (false positive). To control for the false discovery rate, we used the two-stage linear step-up procedure, which outperformed 13 other methods in computer simulations (Benjamini, Krieger & Yekutieli, 2006).

**Results**

We start with our findings of the discourse analysis. By discussing two representative excerpts, we show how different forms of metacognitive scaffolds influence students’ responses. Next, we illustrate how metacognitive activities influence peer interactions and foster domain and metacognitive knowledge. Lastly, we report the findings of the multivariate, multi-level analyses.
Discourse analysis of representative excerpts

First, we look at the student responses to different scaffolds. A structuring scaffold is typically followed by either the implementation of the scaffold example or a group discussion elaborating on the example. On the other hand, problematizing scaffolds elicit student activities, leading the group to elaborate, share knowledge, resolve a conflict or co-construct new metacognitive activities. We illustrate this with two examples, the structuring scaffold excerpt in example 2 and the problematizing excerpt in example 3.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Code</th>
<th>Conversation turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avatar</td>
<td>Structuring scaffold</td>
<td>A learning goal is what you want to learn. For instance, we would like to learn more about New Zealand to decide if we would like to live there.</td>
</tr>
<tr>
<td>Paul</td>
<td>Metacognitive</td>
<td>Ok, so we will say</td>
</tr>
<tr>
<td>Simon</td>
<td>Metacognitive</td>
<td>We are going to make a paper about</td>
</tr>
<tr>
<td>Loes</td>
<td>Metacognitive</td>
<td>We are going to make a paper about Iceland.</td>
</tr>
</tbody>
</table>

Example 2. An example of a response to a structuring scaffold (underlined texts is spoken by the avatar)

After the structuring scaffold, Paul accepted the example given (“Ok”) and started to apply the example to their assignment with a planning activity (“we will say..”). Simon and Loes finished his effort by applying the example of the avatar to their assignment (“We are going to make a paper about Iceland.”). Unlike the structuring scaffold, the problematizing scaffold in example 3 stimulated a rich discussion about a learning goal’s meaning, its purpose, and its role, rationale and implementation in this assignment. The problematizing scaffold ignites a chain reaction of metacognitive activities. First, Mien asks for the meaning of a learning goal (“What is a learning goal?”). Jan answers by defining a learning goal as “what you want to learn” and by giving an example “become a president.” After clarifying that “become president” was an example, Joost claims that the purpose of learning is “because we want to know things.” In response, Mien asks for their immediate learning goal (“but what do we want to learn now”). Jan answers with their learning goal for this assignment (“We want to learn about a country,”) and its rationale (“to see if we want to live there.”) Joost concurs (“Right”) and articulates its implementation, (“this we have to explain to the expert.”). Through their exploration of the learning goal, the group members orient to the task and construct a better understanding of it. Each student’s metacognitive activity triggers another group member’s metacognitive activity. Furthermore, each metacognitive activity provides validating feedback to the previous one and provides grist from which to co-construct the next one, thereby valuing the importance of metacognitive activities and encouraging its subsequent use and development.

Thus these two examples illustrate how the metacognitive activities elicited by problematizing scaffolds result in more student involvement and interaction, which seem qualitatively different than the activities stimulated by structuring scaffolds.
Scaffolding of Small Groups’ Metacognitive Activities with an Avatars

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Code</th>
<th>Conversation turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avatar</td>
<td>Problematizing scaffold</td>
<td>How are you going to write down a learning goal?</td>
</tr>
<tr>
<td>Mien</td>
<td>Metacognitive</td>
<td>What is a learning goal?</td>
</tr>
<tr>
<td>Jan</td>
<td>Metacognitive</td>
<td>A learning goal is what you want to learn, for example I become a president.</td>
</tr>
<tr>
<td>Joost</td>
<td>Metacognitive</td>
<td>For example, right?</td>
</tr>
<tr>
<td>Jan</td>
<td>Metacognitive</td>
<td>Yes for example there are many things you have to learn.</td>
</tr>
<tr>
<td>Joost</td>
<td>Metacognitive</td>
<td>Because we want to know things.</td>
</tr>
<tr>
<td>Mien</td>
<td>Metacognitive</td>
<td>Yes, but what do we want to learn now?</td>
</tr>
<tr>
<td>Jan</td>
<td>Metacognitive</td>
<td>We want to learn about a country to see if we want to live there.</td>
</tr>
<tr>
<td>Joost</td>
<td>Metacognitive</td>
<td>Right, and this we have to explain to the expert.</td>
</tr>
</tbody>
</table>

**Example 3. An example of a response to a problematizing scaffold (underlined texts is spoken by the avatar)**

**Metacognitive activities as mediating mechanism**

Next, we illustrate how metacognitive activities mediate student learning during collaboration. First, we show an example which illustrates how metacognitive feedback is given during collaborative learning. Second, we show how metacognitive activities improve student’s cognitive activities. Metacognitive knowledge is developed through practice, examples and feedback. In example 4, Joep contributes a plan (“let’s write down hobbies”) to write the introduction assignment. Eline and Noor immediately start implementing this plan (“My hobbies are tennis and ballet”). Eline’s and Noor’s contributions give feedback to Joep that his planning remark was useful. This feedback may positively influence Joep’s metacognitive knowledge.

<table>
<thead>
<tr>
<th>Student</th>
<th>Code</th>
<th>Conversation turns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joep</td>
<td>Metacognitive</td>
<td>Let’s write down hobbies</td>
</tr>
<tr>
<td>Eline</td>
<td>Cognitive</td>
<td>My hobbies are tennis and ballet</td>
</tr>
<tr>
<td>Noor</td>
<td>Cognitive</td>
<td>I play the guitar</td>
</tr>
</tbody>
</table>

**Example 4. An example of metacognitive activity that is implemented in activity**

In example 3 (see section above), there was a more elaborate interaction around metacognitive activities, in which group members actively construct metacognitive activities, but also built on one another’s contributions. In these types of interaction, the elaboration, feedback and co-constructive contributions can help build students’ metacognitive knowledge.

With respect to domain knowledge, cognitive activities built and elaborate on the topic studied. Metacognitive activities in interaction monitor and control these cognitive activities as shown in example 5. While writing their paper, Ine expressed a new idea (“not imported”) and Mark wrote it down. When Mark misunderstands it (“does have to import”), Ine does not notice and repeats (“does import”). However, Sophie detects and corrects the error (“that is wrong, does not import”). Sophie’s monitoring controls her group mates’ cognitive activities. Next, Ine continues to clarify and correct the sentence (“not imported”). Mark accepts and evaluates it (“good sentence”), and Sophie confirms
and plans to continue the formulation of the next sentence. Sophie’s metacognitive activity improves her group’s cognitive activities and receives validation from other group members, which highlights its importance and encourages its further use and development. This instance is likely to help the group members remember that New Zealand does not import all these products, thus affecting the group members’ domain knowledge.

<table>
<thead>
<tr>
<th>Student</th>
<th>Code</th>
<th>Conversation turns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ine</td>
<td>Cognitive</td>
<td>These are all products of New Zealand… not imported …</td>
</tr>
<tr>
<td>Mark</td>
<td>Cognitive</td>
<td>Does have to import.</td>
</tr>
<tr>
<td>Ine</td>
<td>Cognitive</td>
<td>New Zealand that does import.</td>
</tr>
<tr>
<td>Sophie</td>
<td>Metacognitive</td>
<td>That is wrong, does not import.</td>
</tr>
<tr>
<td>Ine</td>
<td>Cognitive</td>
<td>All products of New Zealand, thus not imported.</td>
</tr>
<tr>
<td>Mark</td>
<td>Metacognitive</td>
<td>That is a good sentence.</td>
</tr>
<tr>
<td>Sophie</td>
<td>Metacognitive</td>
<td>Yes and now it is right, lets continue …</td>
</tr>
</tbody>
</table>

**Example 5. An example of cognitive and metacognitive activities**

**Descriptive findings**

Starting with a low domain knowledge pre-test mean of 7.07, the students scored much higher on its post-test (M = 20.72; maximum = 36). Scores on the subsequent metacognitive knowledge test were modest (M = 5.30; maximum = 12). During their group interactions, student’s activities included many cognitive activities (9% of the triad’s turns on average), metacognitive activities (7%), relational activities (7%) and fewer off-task activities (4%). Other group members engaged in substantial relational activities (14%). (The percentages do not sum to 100% due to codes for group mates’ activities and for other activities, such as procedural activities. See summary statistics in Appendix 6B, table 6B1.)

**Multilevel analyses**

The variance components multi-level model (intercept-only) for domain knowledge scores showed that 45% of the differences were between groups, and 55% were among students within each group (see table 12). For metacognitive knowledge test scores, 65% of the differences were between groups and 35% were across students within each group.

**Relation between metacognitive scaffolds and learning**

Hypothesis 1 concerned the direct effect of scaffolding and different scaffolds on domain and metacognitive knowledge. Findings indicate that students in the structuring and problematizing condition outscored students in the control condition on the domain knowledge post-test by 2.65 (not significant) and 4.55 (significant) points respectively on average (see Table 12, Domain knowledge, Model 1). Furthermore, students whose proportion of cognitive activities exceeded its mean by 10% averaged 6.35 points higher on the post-test (see Table 12, Domain knowledge, Model 2). When other group members’ proportion of relational activities exceeded its mean by 10%, a student averaged 6.67 points higher (see Table 12, Domain knowledge, Model 2). Controlling for other learning
activities (cognitive and relational activities), regression coefficients of the different scaffolds on domain knowledge are only slightly smaller (see Table 12, Domain knowledge, Model 3). Students in the problematizing condition still outperformed students in the other conditions. Students in the structuring and problematizing conditions outscored students in the control condition by 1.98 or 2.19 points respectively on the metacognitive knowledge test on average (see Table 6b in appendix 6B, Metacognitive knowledge, model 1). Furthermore, students whose proportion of cognition turns exceeded its mean by 10% averaged 2.32 points higher, respectively, on the metacognitive knowledge test (see Table 12, Metacognitive knowledge, model 2). In contrast, students whose proportion of off-task behaviors exceeded its mean by 10% averaged 4.31 points lower on the metacognitive knowledge test (see Table 12, Metacognitive knowledge, model 2). Controlling for other learning activities (cognitive activities and relational activities), the findings show that the effect of problematizing scaffolds on metacognitive knowledge, although a little bit smaller, is still stronger compared to structuring scaffolds (see Table 12, Metacognitive knowledge, Model 3). Controlling for other learning activities, students in the problematizing scaffolds condition still outperformed students in both other conditions.

Hypothesis 2 concerned the effect of scaffolding and different scaffolds on metacognitive activities. The results in table 13 show that the students receiving metacognitive scaffolding displayed proportionately more metacognitive activities than other students. Students receiving problematizing scaffolds showed slightly more metacognitive activities than students receiving structuring scaffolds, but this difference was not significant.

Hypothesis 3 concerned the extent to which metacognitive activities mediate the relationship between different scaffolds and students’ domain knowledge and metacognitive knowledge. The findings show that students whose proportion of metacognition exceeded their mean by 10% averaged 9.06 points higher on the post-test (see Table 12, Domain knowledge, Model 4). Controlling for individual proportion of metacognitive actions reduced the problematizing scaffold condition regression coefficient by 35% (multi-level mediation test z = 2.02; p < .05; r = .50; Table 12, Domain knowledge, Models 3 and 4). Together, these explanatory variables accounted for 25% of the domain knowledge post-test score variance.

With regard to the mediating effect of metacognitive activities on metacognitive knowledge, the findings show that students whose proportion of metacognition exceeded their mean by 10% averaged 3.01 points higher on the post-test (see Table 12, Metacognitive knowledge, Model 4). Controlling for individual proportion of metacognitive actions reduced the structuring scaffold and problematizing scaffold conditions’ regression coefficients by 86% and 77% respectively (multilevel mediation tests: z = 2.02; p < .05; r = .39; and z = 2.01; p < .05; r = .50). Together, these explanatory variables accounted for 39% of the metacognitive knowledge test score variance.
Table 12. Unstandardized regression coefficients (with Standard errors) of multivariate, multilevel regression model results simultaneously predicting post-test and metacognitive knowledge test (N = 54)

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Domain knowledge test</th>
<th>Metacognitive Knowledge Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1 (^a)</td>
<td>Model 2 (^b)</td>
</tr>
<tr>
<td>Structuring scaffolds</td>
<td>2.65 ((1.92))</td>
<td>2.56 ((1.90))</td>
</tr>
<tr>
<td>Problematizing scaffolds</td>
<td>4.55 ** ((1.74))</td>
<td>4.26 ((1.62)) * 2.75 ((1.66))</td>
</tr>
<tr>
<td>% My Cognitive activities</td>
<td>63.53 * ((26.06))</td>
<td>59.09 ((23.03)) * 57.85 ((23.02)) *</td>
</tr>
<tr>
<td>% Group mates’ relational activities</td>
<td>66.76 * ((28.04))</td>
<td>60.09 ((27.84)) * 58.64 ((23.23)) *</td>
</tr>
<tr>
<td>% My Metacognitive activities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Variance at each level

<table>
<thead>
<tr>
<th></th>
<th>Explained variance at each level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group level (45%)</td>
<td>0.12 (0.08) 0.28 (0.15) 0.29 (0.21)</td>
</tr>
<tr>
<td>Student level (55%)</td>
<td>0.14 (0.15) 0.15 (0.15) 0.21 (0.21)</td>
</tr>
<tr>
<td>Total variance explained</td>
<td>0.13 (0.12) 0.21 (0.21) 0.25 (0.25)</td>
</tr>
</tbody>
</table>

Explanatory variables only include metacognitive scaffolding conditions
Explanatory variables only include significant turns characteristics other than % my metacognitive activities
Explanatory variables include metacognitive scaffolding conditions and significant turn characteristics other than % my metacognitive activities
Explanatory variables include all scaffolding conditions and significant turn characteristics
Table 13. Unstandardized regression coefficients (with standard errors) of multivariate, multilevel regression model results predicting the % of metacognition (N = 54)

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>% Metacognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structuring scaffolds</td>
<td>0.017 **</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
</tr>
<tr>
<td>Problematizing scaffolds</td>
<td>0.020 **</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
</tr>
<tr>
<td>Variance at each level</td>
<td>Explained variance at each level</td>
</tr>
<tr>
<td>Group level (33%)</td>
<td>.558</td>
</tr>
<tr>
<td>Student level (67%)</td>
<td>.000</td>
</tr>
<tr>
<td>Total variance explained</td>
<td>.186</td>
</tr>
</tbody>
</table>

Discussion

In this study, we examined to what extent metacognitive activities mediated the effect of different scaffolds on students’ domain knowledge and metacognitive knowledge. Three hypotheses were assessed to answer this question. The first hypotheses addressed whether different forms of metacognitive scaffolding affected students’ metacognitive knowledge and domain knowledge. In the structuring condition, the avatar showed contextually-suitable examples of metacognitive activities, whereas in the problematizing condition it posed questions to elicit metacognitive activities. Both metacognitive scaffolds (structuring and problematizing) were associated with higher scores on the metacognitive knowledge test. Only problematizing scaffolds were linked to greater domain knowledge; structuring scaffolds did not significantly affect domain knowledge. With regard to the second hypotheses, the findings show that scaffolding stimulated metacognitive activities (the two scaffolds did not differ significantly). Regarding the third hypothesis, students receiving either metacognitive scaffold engaged in more metacognitive activities, which were linked to their higher metacognitive knowledge test scores. Meanwhile, only problematizing scaffolds were linked to greater domain knowledge, and individual metacognitive activities also mediated this relationship.

These findings suggest that both forms of scaffolding affect students’ metacognitive knowledge mainly through the metacognitive activities that they stimulate. Contrary to our expectations, we did not find a significant difference in the number of metacognitive activities in each scaffolding condition. However, only problematizing scaffolds were linked to greater domain knowledge, suggesting that the metacognitive activities elicited by problematizing scaffolds differed from those elicited by structuring scaffolds. The discourse analysis suggests that structuring scaffolds encouraged students to discuss the application of the example while problematizing scaffolds stimulated students to construct metacognitive activities in interaction with their group members. Hence, structuring scaffolds might foster active metacognitive activities from the students, whereas problematizing scaffolds might trigger more constructive activities embedded in intensive interaction. Constructive activities are likely more effective than active activities at aiding
knowledge acquisition (Chi, 2009). Thus, this qualitative difference in the student interactions might help explain why problematizing scaffolds were associated with greater domain knowledge, while structuring scaffolds were not. This is an important finding because it suggests that the effect of metacognitive scaffolds on learning operates through both a greater number of metacognitive activities within the group and the student’s own involvement in the metacognitive activities.

Finally, we controlled for other learning activities that can affect learning during collaboration (Janssen et al, 2010; McGrath, 1991). The analysis showed that both forms of metacognitive scaffolds were associated with greater metacognitive activities without significantly influencing other activities. Yet, other learning activities did influence students’ metacognitive and domain knowledge. Students performing proportionately more cognitive or metacognitive activities scored higher on both the domain knowledge test and the metacognitive knowledge test, consistent with earlier findings (Janssen et al, 2010). However, other group members’ cognitive and metacognitive activities did not significantly contribute to the student’s domain or metacognitive knowledge in this study, in contrast to earlier studies claiming that students’ elaborations on one another contribution fosters learning (Chi, 2009; Mercer, 1996; Piaget, 1932; Webb, 2009; Weinberger & Fischer, 2006; van Boxtel, 2004). This issue needs more attention in future research especially since we know so little about how metacognitive activities embedded in interaction influence students’ learning (Dillenbough et al, 2009; Iiskala et al, 2011).

We did find some evidence that group mates influence a student’s learning. When a student’s group mates performed proportionately more relational activities, the student scored higher on the domain knowledge test. Relational activities were previously found to foster a positive group climate (Kreijns, et al 2003; Massey et al, 2003; McGrath 1999; Jehn & Shah, 1997; Wilson et, 2006), but were not yet explicitly connected to learning. This study suggests that group mates’ relational activities (but one’s own) foster a student’s domain knowledge. An example of how the relational activities could influence the domain knowledge is given in Appendix 6C. Finally, students who were off-task more often scored lower on the metacognitive knowledge test, but not on their domain knowledge, unlike previous studies linking off task activity with less domain knowledge (e.g., Chiu, 2004). Overall, these results highlight the effects of different activities on learning and the importance of distinguishing between the student’s activities or those of group mates.

In summary, the problematizing scaffold is more strongly linked to student learning than the structuring scaffold is, perhaps due to the qualitative differences in their respective students’ metacognitive activities. However, we have not systematically investigated the effects of different scaffolds on student involvement in the group’s interaction throughout the whole learning assignment. Interaction patterns are often established early in the learning assignment and remain rather stable through the collaboration (Kapur, Voiklis & Kinzer, 2008). This could entail that groups supported with problematizing scaffold
continue to show more intensive interaction through the learning assignment. Future research can examine how scaffolding influences the interaction among the group members during earlier and later time periods of their collaboration. Finally as discussed above, metacognitive activities have received relatively little attention in collaborative learning research as an explanatory factor for learning (Dillenbourgh, Järvelä & Fischer, 2009). We showed that they influence student domain and metacognitive knowledge in collaborative settings, but further research can examine how they are embedded in interaction and how that influences their monitoring and control of cognitive activities.

Conclusions

In this study, we examined if metacognitive activities mediate the learning effects of metacognitive scaffolding. Our analysis of the discourses and achievements of 54 elementary school students showed that students receiving either form of metacognitive scaffolds (structuring or problematizing) engaged in more metacognitive activities and showed more metacognitive knowledge than students who did not receive any scaffolding. However, only students receiving problematizing scaffolds showed greater domain knowledge, which was also mediated by their own metacognitive activities. The discourse analysis suggests that qualitative differences in students’ metacognitive activities can account for the differences between problematizing and structuring scaffolds. These results suggest the superiority of problematizing scaffolds over structuring scaffolds for some tasks.

This study has several limitations regarding sample size, the interaction context of the metacognitive activities, and time/sequence. As this study only has 54 students, non-significant results at the student level must be interpreted cautiously (even though there are 51,339 conversation turns). Meanwhile, we did not examine the micro-time context of recent conversation turns in which metacognitive activities are embedded. One approach to modeling the micro-time context is to examine the characteristics of sequences of recent conversation turns. The impact of a student activity (e.g., metacognition) might differ across micro-time contexts. Likewise, the impact of a student activity (e.g., planning) at the beginning of the session (earlier time period) might differ from the same activity at the end of a session (later time period, Reimann, 2009). Lastly, different sequences of the same set of activities (M,C,M,C,M,C vs. M,M,M,C,C,C) can have different effects on student learning (Chiu, 2008).

On a practical level, the results suggest that problematizing scaffolds and some activities in collaborative settings can aid learning. Specifically, designing problematizing metacognitive scaffolds into virtual learning environments for some tasks can enhance individual group members’ metacognitive activities to aid acquisition of domain knowledge and metacognitive knowledge more than learning environments with structuring scaffolds or with no scaffolds. Furthermore, instructional designs might enhance individual group member’s domain knowledge by engaging all group members in
cognitive and metacognitive activities and encouraging group members to engage in relational activities. Additionally, instructional designs might enhance individual group member’s metacognitive knowledge by engaging all group members in cognitive and metacognitive activities and by reducing their off task behavior.

Acknowledgements

This research was supported by grants from the National Scientific Organization of the Netherlands (NWO) 411-04-102 and from the European Commission under the FP6 Framework project Atgentive IST 4-027529-STP. We acknowledge the contribution of all Atgentive project partners to the development of the AtgentSchool scaffolding system, especially the work of Claudia Roda. We appreciate Yik Ting Choi’s research assistance.
### Table 6A1. Subcategories of cognitive activities.

<table>
<thead>
<tr>
<th>Cognition</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading out</td>
<td>Reading out the information from the instruction, the learning environment or statements of the avatar.</td>
<td>You are going to write a paper. My name is Jan I live in Iceland.......</td>
</tr>
<tr>
<td>Processing</td>
<td>Cognitive processing of the task through: Selection of pictures Writing of text Naming mind map words</td>
<td>I find this picture goes with the texts In New Zealand there are many different animals.....</td>
</tr>
<tr>
<td>Questioning</td>
<td>Asking a question that is related to the content of the task</td>
<td>Do Maoris live in New Zealand?</td>
</tr>
<tr>
<td>Elaboration</td>
<td>Elaboration of task content: relating to other concepts, giving examples or connecting to own experiences.</td>
<td>If there are mountains, it is probably quite high No, you also find tobacco in cigarettes</td>
</tr>
<tr>
<td>Summarizing</td>
<td>Summarizing what has been said before</td>
<td>We have windmills, tulips, traditional clothing and cheese</td>
</tr>
</tbody>
</table>

### Table 6A2. Subcategories of metacognitive activities

<table>
<thead>
<tr>
<th>Metacognition</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>Orientation on prior knowledge, task demands and feelings about the task</td>
<td>What do we need to do? Do you know what a learning goal is?</td>
</tr>
<tr>
<td>Planning</td>
<td>Planning of the learning process, for instance, sequencing of activities or choice of strategies.</td>
<td>Now we are going to ask questions.</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Monitoring of the learning process: checking progress and comprehension of the task.</td>
<td>I do not understand You are doing it wrong Wait, please just leave it like that</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Evaluation of the learning process; checking of the content of the learning activities.</td>
<td>We posted a good question These are the most important issues</td>
</tr>
<tr>
<td>Reflection</td>
<td>Reflection on the learning process and strategies through elaboration on the learning process.</td>
<td>Let me think, this is more difficult than I thought. Why do we have the most difficult task?</td>
</tr>
</tbody>
</table>
**Table A3. Subcategories of relational activities**

<table>
<thead>
<tr>
<th>Relational activities</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engaging</td>
<td>Asking group members to engage in the task</td>
<td>Danick please continue. Jocyce that is not funny.</td>
</tr>
<tr>
<td>Task division</td>
<td>Division of tasks between the group members</td>
<td>She is thinking, I am asking questions and you write. Pascall is typing.</td>
</tr>
<tr>
<td>Support</td>
<td>Repetition or support of a previous speaker</td>
<td>We have to write a paper. Yes, we have to write it.</td>
</tr>
<tr>
<td>Reject</td>
<td>Rejection of previous speaker</td>
<td>No. Do not do that!</td>
</tr>
</tbody>
</table>

**Appendix 6B ancillary tables and results**

**Table 6B1. Summary statistics (N = 54)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>S. D.</th>
<th>Min</th>
<th>Median</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain Knowledge Post-test</td>
<td>20.72</td>
<td>5.83</td>
<td>8</td>
<td>20</td>
<td>36</td>
</tr>
<tr>
<td>Domain Knowledge Pre-test</td>
<td>7.07</td>
<td>3.37</td>
<td>0</td>
<td>7.5</td>
<td>16</td>
</tr>
<tr>
<td>Metacognitive knowledge Post-test</td>
<td>5.30</td>
<td>2.41</td>
<td>1</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Structuring scaffolds</td>
<td>0.33</td>
<td>0.48</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Problematizing scaffolds</td>
<td>0.33</td>
<td>0.48</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>% My Cognitive activities</td>
<td>0.09</td>
<td>0.03</td>
<td>0.01</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>% My Metacognitive activities</td>
<td>0.07</td>
<td>0.02</td>
<td>0.01</td>
<td>0.07</td>
<td>0.12</td>
</tr>
<tr>
<td>% My Procedural activities</td>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
<td>0.04</td>
<td>0.11</td>
</tr>
<tr>
<td>% My relation activities</td>
<td>0.07</td>
<td>0.02</td>
<td>0.01</td>
<td>0.07</td>
<td>0.11</td>
</tr>
<tr>
<td>% My Off-task activities</td>
<td>0.04</td>
<td>0.03</td>
<td>0.01</td>
<td>0.03</td>
<td>0.13</td>
</tr>
<tr>
<td>% Group mates’ Cognitive activities</td>
<td>0.18</td>
<td>0.04</td>
<td>0.09</td>
<td>0.18</td>
<td>0.28</td>
</tr>
<tr>
<td>% Group mates’ Metacognitive activities</td>
<td>0.13</td>
<td>0.03</td>
<td>0.07</td>
<td>0.14</td>
<td>0.19</td>
</tr>
<tr>
<td>% Group mates’ Procedural activities</td>
<td>0.08</td>
<td>0.02</td>
<td>0.05</td>
<td>0.09</td>
<td>0.14</td>
</tr>
<tr>
<td>% Group mates’ Relational activities</td>
<td>0.14</td>
<td>0.03</td>
<td>0.05</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>% Group mates’ Off-task activities</td>
<td>0.07</td>
<td>0.04</td>
<td>0.01</td>
<td>0.06</td>
<td>0.22</td>
</tr>
</tbody>
</table>

**Table 6B2. Correlations, variances, and co-variances are along the lower left triangle, diagonal, and upper right triangle of the matrix (N = 54)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Domain Knowledge Post-Test</td>
<td>32.02</td>
<td>5.98</td>
<td>0.23</td>
<td>0.70</td>
<td>0.06</td>
<td>0.06</td>
<td>-0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>Metacognitive knowledge Post-test</td>
<td></td>
<td>0.47</td>
<td>5.09</td>
<td>0.17</td>
<td>0.24</td>
<td>0.03</td>
<td>0.03</td>
<td>-0.03</td>
</tr>
<tr>
<td>2 Test</td>
<td></td>
<td></td>
<td>0.09</td>
<td>0.17</td>
<td>0.22</td>
<td>-0.11</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3 Structuring scaffolds</td>
<td></td>
<td></td>
<td></td>
<td>0.26</td>
<td>0.23</td>
<td>-0.49</td>
<td>0.22</td>
<td>0.00</td>
</tr>
<tr>
<td>4 Problematizing scaffolds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.34</td>
<td>0.46</td>
<td>-0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>5 % My Cognitive activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.49</td>
<td>0.56</td>
<td>0.39</td>
</tr>
<tr>
<td>6 % My Metacognitive activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.49</td>
<td>0.56</td>
</tr>
<tr>
<td>7 % My Off-task activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.28</td>
</tr>
<tr>
<td>8 % Group mates’ relational activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 6C. Example of how relational activities influence domain knowledge

Other group members’ relational activities can engage a student and thereby aid the student’s learning, as shown in example C1. While Els and Joris are discussing the task, they notice that Lies is not engaged.

<table>
<thead>
<tr>
<th>Student</th>
<th>Code</th>
<th>Conversation turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Els</td>
<td>Relational activities</td>
<td>Lies, what are you doing?</td>
</tr>
<tr>
<td>Joris</td>
<td>Relational activities</td>
<td>Lies can you write this down?</td>
</tr>
<tr>
<td>Lies</td>
<td>Relational activities</td>
<td>Yes, I am sorry, where are we?</td>
</tr>
</tbody>
</table>

Example 6C1. an example of relation activities engaging group members

Els calls Lies by his name to get his attention (“Lies”) and asks him, “What are you doing?” (relational-engaging). Joris further specifies a task for Lies to do (“Can you write this down,” relational -division of labor). In response, Lies agrees (“yes”), apologizes (“sorry”) and starts attending to their task (“where are we?”), thereby aiding his subsequent domain knowledge acquisition. This example shows how other group members’ relational activities can engage a student to work on the task and thereby aid the student’s learning. Having illustrated the two types of metacognitive scaffolds and the students’ activities, we statistically test these relationships.
Part III. Metacognitive Activities and Scaffolding Embedded in Interaction
6 Metacognitive Activities Embedded in Interaction

Abstract In this article we investigate how metacognitive activities are embedded in the interaction between the group members during collaborative learning. Research indicates that the quality of cognitive activities is positively influenced by transactive interaction in which group members relate to and engage in each other’s contributions. We examine if metacognitive activities embedded in different types of interaction are more likely to facilitate the group process. Moreover, we inspect the provisional role of shared attention on interaction. We analyzed 996 metacognitive episodes embedded in the interaction of 6 triads collaborating on a research task in a computer-based learning environment. We found that metacognitive activities can be ignored, accepted, shared and co-constructed among the group members. Shared attention indeed supported more transactive interaction. Moreover, metacognitive activities embedded in more transactive interaction were more likely to facilitate the group process than those embedded in less transactive interaction. These findings confirm that interaction between the group members can positively influence the quality of metacognitive activities and that in collaborative settings it is important to look how metacognitive activities are embedded in interaction.

Keywords ∙ Metacognition ∙ social systems ∙ Collaborative learning ∙ Elementary Education ∙ discourse analysis

Introduction

In the learning sciences there is a strong focus on computer-supported collaborative learning (Stahl, Koschmann & Suthers, 2006). Many studies aim to explain under which circumstances collaboration among students facilitates learning (Dillenbourgh, Jarvala & Fischer, 2009). A central issue is how learning activities are embedded in the group’s interaction (Chi, 2009; Weinberger & Fischer, 2006). Group members elaborating on each other’s contributions, such as providing feedback, giving critical comments and engaging in arguments, fosters learning (Barron, 2003, Webb, 2009). Yet, this research so far has focused mostly on content-related activities, the cognitive activities. From self-regulated learning research, we know that successful learners not only employ cognitive activities, but also control and monitor their learning with metacognitive activities (Azevedo, Moos, Greene, Winters & Cromley, 2008; Zimmerman, 2002). Successful learners orientate on the learning assignment to set clear learning goals and consequently plan, monitor and evaluate their cognitive activities during learning (Veenman, 2011). Until now, metacognitive activities have received little attention in computer-support collaborative learning as explanatory factor for learning (Dillenbourgh, Jarvala & Fischer, 2009).

Moreover, the discussion of metacognition in the literature does not adequately attended to the social nature of collaborative learning (Hadwin & Oshige, 2011; Iiskalla, Vauras, Lehtinen & Salonen, 2011). There is little research that explores how metacognitive activities are embedded in interaction between the group members. Some studies did find that interaction between the group members positively influences metacognitive activities (Goos, Galbraith & Renshaw, 2002; Iiskala et al, 2011; Lin & Sullivan, 2008). However, these studies focused on full reciprocal interaction among the group members, which is fairly rare in collaborative learning (Dillenbourgh, 1999). Therefore the goal of this article is to further enlarge our understanding how metacognitive activities are embedded in interaction during collaborative learning. This article contributes to our current understanding by differentiating between different types of interaction in which metacognitive activities are embedded. Additionally, we investigate how these metacognitive activities embedded in different types of interaction facilitate the group process and what the provisional role of shared attention is. We analyzed 996 episodes of social metacognitive activities from 6 groups that collaboratively worked on a research task in a computer-based learning environment. First, we introduce the construct of metacognition and elaborate on how it facilitates collaborative learning. Then we argue that analyzing metacognitive activities in small groups needs to consider how these activities are embedded in the groups’ interaction.

Metacognitive activities in social settings

The construct of metacognition originates from cognitive information processing theory (Flavell, 1979). It was originally defined as “cognition over cognition” or “knowledge about knowing”, which a learner needs to control and monitor his learning. A distinction is made between metacognitive knowledge, i.e. the knowledge students have about the
interaction between person, task and strategy characteristics (Flavell, 1979) and metacognitive skills, i.e. the skills to apply metacognitive activities to control and monitor cognitive activities (Veenman, 2005). In order to distinguish clearly between cognitive and metacognitive activities Nelson (1996) defined the object- and the meta-level of learning. Cognitive activities are those activities dealing with the content of the task (the object-level) and metacognitive activities are those activities dealing with controlling and monitoring cognitive activities (the meta-level), such as orientation, planning, monitoring, evaluation and reflection activities (Meijer, Veenman, Van Hout-Wolters, 2006). In educational psychology, students’ ability to regulate their learning is considered important for learning in complex computer-based learning environments (Azevedo & Greene, 2010; Winne & Hadwin, 2011; Zimmerman, 2002). Moreover, the literature emphasizes that metacognitive activities facilitate learning and students that use more metacognitive activities gain higher learning achievements (Veenman, 2005; 2011). However, it is important to acknowledge that metacognitive activities can also be inappropriately used and become ineffective when over used (Moos, 2010). Metacognitive activities facilitate learning when they support develop, activate or confirm cognitive activities that consequently help the student to achieve his/her learning goals (Iskala et al., 2011). However, metacognitive activities can also not facilitate the student when they stop appropriate cognitive activities or slow cognitive activities eliciting inappropriate conceptualizations or representation (Iskala et al., 2011).

In small groups learners also need to control and monitor their group’s learning (Hadwin & Oshige, 2007). This entails that groups need to use the appropriate cognitive activities to attain their learning goals and use metacognitive activities to control and monitor their learning (Hadwin & Oshige, 2011, Iskala et al, 2011; Volet, Vauras & Salonen, 2009). For example, group members orientate on their learning assignment, plan the group’s activities, monitor the group’s actions and evaluate the correctness of the group’s learning and finally reflect on the learning strategies followed by the group. In group settings it has been proposed that different forms of metacognitive activities occur at various points along the social spectrum, namely individual, other and social metacognitive activities (Iskala, Vauras & Lehtinen, 2004, Iskala et al., 2011; Hadwin & Oshige, 2011). Individual metacognitive activities occur when a student controls or monitors his/her own cognitive activities (Volet et al, 2009). For example, a student evaluates whether the answer he calculated is correct. Other metacognitive activities are transitional activities between two group members, when one student controls or monitors another student’s cognitive activity (Iskala et al., 2011; Volet et al., 2009). For example, a group member evaluates the answer a group member calculated, supporting the evaluation of the cognitive activity of that group member. Finally, social metacognitive activities occur when one or more group members control or monitor the group’s collaborative cognitive activities (Volet, et al, 2009). For example, a group member evaluates whether the answer the group calculated is correct, supporting the evaluation of the cognitive activity of the group.
In this chapter, we focus on social metacognitive activities. As indicated in the introduction an important issue is the way social metacognitive activities are embedded in the interaction among the group members. Collaborative learning research consequently found that cognitive activities embedded in more intensive interaction between the group members had higher quality and supported learning more (Teasley, 1997; Roschelle, 1996; Stahl, 2005; Suthers, Dwyer, Medina & Vatrapu, 2010). In small groups learning activities are formed through reciprocal activities between the students in which they exchange, share and co-construct activities (Volet et al, 2009). Consequently, students influence each other in a spiral-like fashion; students contribute activities to the social system, which can elicit new activities from the group members (Salomon, 1993). This mechanism is likely to also affect metacognitive activities, for example, one student monitors the groups learning activity by stating that he thinks the calculation the group is performing is wrong. Another group member can ask the student why the calculation is wrong, asking the first student to further elaborate on his monitoring. Hence when the group members engage in intensive interaction around metacognitive activities, this is likely to alter metacognitive activities. Goos, Galbraith and Renshaw (2002) highlight the significance of intensive interaction in contributing to productive metacognitive decisions by the group.

However, previous research only looked at instances of so-called socially shared metacognitive activities. These were embedded in fully reciprocal interaction between group members (Iiskala et al. 2011). From collaborative learning research we know cognitive activities can be embedded in different ways in the group member’s interaction and that fully reciprocal interaction happens relatively infrequently (Weinberger & Fischer, 2006). Therefore, it is important to consider how metacognitive activities are embedded in the interaction between the group members beyond the most intensive type of interaction. In the next section we discuss different types of interaction and how metacognitive activities can be embedded this interaction.

**Metacognitive activities embedded in interaction**

Research clearly shows that the advantage of the group’s interaction on learning depends on the quality of students’ interaction and their discussions (Webb, 2009). Different types of interaction are distinguished in collaborative learning theory. In individual dialogue group members externalize their own knowledge without reference to other students’ activities or engage in disputational talk that is characterized by disagreements, short exchanges and assertions (Chi, 2009; Mercer, 1996; Weinberger & Fischer, 2006). In joint dialogue group members do respond to each others contributions in different ways. Students can elicit activities from other group members through asking questions or explanations (Weinberger & Fischer, 2006). Moreover in cummulative talk they exchange and share existing knowledge making substantive contributions to the same topic (Chi, 2009; Hatano, 1993; Mercer, 1996, Webb, 2009). However, students are not always critical to each other’s contributions. Often they do not disagree with each other or demand for justifications, therefore this type of interaction is also referred to as quick consensus
building (Clark & Brennan, 1991; Fischer et al, 2002; Weinberger, 2003). In conflict oriented consensus building students do challenge each other’s ideas through disagreement (Fischer et al, 2002, Weinberger & Fischer, 2006). Whereas integrated-orientated consensus building (Fischer et al, 2002, Weinberger & Fischer, 2006) or explorative talk (Mercer, 1996, Webb, 2009) refers to students that built on each other’s activities collaboratively constructing new knowledge. Students share each other’s knowledge and additionally explain and question each other’s thinking and provide feedback one and other. Co-construction among group members often leads to knowledge that individual group members are unlikely to generate by themselves (van Boxtel, van der Linden, Roelofs & Erkens, 2002; Damon, 1984).

In these different descriptions of interaction, the constructs “relate to” and “engage in” are very important. Students relate to a group member’s previous contribution when they are referring to the same topic in their next contribution (Barron, 2000; 2003). They engage in a group member’s contribution when they are responding, discussing and elaborating on the previous contribution (Barron, 2000; 2003). During collaborative learning the extent to which students relate to and engage in on each other’s contributions is called transactivity. It has been shown that more transactive interaction supports groups to benefit from their collaboration, gaining more knowledge and better learning (Weinberger & Fischer, 2006). Transactivity varies in different types of interaction (Weinberger & Fischer, 2006; Fischer et al., 2002). Until now this construct is mostly used to analyze how students’ cognitive activities are embedded in interaction, but can also be applied to analyze metacognitive activities embedded in interaction.

Based on the above, we make a distinction between 4 different types of interaction that describe how metacognitive activities can be embedded in groups’ interaction (see figure 13). First, when metacognitive activities are not related to nor engaged in, we call them ignored metacognitive activities. These activities occur when a group member attempts to control or monitor the group’s learning activities, but the other group members ignore this effort. For example, a student evaluates the answer of the group calculated commenting that he thinks the answer is wrong and the other group members do not react.

Second, when metacognitive activities are engaged in but not related to, we call them accepted metacognitive activities. They occur when a group member engages in a metacognitive contribution within a cognitive activity that applies the controlling or monitoring activity suggested. For example, a student evaluates the answer the group calculated commenting that he thinks the answer is wrong. Another group member starts to re-calculate the answer. This indicates that the evaluation activity is noticed and followed up in the calculation.
Third, another form of metacognitive activities embedded in interaction are shared metacognitive activities. They occur when a group member monitors or controls the group’s learning activity and another group member relates to this activity with a metacognitive activity. The students share existing metacognitive knowledge, but do not engage in discussion, elaboration or revision of the metacognitive activities. For example, a student evaluates the answer the group calculated commenting that he thinks the answer is wrong. Another group member comments that he believes the answer might be wrong too.

Fourth, students can co-construct metacognitive activities. This occurs when group members relate to and engage in each other’s metacognitive activities. The metacognitive contributions become object of discussion, revision or elaboration by the group members. Group members build on each other’s metacognitive activities regulating the group’s cognitive activities co-constructing metacognitive activities. For example, a student evaluates the answer of the group calculated commenting that he thinks the answer is wrong. Another group member comments that he believes the answer might be right and justifies this comment. The third student evaluates the comments of the previous two.

To summarize the above, we expect metacognitive activities to be embedded in different types of interaction; ignored, accepted, shared or co-constructed metacognitive activities. In ignored metacognitive activities there is no transactivity. We speak of medium transactivity as group members relate to or engage in each other’s contributions. Finally, high transactivity is occurring when members relate to and engage in each other’s contributions. Moreover groups that are successful at collaborative problem solving are better able to regain shared attention focusing the collaborative group effort. These students relate to each other’s contributions sharing perspectives on a similar topic and engage in each other’s questions, discussions and explanations (Barron, 2000, 2003). On the other hand, groups that are less successful at problem solving often show relational
issues such as competitive and self-focused interactions (Barron, 2000). Group members ignore each other’s contributions and externalize their own thoughts without refereeing to their group members ideas. Thus differences between successful and unsuccessful groups can be explained by the type of interaction between the group members. Moreover, shared attention among the group members seems provisional to create reciprocal and symmetric interaction to which all group members contribute (Barron, 2003; Sfard & Kieran, 2001).

This study

The purpose of this study is to understand how metacognitive activities are embedded in students’ interaction. Group members could engage in ignored, accepted, shared or co-constructed metacognitive activities which are accompanied with no transactivity to high transactivity. One factor associated in the literature with transactive interaction is the group’s shared attention. We expect that shared attention among the group members positively affects the transactivity in the interaction. Moreover, transactive interaction is found to support the quality of the activities. Therefore we expect that metacognitive activities embedded in more transactive interaction are more likely to facilitate the group’s process. We will analyze 996 social metacognitive episodes of 6 groups to answer the following research questions:

1. How are metacognitive activities embedded in the group’s interaction, i.e., to what extent do ignored, accepted, shared and co-constructed metacognitive activities occur?
2. Does shared attention among the group members support transactive interaction?
3. Are metacognitive activities embedded in more transactive interaction more likely to facilitate the group process?

The data were taken from 6 groups that work face to face in a computer-based learning environment on a writing task.

Method

Participants

For this study, we used the discourse from 6 triads taken from a study into the effects of scaffolding on metacognitive activities (Molenaar, van Boxtel & Sleegers, 2010). The selected triads were in the control group of this study. We selected these groups because the metacognitive activities in their discourse are not influenced by scaffolding and represent how groups normally monitor and control their learning in computer-based learning environments. The triads were from 6 different classes divided over three schools. The teachers assigned the students to triads based on the principle of heterogeneity (mixed gender, reading and computer ability and school performance). The triads came from grade 4(1), 5(3) and 6(2) of elementary education in the Netherlands. Names used in the examples are not the real names of the students and students and their parents agreed to participate in this study.
Virtual learning environment and assignment

The e-learning environment used in this study is called Ontdeknet. It focuses on supporting students in their virtual collaboration with experts (Molenaar, 2003). The experts provide students with information about their expertise, namely knowledge about their country for this study. The experts’ contributions were edited by the editor of Ontdeknet. The teacher gives the assignment to the students and monitors their progress. Collaborative learning is implemented at two levels: students collaborating with an expert in a virtual environment and with each other face-to-face in small groups behind the computer. The total duration of the study was 8 lessons of 1 hour. In the first lesson, the students were given instructions about the task and the electronic learning environment in which they performed the task and made a pre-test and during the last lesson they filled in different questionnaires. In 6 lessons the triad worked on a task called “Would you like to live abroad?” The goal of the task was to explore a country of choice (New Zealand or Iceland), write a paper on the findings and decide if they would like to live in this country. The triads worked on one computer and had access to an inhabitant of the country. They could consult the expert by asking questions and requesting information about different topics about the country that they were interested in. In the expert section, the requested information about the country was written by the expert and questions were answered in a forum. The task to write a paper about the country was preceded by 4 sub-tasks: introducing the group, writing a goal statement, selecting a country and specifying topics of interest in a mind map to further support the collaboration with the expert. All tasks were integrated into the working space of the triads, where they also wrote the paper. The performance of the triads was stored in the learning environment. All lessons were supervised by the same researcher (the first author).

Measurement

The discourse analysis

The discourse of 6 groups (36 hours) was audio-taped, transcribed (15,531 turns) and analyzed in six steps. The reliability reported for every step is based on the coding of two independent raters that analyzed the discourse of 2 randomly selected triads (2500 turns). First, we detected the metacognitive activities in the groups (Molenaar et al., 2010). All turns were coded with mutually exclusive and exhaustive categories. The categories were cognitive, metacognitive, relational, procedural, off task, not-codable activities and teacher activity (see table 14 for an overview). There was excellent (Fleiss, 1981) agreement for these categories: the kappa was $K=0.92$. Cohens’ kappa was highest for the category metacognitive activities $K=0.94$ and lowest for category non-codable activities $K=0.82$. 
Table 14. Main categories of our coding schema

<table>
<thead>
<tr>
<th>Main category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacognitive activity</td>
<td>Turns about monitoring and controlling the cognitive activities during learning</td>
</tr>
<tr>
<td>Cognitive activity</td>
<td>Turns about the content of the task and the elaboration of this content</td>
</tr>
<tr>
<td>Relational activity</td>
<td>Turns regarding the social interaction between the students in the triad</td>
</tr>
<tr>
<td>Procedural activity</td>
<td>Turns regarding the procedures to use the learning environment</td>
</tr>
<tr>
<td>Teacher/researcher</td>
<td>Turns that are made by the teacher or the researcher.</td>
</tr>
<tr>
<td>Off task</td>
<td>Turns that are not relevant to the task.</td>
</tr>
<tr>
<td>Not codable</td>
<td>Turns that are too short or unclear to interpret</td>
</tr>
</tbody>
</table>

Second, we determined the metacognitive episodes. Metacognitive episodes are sequences of turns that discuss the same topic and of which at least one turn is a metacognitive activity. The episode starts with the first metacognitive activity and ends with the last turn dealing with the same topic. An example of a metacognitive episode: (“We start with the first chapter of our paper; What are we going to discuss in the first chapter?; Let's read the information about animals in New Zealand”). Two researchers independently determined the metacognitive episodes of the 6 groups; the intercoder-agreement was 71%. All inconsistencies between the two coders were re-coded in mutual agreement.

Third, we determined the form of metacognitive activities namely individual-, other- or social metacognitive activities in the episodes. Individual metacognitive activities occur when one student is regulating his or her own cognitive activities; for example (“Stop I need to think about this”). Other-metacognitive activities occur when a group member regulates the individual cognitive activity of another group member, for example (“What are you doing?; I am trying to understand this question”). Social metacognitive activities occurs when one or more group members regulate their collaborative cognitive activities, for example: (“What are we writing? The goal statement; What is the goal statement?; That is where you write what you want to learn”). Cohen’s kappa was 0.91 which indicates excellent agreement (Fleiss, 1981).

Fourth, we established if there was shared attention among the group members at the start of the metacognitive activities. In case the topic discussed in the episode was talked about in the turns preceding the metacognitive episode, we coded it as in the group’s shared attention. An example of a metacognitive episode shared in attention is (“In New Zealand there are much different animals; This is wrong we cannot write there are much different animals; Ok let’s write many different animals”). In this example, the topic is (“In New Zealand there are much different animals”). This sentence is in the group’s shared attention, as two group members are contributing to the construction of the same sentence, when one group member monitors that the sentence is wrong. An example of a metacognitive episode not shared in attention: (“In New Zealand there are many different animals; We need to discuss the language too”). Here a group member introduces a new
topic to discuss in the group’s paper, when the group’s attention is focused on constructing
the sentence. Cohen’s kappa was 0.72 which indicates acceptable agreement (Fleiss, 1981).

Fifth, for the social metacognitive activities which are a proportion of all
metacongitive episodes, we distinguished four types of interaction around metacognitive
activities: ignored, accepted, shared or co-constructed metacognitive activities. Ignored
metacognitive activities occur when the group members do not relate to nor engage in
another group member’s metacognitive activity, for example: *Let’s read this chapter; I am
so happy*”. Accepted metacognitive activities occur when the group members engage in a
metacognitive activity with a cognitive activity, for example: (“*Let’s write down hobbies;
My hobbies are Tennis and Ballet*”. Shared metacognitive activities occur when a group
member relates to a metacognitive activity with another metacognitive activity, for
example: “*We do not know what to do next; True, but I do not know what to do either;
What do you think?*”. Finally, when group members not only relate to but also engage in
each other’s metacognitive activities, we speak of co-constructed metacognitive activities,
for example: “*Let’s start again with the first part of the chapter; Ok what are we
describing in the first chapter; We discuss the language of the country, let’s read the
chapter about language*”. Cohen’s kappa was 0.86 which indicates good agreement
(Fleiss, 1981).

Finally, we determined whether the metacognitive activities are facilitating the
group’s process. A facilitating metacognitive episode develops, activates or confirms the
group’ cognitive activities that consequently support the group process (Iiskala et al, 2011).
For example “*Let’s start again with the first part of the chapter; Ok what are we
describing in the first chapter; we discuss the language of the country, let’s read the
chapter about language*”. This metacognitive episode facilitates the group process as it
activates new activities that support the group progress. Metacognitive activities that do
not facilitate the group process when they stop appropriate cognitive activities or slow
cognitive activities with inappropriate representations (Iiskala et al, 2011). For example
“*We do not know what to do next*”; “True, but I do not know what to do either”; “*What do
you think?*”. This metacognitive episode slows the group process and it does not support
further progress, thus does not facilitate the group process. Cohen’s kappa was 0.71 which
indicates acceptable agreement (Fleiss, 1981).

Analysis

To answer our first research question, we the frequency of different types of interaction
around metacognitive activities in social metacognitive episodes are computed. To answer
our second research question, we calculated the association between shared attention and
different types of metacognitive interaction using the Chi-square ($\chi^2$). A significant $\chi^2$
indicates that the occurrence of shared attention among the different types of metacognitive
interaction is significantly different from chance. To analyze the relationship between
shared attention and each type of metacognitive activities, we calculated the odds ratios.
The odds ratio is an effect size for categorical data (Fields, 2005), which indicates how much more/less likely it is for a particular type of metacognitive interaction to be in shared attention compared to the other types of interaction. We use the same analysis to determine the relation between the type of interaction and the function of the metacognitive episodes (third research question).

**Results**

We start with descriptive information about the number of metacognitive episodes and the forms of metacognitive activities in the episodes. Among the 15,153 turns in the conversation of the triads during 36 hours, there were 2,649 metacognitive turns (17.5%). We saw a relatively equal participation of all group members in the different episodes. We found 1,150 metacognitive episodes of which 62 (6.2%) were individual metacognitive activities, 92 (9.3%) other-metacognitive activities and the remaining 996 (84.5%) were social metacognitive activities. There was a clear distinction between the individual, other and social metacognitive activities. Examples of individual metacognitive activities “Stop I need to read that” and “I need to write this down to remember it” and examples of other metacognitive activities “Where are you?” and “What is it you do not understand?” clearly focused at individual cognitive activities. Social metacognitive activities are clearly directed at the group’s cognitive activities, such as “We have not read this properly” or “We have not writing about the language of the country”. This indicates that although there are different forms of metacognitive activities during collaborative learning the amount of individual and other- metacognitive activities in this sample is not very high.

**Metacognitive activities embedded in interaction**

The first research question is: how are metacognitive activities embedded in the group’s interaction, i.e., to what extent do ignored, accepted, shared and co-constructed metacognitive activities occur? As mentioned earlier, to find answers for this question we only used the social metacognitive activities, thus all social metacognitive activities accumulate to 100%. Figure 14 provides an overview of the frequency of different types of interaction and table 15 provides the specifications per triad.

We found 218 (22%) episodes with ignored metacognitive activities. There is some variation between the six triads ranging from 18% to 27% of ignored metacognitive activities (see table 15). Many instances of ignored metacognition are simple comments such as (“What are we doing?”). Group members just ignore these attempts. However, there are also examples were the group ignores social metacognitive activities that are precise statements. For example, the group members were writing a chapter about the

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9 Odds ratio\textsubscript{\text{ignoredMC in shared attention}} = \frac{\text{odds ignored metacognitive activities in shared attention}}{\text{odds ignored metacognitive activities not in shared attention}}.

Odds ratio\textsubscript{\text{otherMC in shared attention}} = \frac{\text{odds other metacognitive activities in shared attention}}{\text{odds other metacognitive activities not in shared attention}}.

\text{Odds ratio} = \text{Odds ratio}_{\text{ignoredMC in shared attention}}/\text{Odds ratio}_{\text{otherMC in shared attention}}.
economy of Iceland. They formulate sentences together such as (“Everything is really expensive on Iceland”). Kim monitors that the last sentence is not correct and asks (“Can we please remove the last sentence; it does not fit in this context?”) Ellen just ignores this comment and continues with (“I write; everything is really expensive on Iceland”). Here the group continues without taking the comment from Kim into consideration, even though here statement is not difficult to interpret.

![Figure 14. Percentage of metacognitive activities embedded in different types of interaction](image)

We found 218 (22%) episodes with ignored metacognitive activities. There is some variation between the six triads ranging from 18% to 27% of ignored metacognitive activities (see table 15). Many instances of ignored metacognition are simple comments such as “What are we doing?”. Group members just ignore these attempts. However, there are also examples were the group ignores social metacognitive activities that are precise statements. For example, the group members were writing a chapter about the economy of Iceland. They formulate sentences together such as “Everything is really expensive on Iceland”. Kim monitors that the last sentence is not correct and asks “Can we please remove the last sentence; it does not fit in this context?” Ellen just ignores this comment and continues with (“I write; everything is really expensive on Iceland”). Here the group continues without taking the comment from Kim into consideration, even though here statement is not difficult to interpret.

We found 317 (32%) episodes with accepted metacognitive activities. There is some variation between the six triads ranging from 22% to 32% of accepted metacognitive activities. Accepted metacognitive activities are followed by a cognitive activity indicating that the group member(s) engaged in the metacognitive contribution. For example, Joep makes a plan to enter words into the mind map “What do we want to know about Iceland?” Kim immediately makes a new entry in the mind map “I want to know which the language they speak; what language do you speak?” Kim’s contribution indicates that her response to Joep’s planning contribution proposing another topic that can be discussed in the mind map.
<table>
<thead>
<tr>
<th>Group</th>
<th>Total</th>
<th>Ignored</th>
<th>Accepted</th>
<th>Shared</th>
<th>Co-constructed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>125</td>
<td>34 (27%)</td>
<td>45 (36%)</td>
<td>41 (33%)</td>
<td>5 (4%)</td>
</tr>
<tr>
<td>Group 2</td>
<td>136</td>
<td>31 (23%)</td>
<td>39 (29%)</td>
<td>52 (38%)</td>
<td>14 (10%)</td>
</tr>
<tr>
<td>Group 3</td>
<td>162</td>
<td>33 (20%)</td>
<td>53 (33%)</td>
<td>68 (42%)</td>
<td>8 (5%)</td>
</tr>
<tr>
<td>Group 4</td>
<td>205</td>
<td>37 (18%)</td>
<td>46 (22%)</td>
<td>115 (56%)</td>
<td>7 (3%)</td>
</tr>
<tr>
<td>Group 5</td>
<td>168</td>
<td>31 (18%)</td>
<td>64 (38%)</td>
<td>70 (42%)</td>
<td>3 (2%)</td>
</tr>
<tr>
<td>Group 6</td>
<td>200</td>
<td>52 (26%)</td>
<td>70 (35%)</td>
<td>72 (36%)</td>
<td>6 (3%)</td>
</tr>
<tr>
<td>Total</td>
<td>996</td>
<td>218 (22%)</td>
<td>317 (32%)</td>
<td>418 (41%)</td>
<td>43 (5%)</td>
</tr>
</tbody>
</table>

Table 15. Types of interaction per group and percentage of the total social metacognitive activities per group

We found 418 (41%) episodes with shared metacognitive activities, in which group members relate to the same topic in different metacognitive contributions. There is quite some variation between the six triads ranging from 33% to 56% of shared metacognitive activities. For example, we see a group trying to formulate their next activity “What did it say there?”. They relate to each other’s contributions “Why do we do that?” and “What are we going to do next?”, but they do not engage in each other’s questions providing answers to each other. Consequently, they do not manage to construct a new plan to continue.

Finally, 43 (5%) episodes showed co-constructed metacognitive activities. There is quite some variation between the six triads ranging from 2% to 10% of co-constructed metacognitive activities. In these episodes, the group members related to the same topic and engaged in collaboratively constructing new metacognitive activities. For example, the group members collaboratively monitor their progress on filling in the mind map. Kim states that they are done as they have 6 entries “We are done we have six entries”, which is confirmed by Joep “Yes we have 6 entries”. Then Ellen suggests to do one more “Let’s do one more”, contradicting the fact that they are finished. Then Kim claims that 6 is enough, “No we only need 6 entries”. This raises Ellen’s counter argument that an essential element is missing “No, we also need to put language as an entry”. In this example, the group members engage in a discussion about whether they are going to add more entries, integrating each other’s knowledge in criticizing each other’s contributions collaboratively building towards cognitive activities that optimize their work.

**Shared attention**

In our second research question we proposed that shared attention at the beginning of an episode could sustain more transactive interaction. As expected, we found a significant association between the type of the interaction and shared attention $\chi^2 (3)=29.86$, p<0.000. In figure 15 an overview is given of the relation between the type of interaction and in shared attention. The percentage indicated in the circles shows the percentage of the episodes that were started with shared attention among the group members, thus 54% of the accepted metacognitive activities started with shared attention among the group members. In order to understand this association better, we looked at the odds ratio, which
indicates the odds of specific type of interaction to be in shared attention compared to the odds of other types of interaction to be in shared attention.

![Figure 15. Percentage of episodes in shared attention specified per type of interaction.](image)

Episodes with ignored metacognitive activities were in shared attention 37.6% of the time. This seems to represent the fact that based on the odds ratio ignored metacognitive activities were 2.2 times less likely to be in shared attention at the beginning of the episode compared to the other types of metacognitive activities embedded in interaction. Episodes with accepted metacognitive activities were in shared attention 53.6% of the time. This seems to represent the fact that based on the odds ratio ignored metacognitive activities were 1.4 times more likely to be in shared attention at the beginning of the episode compared to the other types of metacognitive activities embedded in interaction. Episodes with shared metacognitive activities were in shared attention 59.4% of the time. This seems to represent the fact that based on the odds ratio ignored metacognitive activities were 1.56 times more likely to be in shared attention than metacognitive activities embedded in interaction differently. This seems to represent the fact that based on the odds ratio ignored metacognitive activities were 1.63 times more likely to be in shared attention at the beginning of the episode compared to the other types of metacognitive activities embedded in interaction.

**Function**

To answer our third research question, we examined if episodes with more transactive interaction would be more likely to facilitate the group process. We found a significant association between the type of interaction and facilitation $\chi^2 (3)=423.63$, $p<0.000$. In figure 16 an overview is given of the relation between the type of interaction and facilitation, representing the percentage of metacognitive activities that were facilitating the group process of a particular type of interaction. For example, 98% of the co-constructed metacognitive activities facilitated the group process.
Figure 16. The percentage of episodes that facilitate learning specified per type of interaction.

In order to understand this association better, we calculated the odds ratio, which indicates the odds of specific type of interaction to facilitate the group process compared to the odds of other types of interaction to facilitate the group process. Episodes with ignored metacognitive activities did hardly facilitate the group process. This seems to represent the fact that based on the odds ration ignored metacognitive activities were 67 times less likely to facilitate the group process compared to metacognitive activities embedded in other types of interaction. Episodes with accepted metacognitive activities facilitated the group process 82% of the time. This seems to represent the fact that based on the odds ratio accepted metacognitive activities were 15.1 times more likely to facilitate the group process than metacognitive activities embedded in other types of interaction. Episodes with shared metacognitive activities facilitated the group process 70% of the time. This seems to represent the fact that based on the odds ration shared metacognitive activities were 2.1 times more likely to facilitate the group process than metacognitive activities embedded in other types of interaction. Finally, episodes with co-constructed metacognitive activities facilitated the group process 98% of the time. This seems to represent the fact that based on the odds ration co-constructed metacognitive activities were 30 times more likely to facilitate the group process than metacognitive activities embedded in other types of interaction.

Co-constructed metacognitive activities that facilitate the group process

Our findings indicate that co-constructed metacognitive activities are most likely to facilitate learning and that they are most likely to occur when the group has a shared attention at the beginning of the episode. In example 6, we show an example of this type of interaction between the students. In this example the group is formulating sentences for their paper based on the summary they made from experts’ information. All three students are participating in this discussion and thus there is shared attention at the start of the metacognitive episode. It starts with Rob who notices that they are done writing the summary of the first diary of the expert. Then Jacob adds that this is already more than the
summary, but Rob insist this is the summary of general information about New Zealand. Susan contributes to this discussion that the last sentences were really about distances. Rob agrees and suggests a different approach namely making two chapters. Susan agrees and creates a new chapter. Then the group continues to formulate new sentences for the new chapter about distances. The metacognitive activities are embedded in an interaction that is co-constructive as Jacob is engaging in Rob’s contribution, Rob relates to Jacob’s comment and Susan engages in both previous comments. Rob and Jacob finalize the metacognitive episode engaging in Susan’s comment. These co-constructed metacognitive activities support the group to monitor their cognitive activities and help them to construct a paper with a better quality. Hence, they facilitate the group’s process differentiating between two different elements in the group’s paper.

Example 6. An example of co-constructed metacognitive activities that facilitate learning

<table>
<thead>
<tr>
<th>Student name</th>
<th>turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susan</td>
<td>Trains drive for long days,</td>
</tr>
<tr>
<td>Jacob</td>
<td>Doctors often come by airplane, komma, they…..</td>
</tr>
<tr>
<td>Susan</td>
<td>With the airplane</td>
</tr>
<tr>
<td>Rob</td>
<td>This is what we had to write down; this was the summary of the first diary of the expert.</td>
</tr>
<tr>
<td>Jacob</td>
<td>This was already more than the first summary</td>
</tr>
<tr>
<td>Rob</td>
<td>This is about the country, are we still writing about the country,</td>
</tr>
<tr>
<td>Susan</td>
<td>No actually we are not writing about the country, but about distances</td>
</tr>
<tr>
<td>Rob</td>
<td>Then we have to do this differently;</td>
</tr>
<tr>
<td>Jacob</td>
<td>Then we can make two chapters; the country and the distances</td>
</tr>
<tr>
<td>Susan</td>
<td>Ok hold on I make a new chapter</td>
</tr>
<tr>
<td>Rob</td>
<td>Lets’ start with the chapter about the distances</td>
</tr>
<tr>
<td>Susan</td>
<td>Yes, we can use the sentence: trains drive for long days</td>
</tr>
<tr>
<td>Jacob</td>
<td>Yes and doctors often come with an airplane,</td>
</tr>
<tr>
<td>Rob</td>
<td>Perfect and we can add the size of the country….</td>
</tr>
<tr>
<td>Rob</td>
<td>New Zealand consists of two island</td>
</tr>
</tbody>
</table>

Discussion

In this article we focused on how metacognitive activities were embedded in the interaction between the group members and how that influences the quality of the metacognitive activities. Additionally, we explored if more transactive interaction is supported by shared attention. We analyzed 996 metacognitive episodes of 6 triads working on an open research task in an electronic learning environment. We found that the majority of metacognitive activities were focused at the group level. Yet, there also were individual and other metacognitive activities confirming the proposition that there are several forms of metacognitive activities along the social spectrum (Hadwin & Oshige, 2011; Iiskala et al, 2011). The study showed that instances of individual and other metacognitive activities are clearly distinguishable from instances of social metacognitive activities. From these data we learned that social metacognitive activities are not necessarily performed by more than one group member. An example of social
metacognition produced by one person is “After this we are going to write the goal statement”. This planning activity is clearly directed at the social level, namely the activities of the group. Thus even though this activity is produced by only one group member, we believe it should be considered as social metacognition.

Furthermore, this analysis indicated that groups’ metacognitive activities are indeed embedded in different types of interaction. We found ignored, accepted, shared and co-constructed metacognitive activities in our sample. Most metacognitive activities were shared, as they were embedded in episodes in which the group members related to each other’s metacognitive contributions with new metacognitive remarks. There also was a substantial amount of accepted metacognitive activities that were immediately engaged in by the group members in new cognitive activities. There were quite some ignored metacognitive activities that were not taken up by the group members at all. Finally, we only found a restricted number of co-constructed metacognitive activities. The results showed that the metacognitive activities in small groups are indeed embedded in different types of interaction. The co-constructed social metacognitive activities were also found in other studies of metacognitive activities in collaborative settings. There it was referred to as socially shared metacognition (Iiskala et al., 2004; 2011). However, co-constructed metacognitive activities did as expected not occur frequently and therefore we showed that it is important to investigate how metacognitive activities are embedded in less transactive interaction.

In this study we further elaborated on the role of shared attention supporting transactive interaction among the group members. We found that ignored metacognitive activities were less likely to be in shared attention of the group members. On the other hand, accepted and shared metacognitive activities were more likely to have shared attention at the beginning of the metacognitive episode. Finally, co-constructed metacognitive activities were even more likely to have shared attention at the beginning of the episode. Therefore it seems that shared attention is supportive to medium and high transactive interaction, which is in concurrence with earlier findings of Barron (2000; 2003) that shared attention supports transactive interaction.

We also explored if more transactive interaction was more likely to facilitate the group’s process. Episodes with ignored metacognitive activities never facilitated the group process. Metacognitive episodes with accepted metacognitive activities are likely to facilitate the group process as do episodes in which metacognitive activities are shared. Finally, episodes in which metacognitive activities are co-constructed were as expected much more likely to facilitate the group process. Thus metacognitive activities embedded in medium transactive interaction are likely to facilitate and metacognitive activities embedded in high transactive interaction almost always facilitate the group process. These findings co-occur with earlier findings from collaborative learning research (Chi, 2009; Webb, 2009; Weinberger & Fischer, 2006). We verified that metacognitive activities in more transactive interaction are more likely to facilitate the group process.
These findings have two consequences: first, for the analysis of metacognitive activities in small groups, it is important to take into account the type of interaction these activities are embedded in. Consequently, in comparative analysis of metacognitive activities during collaborative learning, for example, to understand why one group outperforms another group, the focus should not only be on the quantity of metacognitive activities, but also on the type of interaction these metacognitive activities are embedded in. Looking at these two elements can enhance our understanding of how metacognitive activities in social settings influence learning.

Second, our findings have a number of implications for instructional designs that focus on supporting metacognitive activities in small groups. They should aim at creating shared attention among the group members to support more transactive interaction. Moreover, designs should intend to reduce ignored metacognitive activities and elicit accepted, shared and especially co-constructed metacognitive activities. So far, instructional designs supporting metacognitive activities such as scaffolding have mainly looked at the effect on students’ learning achievements and the stimulation of metacognitive activities. This study indicates that the students’ interaction around metacognitive activities is also an important aspect to take into consideration when evaluating the effect of instructional designs in collaborative settings. As more transactive interaction is more likely to facilitate the group process an important future research question is to gain a better understanding of what stimulates groups to engage in transactive interaction and how instructional designs can influence this.

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Abstract This chapter explores the effect of computerized scaffolding with different scaffolds (structuring vs. problematizing) on the way metacognitive activities are embedded in the interaction among group members during collaborative learning. In this study, we investigate different types of interaction around metacognitive activities of 18 triads (6 control groups and 12 scaffolding groups (6 structuring and 6 problematizing)). We found that groups receiving scaffolding showed significantly more co-constructed metacognitive activities. Groups receiving problematizing scaffolds showed significantly less ignored and more co-constructed metacognitive activities compared to groups receiving structuring scaffolds. These findings indicate that scaffolding positively influenced the way metacognitive activities are embedded in the interaction among group members. Moreover, these findings seem to explain the differential learning effects of different forms of scaffolds. Therefore future research should consider how to design scaffolds that support metacognitive activities embedded in more transactive interaction.

Keywords · Metacognition · social systems · Collaborative learning · Elementary Education.

Introduction

Cognitive and metacognitive activities are key to self-regulating one’s learning in Computer-Based Learning Environments (CBLE’s) (Azevedo, Moos, Johnson & Chauncey, 2010). Students who orientate, plan, monitor and evaluate learn more and show higher motivation than students who engage in less metacognitive activities (Azevedo, Moos, Greene, Winters, & Cromley, 2008; Land & Green, 2000; Veenman, Kok, & Blote, 2005). Additionally, metacognitive skills are an important predictor of students’ learning abilities, possibly even more important than intelligence (Van der Stel & Veenman, 2010). Even though the importance of metacognitive activities is recognized, students generally refrain from sufficiently regulating their learning in CBLE’s (Azevedo & Hadwin, 2005). Therefore, metacognitive scaffolding is used to foster student’s metacognitive activities (Veenman et al, 2005). In CBLE’s students often engage in collaborative learning in small groups (Stahl, Koschmann & Suthers, 2006). Metacognitive scaffolding has also been applied in small group settings showing similar results as in individual settings (Azevedo, & Cromely, 2004; Molenaar, van Boxtel, Sleegers, 2010).

In small groups, we speak of social regulation or social metacognitive activities that control and monitor the group’s cognitive activities (Iiskalla, Vauras, Lehtinen & Salonen, 2011Molenaar, van Boxtel & Sleegers, submitted). Social metacognitive activities are embedded in different types of interaction, which are associated with different amounts of transactivity (Molenaar et al., submitted). Transactivity refers to the extent to which group members relate to and engage in each other’s contributions in activities such as providing feedback, giving critical comments and engaging in arguments (Teasley, 1997; Weinberger & Fischer, 2006). Research indicates that the advantage of collaborative learning depends largely on the transactivity of the groups’ interaction (Webb, 2009). In line with these findings, we recently found that metacognitive activities embedded in more transactive interaction are more likely to facilitate the group process and that shared attention among the group members supports transactive interaction (Molenaar et al., submitted).

However up until now, we know little about the effect of scaffolding on the type of interaction metacognitive activities in small groups are embedded in. Interaction among students can be supported with different instructional designs, such as scripts, Jigsaw and role play (Dillenbourgh, 1999; Rummel & Spada, 2005). We do know that scaffolding stimulates the metacognitive activities of the group (Molenaar, van Boxtel & Sleegers, 2011) and consequently could influence the type of interaction these metacognitive activities are embedded in. Therefore, the question addressed in this chapter is: What is the effect of metacognitive scaffolding on the way metacognitive activities are embedded in interaction during collaborative learning in small groups? We will examine this question in an experimental study comparing students in a control group with students in an experimental group that received computerized scaffolding. Students in the experimental group are supported with two different forms of metacognitive scaffolds (problematizing vs. structuring scaffolds). Previously, we found that metacognitive scaffolding stimulates
metacognitive activities, which in turn enhances student’s metacognitive knowledge (Molenaar, Chiu, Sleegers & van Boxtel, in press). Different forms of scaffolds appeared to have a differentiating effect on student’s metacognitive knowledge, but not on the amount of metacognitive activities performed by the groups (Molenaar et al., in press). We proposed that the differences in student’s metacognitive knowledge could be explained by qualitative differences in the group’s metacognitive activities. In this study, we analyze this proposition examining the extent to which scaffolding influences the way metacognitive activities are embedded in the interaction between the group members. First, we elaborate on how metacognitive activities are embedded in interaction during collaborative learning. Second, we discuss how metacognitive scaffolding and different forms of scaffolds influence the group’s interaction.

**Metacognitive activities embedded in interaction**

Metacognition is defined as knowledge about and regulation of cognitive activities (Flavell, 1979). Different metacognitive activities such as orientation, planning, monitoring, evaluation and reflection regulate student’s learning (Veenman, Van Hout-Wolters, & Aflerbach, 2006; Zimmerman, 2002). In small groups metacognitive activities occur at various points along the social spectrum referred to as individual, other and social metacognitive activities (Iiskala, Vauras & Lehtinen, 2004, Iiskala et al., 2011; Hadwin & Oshige, 2011; Molenaar et al., submitted). Individual metacognitive activities regulate students’ individual cognition, whereas social metacognitive activities are directed at the group’s cognition. Other metacognitive activities are the regulation of individual cognition that is performed by another group member. The majority of metacognitive activities during collaborative learning are social metacognitive activities, but there also is a small proportion of individual and other metacognitive activities in the groups’ interaction (Molenaar et al., submitted). In this chapter, we focus on the social metacognitive activities that control and monitor the group’s cognitive activities. For example, group members orientate on their learning assignment, plan the group’s activities, monitor the group’s actions and evaluate the correctness of the group’s learning and finally reflect on the learning strategies followed by the group.

Social metacognitive activities are embedded in interaction between the group members (Iiskala et al, 2011; Molenaar et al. submitted). Collaborative learning research distinguishes different types of interaction among students associated with different degrees of transactivity (Wienberger & Fischer, 1996). We found that these different types of interaction also company social metacognitive activities. Social metacognitive activities in different types of interaction are called ignored, accepted, shared and co-constructed metacognitive activities (Molenaar et al., submitted). Most metacognitive activities are shared, as they are embedded in episodes in which the group members related to each other’s metacognitive contributions with new metacognitive remarks. There also was a substantial amount of accepted metacognitive activities that are immediately applied in the
group cognitive activities. Finally, there were quite some ignored metacognitive activities that are not taken into consideration by the other group members and only a small number of co-constructed metacognitive activities, in which group members built on each other’s metacognitive contributions. The way metacognitive activities are embedded in interaction is important as metacognitive activities embedded in more transactive interaction are more likely to facilitate the group process (Molenaar et al., submitted).

Ignored metacognitive activities are not taken up by the other group members. Consequently, there is no transactivity in students’ interaction when students ignore each other’s contributions. Accepted metacognitive activities are applied in other group member’s cognitive activities and shared metacognitive activities are responded to with other group member’s metacognitive activities. When students accept or share each other’s metacognitive activities, they either relate to or engage in each other’s contributions. This indicates medium transactivity. Finally, in co-constructed metacognitive activities group members collaboratively built new metacognitive activities (Molenaar et al., submitted). When students relate to and engage in each other’s contributions, we speak of high transactivity. Thus, these four different types of interaction specify how metacognitive activities are embedded in the group’s interaction and indicate the level of transactivity (see figure 17 for an overview).

<table>
<thead>
<tr>
<th>Accepted Metacognitive Activities</th>
<th>Co-Constructed Metacognitive Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>No transactivity</td>
<td>No transactivity</td>
</tr>
<tr>
<td>Medium transactivity</td>
<td>Medium transactivity</td>
</tr>
<tr>
<td>High transactivity</td>
<td>Related</td>
</tr>
</tbody>
</table>

Figure 17. Overview of different types of interaction in which metacognitive activities are embedded and their level of transactivity

Different perspectives on collaborative learning all emphasize that students’ elaborations on each other’s contributions are essential for students to benefit from collaborative learning (Chi, 2009; Doise, 1990; Doise & Mugny, 1984; Hatano, 1993; Mercer, 1996; Piaget, 1932; van Boxtel, 2004; Webb, 2009). Transactive interaction supports group members to learn from each other through exchanging, sharing and co-constructing knowledge (Roschelle, 1996, Teasley, 1997; Weinberger, Stegemann & Fischer, 2007). Moreover, metacognitive activities embedded in more transactive interaction are more likely to facilitate the group’s process as they are developing,
activating or confirming cognitive activities that support the realization of the group’s learning goal (Molenaar et al., Submitted). Therefore, we expect that the way metacognitive activities are embedded in interaction is likely to influence the exchange of metacognitive knowledge among the group members. Ignored metacognitive activities do not support the exchanges of metacognitive knowledge among group members. Accepted metacognitive activities highlight successful metacognitive activities, which can add to metacognitive knowledge. Shared metacognitive activities support the exchange of existing metacognitive knowledge among the group members. Finally, co-constructed metacognitive activities support the collaborative creation of new metacognitive knowledge. Thus metacognitive activities embedded in more transactive interaction are likely to support the development and exchange of metacognitive knowledge among the group member, which consequently can be beneficial for individual group members. Yet, collaborating students in CBLE’s have difficulties to sufficiently regulate their learning. In the next section we discuss how scaffolding can support these small groups to perform metacognitive activities and how scaffolding is likely to also influence the way metacognitive activities are embedded in transactive interaction.

**Effects of scaffolding on types of interaction among the group mates**

Scaffolding is directed at stimulating students to perform activities they are unable to perform successfully by themselves (Wood, Bruner & Ross, 1976). Metacognitive scaffolds help students and small groups to perform the needed metacognitive activities to regulate their learning. We found that computerized metacognitive scaffolds provided by a 3D embodied agent stimulated small groups to engage in more metacognitive activities (Molenaar et al. 2010). Moreover, there are differential effects of different forms of scaffolds on students’ metacognitive knowledge which cannot be explained by quantitative differences in metacognitive activities (Molenaar, Ming, van Boxtel & Sleegers, in press). We therefore proposed that qualitative differences in metacognitive activities could explain these differences. These qualitative differences could be grounded in the way metacognitive activities are embedded in interaction. The question we raise in this study is to what extent can scaffolding and in particular different forms of scaffolds affect the way metacognitive activities are embedded in the interaction among students.

We know that different instructional designs support successful interaction among students (Dillenbourgh, 1999; Rummel & Spada, 2005). Scripting, Jigsaw designs and role play all stimulate students to engage in more transactive interaction (Weinberger & Fischer, 2006, Dillenbourgh, 1999, Strijbos & de Laat, 2010). For example, scripts provide procedural guidelines to support argumentation, which have been shown to increase the transactive interaction among the students (Weinberger & Fischer, 2006). Scaffolding can have a similar effect on student’s interaction as it also provides guidelines. Thus like scripting scaffolding provides interventions in the group process, which can influence the interaction among the group members. We can specify how scaffolding influences
interaction by looking at two mechanisms that explain how students learn from scaffolding (Reiser, 2004). Structuring simplifies the learning assignment by reducing its complexity, clarifying the underlying components and supporting performance (i.e. providing the students with an example of a plan for the assignment). Problematizing increases the complexity of the learning assignment by emphasizing certain aspects of the assignment and asking learners to clarify the underlying components and perform actions to construct their own strategies (i.e. asking students to make their own plan for the assignment). These different mechanisms support the formation of different forms of scaffolds that either structure or problematize aspects of the learning assignment.

We know that both of these forms of scaffolds stimulate more metacognitive activities in the group (Molenaar et al., 2011). It is likely that they also influence the type of metacognitive interaction the group. Structuring scaffolds give examples of metacognitive activities to the group as such performing part of the group’s regulation. An example of a structuring scaffold is to show students an exemplary plan for their mind mapping tasks “What would you like to learn; let’s make a mind map with important topics to learn, for instance the climate”. These scaffolds support students to elaborate on this example adjusting and shaping the group’s plan for the mind map task (Molenaar et al., submitted). These types of scaffolds that provide explanations have been found to elicit students’ interaction (King, 1998; 2002). We expect that structuring scaffolds will mostly stimulate groups to engage in accepted and shared metacognitive cognitive activities, in which student either accept the proposed metacognitive activities or relate to each other’s comments about the example.

Problematizing scaffolds, on the other hand, pose questions that elicit students’ metacognitive activities. An example of a problematizing scaffold is asking students to plan their mind mapping task “How are you going to make the mind map?”. In response to the problematizing scaffolds students have discussions about (conflicting) views, exchange, share, or co-construct metacognitive activities together (Molenaar et al., submitted). Other research has also shown that question prompts elicit students’ explanations and support articulation of student’s thinking which initiates interaction (Chi, Siler, Jeong, Yamuachi, & Hausmann, 2001; Davis & Linn, 2000; King, 1998, 2002). Therefore, we expect that problematizing scaffolds will elicit more co-constructed metacognitive activities, in which students collaboratively construct new metacognitive activities.

Even though there are studies that show that scaffolds facilitate interaction, few studies systematically compared the effect of different forms of scaffolds on students’ interaction in small groups. Research does indicate that the interaction pattern between the group members tend to lock in early in their collaboration (Kapur, Voiklis & Kinzer, 2008). The group’s interaction generally remains quite stable throughout the learning assignment (Kapur & Kinzer, 2007). The advice is to support the group’s interaction early in the collaboration to increase transactive interaction (Kapur et al., 2008). This is
particularly important as our scaffolding system provides groups with scaffolds that are dynamically integrated the group’s process during the first two lessons. Moreover, transactive interaction is also assisted by shared attention among the group members (Barron, 2000, 2003; Molenaar et al., submitted). Group members are more likely to develop transactive interaction, when they share a common focus of attention. Scaffolds could focus the group’s attention on a common object. For example, the group receives a scaffold indicating how to plan a particular task. All group members listen to the scaffolding message, which focuses their attention on planning the task. Because the planning of the learning task is now in the attention of all group members, they are more likely to respond to each other’s comments and elaborate on planning their task.

To summarize the above, the main difference between scaffolding in an individual and a group setting is the interaction among the group members. Transactive interaction enhances the exchange, sharing and co-construction of knowledge among the group members, which supports additional learning. We propose that metacognitive scaffolding and different scaffolds can affect students’ interaction around metacognitive activities. Once the interaction pattern is set, the group is likely to continue this throughout the learning assignment. Moreover scaffolds could support transactive interaction between the group members by focusing the group’s attention. In our study, students received scaffolds to support their metacognitive activities. Until now we have established that metacognitive scaffolding increases the number of metacognitive activities in small groups (Molenaar et al., 2010) and that metacognitive activities embedded in more transactive interaction are more likely to facilitate the group process (Molenaar et al., submitted). Thus if we can establish that scaffolding and different forms of scaffolds affects the transactive interaction in which metacognitive activities are embedded, this is likely to account for differential learning effects of different forms of scaffolding.

This study

We report an experiment in which students in elementary school collaboratively worked on a research task in a complex computer-based environment. There were three conditions, two scaffolding conditions and a control group. Triads in the scaffolding conditions received scaffolds to support their metacognitive activities; triads in the control condition did not. Furthermore, the two scaffolding conditions received different forms of scaffolds; namely problematizing scaffolds versus structuring scaffolds. We will analyze the effect of scaffolding and different forms of scaffolds on the way metacognitive activities are embedded in the groups’ interaction. This raises the following research questions:

1. What is the effect of metacognitive scaffolding and different scaffolds on the way metacognitive activities are embedded in interaction?
2. What is the influence of metacognitive scaffolding and different scaffolds on shared attention of the group?
We expect metacognitive scaffolding to elicit metacognitive activities embedded in transactive interaction among group members (transactivity hypothesis 1a.). This is based on the fact that scaffolds intervene in the group process and are thus likely to alter the interaction among group members. We expect problematizing scaffolds to elicit more co-constructed metacognitive activities compared to structuring scaffolds and structuring scaffolds to stimulate more accepted and shared metacognitive activities compared to problematizing scaffolds. This is based on the fact that problematizing scaffolds elicit group members’ constructive activities in interaction compared to a discussion of how to apply the example that are stimulated by structuring scaffolds (transactivity hypothesis 1b.).

Moreover, we also expect that scaffolding will elicit shared attention among the group members (shared attention hypothesis). This is based on the expectation that scaffolds focus the attention of different group members. We do not expect a differentiating effect of different forms of scaffolds on shared attention.

Finally, we want to establish if groups in the scaffolding conditions continue to show more transactive interaction throughout their collaboration. The transactivity in the interaction will be measured analyzing the triads’ metacognitive episodes. If the transactivity hypothesis holds, we expect triads who receive scaffolds to show more metacognitive activities embedded in transactive interaction. Additionally we expect triads in the problematizing condition to outperform triads in the structuring condition on co-constructed metacognitive activities. Whereas triads in the structuring conditions show more accepted and shared metacognitive activities. If the shared attention hypothesis holds, we expect scaffolds triads who receive scaffolds to elicit more shared attention at the beginning of metacognitive episodes than triads who did not receive scaffolds.

**Participants**

Due to the labor intensive nature of discourse analysis, we could not analyze all triads that participated in the full study (Molenaar et al, 2010). In the full study, 156 students from 6 classes in 3 schools participated. The teachers assigned students to heterogeneous triads (52) through the following procedure. First, we asked teachers to rate the students as low, middle or high achievers based on their reading, writing and computer achievement. Then, the teachers created triads containing one low, one middle and one high achiever. Every triad had students of both gender. Next, we randomly assigned the triads to the three experimental conditions, equally divided across the classes: 16 triads with no scaffolds (control group), 17 triads with structuring scaffolds, and 19 triads with problematizing scaffolds, see section below on scaffolding for details. For this study, we randomly drew a smaller sample of 18 triads (one in each scaffolding condition from every class) for the process measurements. This sub-sample consists of 54 students (23 boys and 31 girls) in 6 control triads, 6 structuring scaffold triads and 6 problematizing scaffold triads. These 54 students were in Grade 4 (9), Grade 5 (27) or Grade 6 (18) in 3 elementary schools.
Virtual learning environment and assignment

The e-learning environment used in this study is called *Ontdeknet*. It focuses on supporting students in their virtual collaboration with experts (Molenaar, 2003). The experts provide students with information about their expertise, namely knowledge about their country for this study. The experts’ contributions were edited by the editor of *Ontdeknet*. The teacher gives the assignment and monitors students’ progress. *Collaborative learning* is implemented at two levels: students collaborating with an expert in a virtual environment and with each other face-to-face in small groups with a computer. The study consisted of 8 lessons, each lasting 1 hour. In the first lesson, the students completed a pre-test, and then received instructions about the assignment and the virtual environment. In the last lesson, the students completed several post-tests. All students received the same instructions, and all triads spent the same time working on the assignment (6 hours). During these 6 lessons, the triads worked on an assignment called “Would you like to live abroad?” The goal of the assignment was to explore a country of choice (New Zealand or Iceland), write a paper on their findings and decide if they would like to live in this country. The triads worked on one computer and had access to an expert, namely an inhabitant of the country. They could consult the expert by asking questions and requesting information about different topics about the country. In a separate expert window in the computer environment, the expert provided the requested information, and questions were answered in a forum. Four sub-tasks preceded the task to write a paper about the country: (a) introducing the group to the expert, (b) writing a goal statement, (c) selecting a country and (d) specifying topics of interest on a mind map. All tasks were integrated into the working space of the triads, where they also wrote the paper. The performance of the triads was stored in the learning environment. All lessons were supervised by the same researcher.

The scaffolding system and the conditions

Both types of metacognitive scaffolds were dynamically integrated into the computer environment. The triads of students in both experimental scaffolding conditions received computerized scaffolds supporting their metacognitive activities during the first two lessons at the same instance in the learning process (Molenaar, van Boxtel, Sleegers & Roda, 2010). These scaffolds were given when metacognitive activities are typically executed in the learning process. The timing was based on Zimmerman’s model for self-regulated learning (Zimmerman, 2002). The computerized scaffolding system determined the appropriate instance to send a scaffold based on the students’ attention focus. Students in the scaffolding conditions received a minimum of 12 scaffolds in each condition. The triads in the structuring condition (experimental group 1) received direct support for their metacognitive activities; for example, the computer avatar David showed the students an exemplary plan of a task “The expert would like to know what you want to learn. Please write all the topics about New Zealand that you would like to learn more about in this mind map” (see figure 18). In response, students can elaborate and reformulate the
specifications to the planning activities of group, see 18. The triads in the problematizing condition (experimental group 2) received scaffolds designed to elicit individual students’ metacognitive activities and explanations; for example, the computer avatar David asks, “How are you going to make a mind map?” The triads in the problematizing condition were obliged to answer the avatar’s questions in an answer box on the screen, (see figure 18). In response, students can construct a plan of how to make a mind map. Lastly, the control group triads saw the avatar David, but did not receive any metacognitive scaffolds. The avatar was included in all groups to control for a Hawthorne effect, in which its sole presence could influence the student activities, even without the actual scaffolding (Franke & Kaul, 1978).

Figure 18. Example of structuring and problematizing scaffolds

Measurements

The discourse analysis

The discourse of 16 groups (108 hours) was audio-taped, transcribed (51,339 turns) and analyzed in five steps. The reliability reported for every step is based on the coding of two independent raters that analyzed the discourse of 2 randomly selected triads (2500 turns). First, we detected the metacognitive activities in the groups (Molenaar et al., 2010). All turns were coded with mutually exclusive and exhaustive categories. The categories were cognitive, metacognitive, relational, procedural, off task, not-codable activities and teacher activity (see table 16 for an overview). There was excellent (Fleiss, 1981) agreement for these categories: the kappa was $K=0.92$. Cohen’s kappa was highest for the category metacognitive activities $K=0.94$ and lowest for category non-codable activities $K=0.82$.

Second, we determined the metacognitive episodes. Metacognitive episodes are sequences of turns that discuss the same topic and of which at least one turn is a metacognitive activity. The episode starts with the first metacognitive activity and ends with the last turn dealing with the same topic. An example of a metacognitive episode: “We start with the first chapter of our paper; What are we going to discuss in the first chapter?; Lets read the information about animals in New Zealand”. Two researchers independently
determined the metacognitive episodes of the 6 groups; the intercoder-agreement was 71%. All inconsistencies between the two coders were re-coded in mutual agreement.

Table 16. Main categories of our coding schema.

<table>
<thead>
<tr>
<th>Main category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacognitive activity</td>
<td>Turns about monitoring and controlling the cognitive activities during learning</td>
</tr>
<tr>
<td>Cognitive activity</td>
<td>Turns about the content of the task and the elaboration of this content</td>
</tr>
<tr>
<td>Relational activity</td>
<td>Turns regarding the social interaction between the students in the triad</td>
</tr>
<tr>
<td>Procedural activity</td>
<td>Turns regarding the procedures to use the learning environment</td>
</tr>
<tr>
<td>Teacher/researcher</td>
<td>Turns that are made by the teacher or the researcher.</td>
</tr>
<tr>
<td>Off task</td>
<td>Turns that are not relevant to the task.</td>
</tr>
<tr>
<td>Not codable</td>
<td>Turns that are too short or unclear to interpret</td>
</tr>
</tbody>
</table>

Third, we determined the form of metacognitive activities namely individual, other or social metacognitive activities in the episodes. Individual metacognitive activities occur when one student is regulating his or her own cognitive activities; for example “Stop I need to think about this”. Other-metacognitive activities occur when a group member regulates the individual cognitive activity of another group member, for example “What are you doing?; I am trying to understand this question”. Social metacognitive activities occurs when one or more group members regulate their collaborative cognitive activities, for example: “What are we writing?; The goal statement; What is the goal statement?; That is where you write what you want to learn”. Cohen’s kappa was 0.91 which indicates excellent agreement (1981).

Fourth, we established if there was shared attention among the group members at the start of the metacognitive activities. In case the topic discussed in the episode was talked about in the turns preceding the metacognitive episode, we coded it as in the group’s shared attention. An example of a metacognitive episode shared in attention is “In New Zealand there are much different animals; This is wrong we cannot write there are much different animals; Ok lets write many different animals”. In this example, the topic is “In New Zealand there are much different animals”. This sentence is in the group’s shared attention, as two group members are contributing to the construction of the same sentence, when one group member monitors that the sentence is wrong. An example of a metacognitive episode not shared in attention: “In New Zealand there are many different animals; We need to discuss the language too”. Here a group member introduces a new topic to discuss in the group’s paper, when the group’s attention is focused on constructing the sentence. Cohen’s kappa was 0.72 which indicates acceptable agreement (Fleiss, 1981).

Fifth, for the social metacognitive activities which are a proportion of all metacognitive episodes, we distinguished four types of interaction around metacognitive activities: ignored, accepted, shared or co-constructed metacognitive activities. Ignored
metacognitive activities occur when the group members do not relate to nor engage in another group member’s metacognitive activity, for example: “*Let’s read this chapter; I am so happy*”. Accepted metacognitive activities occur when the group members engage in a metacognitive activity with a cognitive activity, for example: “*Let’s write down hobbies; My hobbies are Tennis and Ballet*”. Shared metacognitive activities occur when a group member relates to a metacognitive activity with another metacognitive activity, for example: “*We do not know what to do next; true, but I do not know what to do either; What do you think?*” Finally, when group members not only relate to but also engage in each other’s metacognitive activities, we speak of co-constructed metacognitive activities, for example: “*Let’s start again with the first part of the chapter; Ok what are we describing in the first chapter; We discuss the language of the country, let’s read the chapter about language*”. Cohen’s kappa was 0.86 which indicates good agreement (Fleiss, 1981).

**Analysis**

As mentioned earlier, the purpose of our study is to determine the effect of scaffolding and different forms of scaffolds on the interaction in which metacognitive activities are embedded and on the group’s shared attention at the beginning of these metacognitive episodes. As a consequence the analyses were done at the triad level. To test the transactivity hypothesis, we assessed the interaction of the triads using discourse analysis. The total dataset entails 108 hours of lessons and 51,339 utterances with 3702 metacognitive episodes of which 3519 were social metacognitive episodes. The distributions of the variable co-constructed metacognitive activities was not normal, it had a skewness to the left. Therefore, we decided to use the Mann-Whitney test to evaluate the hypothesis. We first tested the effect of scaffolding comparing the scaffolding group to the control group; next we assessed the effect of different forms of scaffolds comparing the problematizing and structuring group. Before we started to answer our research questions, we analyzed if the triads receiving scaffolding perform more metacognitive episodes than triads in the control condition. Even though the experimental group (mdn =211) did not outperform the control group (mdn = 165) significantly (U=21, p, 0.09 (one sided), r=0.25), we decided to use relative frequencies due to the small to medium effect of scaffolding on the number of metacognitive episodes. There was no difference in the number of metacognitive episodes performed between the structuring (mdn=212.5) and the problematizing condition (mdn=209.5): U=18, p=0.53 r=0). The mean reported indicates the relative frequency, for example the mean for ignored metacognitive activities in the control group was 0.22 thus 22% of all social metacognitive episodes in the control group. We decided to report the mean, because is a more intuitive number compare to the median. The effect sizes are calculated using the effect size estimate r, following Rosenthal (1991) defining 0.1 as a small effect, 0.3 as a medium effect and 0.5 as a large effect.
Results

Influence of scaffolding on the type of metacognitive interaction

It appeared that triads in the experimental group (m=0.09) showed significantly more co-constructed metacognitive activities compared to the control group (m=0.05), (U=15.5, p=0.03 (one sided), r=0.45). The other comparisons were not significant. Triads in the experimental group (m=0.20) show somewhat less ignored metacognitive activities compared to triads in the control condition (m=0.22), (U=26, p=0.19 (one sided), r=0.23). The experimental group (m=0.29) showed less accepted metacognitive activities compared to the control group (m=0.32), (U=20.5, p=0.08 (one sided), r=0.34). Finally, the experimental groups showed somewhat more shared metacognitive episodes (m=0.42) compared to the control group (m=0.41) (U=26, p=0.19 (one sided), r=0.22). Figure 19 provides an overview of the mean percentages of metacognitive activities embedded in interaction in control and the scaffolding condition.

With respect to the effect of different forms of scaffolding on the metacognitive activities embedded in interaction, we found that triads in the problematizing condition (m=0.18) showed significantly less ignored metacognitive activities compared to the structuring condition (m=0.22) (U=6, p=0.03 (one sided), r=0.56) and significantly more co-constructed metacognitive activities (problematizing m= 0.13 and structuring m=0.05), (U=5, p=0.02 (one sided), r=0.60). The other comparisons were not significant: triads in the problematizing condition (m=0.29) show the same amount of accepted metacognitive activities as triads in the structuring condition (m=0.29), (U=18, p=0.53 (one sided), r=0) and the problematizing condition (m=0.40) showed less shared metacognitive activities compared to the structuring condition (m=0.44 ) (U=12, p=0.19 (one sided), r=0.28). Figure 20 provides an overview of the mean percentages of metacognitive activities embedded in interaction in the problematizing and structuring condition.

Figure 19. Different types of metacognitive activities embedded in interaction of the control and the scaffolding condition.
Influence of scaffolding on shared attention

We expected that scaffolding would focus the group’s attention. However, we found that shared attention at the beginning of metacognitive episodes is similar for all triads. The triads in the scaffolding condition (m=0.55) and triads in the control group (m=0.54) are comparable, (U=30, p=0.30 (one sided), r=0.13); and so are the triads in the problematizing condition (m=0.56) and the structuring condition (m=0.54), (U=13, p=0.24 (one sided), R=0.23). About half of all episodes is shared in attention and there is neither an effect of scaffolding nor of the form of the scaffolds.

Lasting effects of scaffolding on the groups’ interaction

The results reported include the whole time the students worked on the learning assignment, thus both during and after they received scaffolds. A close analysis of the time graphs of the groups receiving scaffolds shows that co-constructed metacognitive activities occur throughout the learning assignment. Also a close look at the time graphs of the groups receiving problematizing scaffolds confirmed that the co-constructed metacognitive activities were evenly distributed throughout the learning task.

Discussion and conclusion

This study aimed to investigate the effects of scaffolding on the way metacognitive activities are embedded in interaction. We proposed that scaffolding supports more transactive interaction and shared attention at the beginning of metacognitive episodes. Moreover we expect that different forms of scaffolding have a differential effect on transactive interaction; i.e. we expect problematizing scaffolds to lead to more co-constructive metacognitive activities compared to structuring scaffolds and structuring to lead to more accepted and shared metacognitive activities. We analyzed the discourse of 18 triads to answer our research questions.
We found evidence for the transactivity hypothesis. Triads in the scaffolding condition showed more co-constructed metacognitive activities than triads in the control condition. These results indicate that scaffolds can support groups to co-construct metacognitive activities. These findings concur with earlier findings of Barron (2000; 2003) regarding the difference between successful and unsuccessful groups. This distinction did not lie in the number of problem solving attempts of the group, but in the number of attempts that was *taken up* by the group in transactive interaction. Here we find the same: all groups show attempts to regulate their learning, but groups in the scaffolding conditions are more likely to get involved in co-constructive metacognitive activities, which in turn increase the likelihood that these attempts will facilitate the group process. Thus as proposed scaffolding indeed has an effect on the interaction in which metacognitive activities are embedded.

With respect to the differentiating effect of different forms of scaffolds, we found that problematizing scaffolds support more transactive interaction among the group members. Triads in the problematizing condition show more co-constructed metacognitive activities compared to triads in the structuring condition. Moreover problematizing scaffolds resulted in less ignored metacognitive activities than structuring scaffolds. We expected problematizing scaffolds to increase co-constructive metacognitive activities due to the fact that they ask students to construct their own metacognitive activities. However, we did not expect this would reduce ignored metacognitive activities. One possible explanation is that groups that co-construct more metacognitive activities increase the group’s shared metacognitive knowledge. Shared knowledge is more likely to be used among the group members (Engelmann & Hess, in press). Thus more shared metacognitive knowledge among the group members could be an explanation for the fact that less metacognitive activities are ignored by other group members. We did expect that group’s receiving structuring scaffolds would show more accepted and shared metacognitive activities. Neither was confirmed, both forms of scaffolds elicit equal amounts of accepted metacognitive activities. The effect on shared metacognitive activities was in the anticipated direction.

We raised the question if qualitative differences in the way metacognitive activities are embedded in interaction could explain the differential effects of problematizing scaffolds on metacognitive knowledge. The results of this study confirm our earlier proposed qualitative differences in metacognitive activities as a result of different forms of scaffolds (Molenaar et al., submitted). We proposed that problematizing scaffolds lead to more transactive interaction compared to structuring scaffolds. The findings suggest that the qualitative difference in metacognitive activities could explain the differential effects of problematizing scaffolds on students’ metacognitive knowledge.

Contrary to our expectations, we did not find that scaffolds increase students’ shared attention at the beginning of metacognitive episodes. It is important to remember that
students only received a small number of scaffolds during the first two lessons, after which scaffolding was ceased. Analyzing the shared attention after scaffolds were provided indicated that they did elicit shared attention, however this effect was not sustained beyond receiving the scaffolds. However, we did find previously that shared attention does support more transactive interaction (Molenaar et al. submitted). To check this for this sample, we calculated the ratio of shared attention prior to different types of interaction. The ratio of shared attention before ignored metacognitive activities was 40%, which indicates that 40% of the ignored metacognitive activities were preceded by shared attention among the group members. The ratio for accepted metacognitive activities was 56% and for shared metacognitive activities it was 58%. Finally, co-constructed metacognitive activities were started in shared attention 74% of the time. These findings indicate that more transactive interaction is indeed more likely to be proceeded by shared attention among the group members. Yet scaffolding does not stimulate more shared attention, which is probably due to the low number of scaffolds.

Moreover, we suggested that scaffolding could initiate lasting changes to the group’s interaction. Taking into account that scaffolds were only given in the first 2 lessons, it is important to know that the increase of co-constructed metacognitive activities in the scaffolding conditions was throughout the learning assignment and not just during the lessons that the groups received scaffolds. This is in line with earlier findings (Kapur et al., 2008) that indicated that the interaction pattern initiated in the beginning of the collaboration remains rather stable over time.

These results initiate a practical implication. We showed that metacognitive scaffolding positively influenced transactive interaction around metacognitive activities. Thus scaffolds could function as a instructional design supporting students’ to engage in metacognitive interaction during collaborative learning. Moreover, it seems that the effects of metacognitive scaffolding and different forms of scaffolds on learning are enhanced by the interaction between the group members. We therefore encourage further research into the design of scaffolds that optimize interaction. This opens up the line of thought about metacognitive scaffolding as an instructional design to support successful collaboration among students and to develop metacognitive knowledge and skills. The relation between scaffolding metacognitive activities and collaboration needs future research. It could be a promising combination to enhance student’s metacognitive knowledge and skills for future learning in complex computer-based environments.

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Discussion and conclusion

This thesis focused on the development of a computerized scaffolding system to dynamically scaffold students’ self-regulated learning and examined the effects of this system in small groups. In this conclusion, we discuss our findings answering the central research question: What are the effects of computerized scaffolding of self-regulated learning on learning of collaborating students? We performed two experimental studies to address this question. The main findings were discussed in three parts that shifted from specifying the effects of scaffolding towards understanding how scaffolds contributed to students’ learning in a social setting. In part I, we discussed the rationale for the design of our scaffolding system and the results of the first study on scaffolding self-regulated learning in dyads. In part II, we discussed the results of the second study on scaffolding triads’ metacognitive activities with different forms of scaffolds (structuring vs. problematizing scaffolds) and elaborated on the current understanding of scaffolding during collaborative learning. Finally in part III, we further specified how metacognitive activities were embedded in the interaction among group members and how scaffolding influenced this. This work contributes to the knowledge on scaffolding, self-regulated learning, metacognition and the socio-cognitive perspective on collaborative learning in educational sciences. On a practical level it should enable refinements to computerized scaffolding systems based on an attention management system.

Part I. Computer-based scaffolding of self-regulated learning

Up until now there have been very few examples of personalized e-learning solutions which adapt to the learners' needs, even though we know that personalized education is more effective than standardized education (Bloom, 1984). Scaffolding is defined as providing learners with support when needed and fading assistance as the student’s competences increase (Wood, Bruner & Ross, 1979). Nevertheless, computer interpretation of students' competences is problematic, especially in ill-structured domains (Woolf, 2009). This is why we chose a different approach in the Atgentive project¹¹, in which we developed our computerized scaffolding system. An attention management system was used that focused on capturing learners’ attentional focus. This information was the source for deciding when to support learners with scaffolding.

In chapter two we addressed the sub-question: How can an attention management system enable dynamic scaffolding of self-regulated learning? In order to answer this question, a conceptual framework was created based on theories of scaffolding, attention and self-regulated learning (Molenaar & Roda, 2008). This conceptual framework guided

¹¹ The Atgentive project was an European STREP under the sixth Framework program. Atgentive stands for “Attentive Agents for Collaborative Learners”. The objective was to investigate the use of artificial agents for supporting the management of the attention of young or adult learners in the context of individual and collaborative learning environments.
the development of our attention-based scaffolding system called AtgentSchool that applies the central elements of scaffolding (diagnosis, calibration and fading). The system uses an attention management system which derives information from the student’s environment to model the attentional focus of the student with observable events (diagnosis). The attentional focus is compared to the logical attentional focus based on the learning assignment. This comparison is the basis for the selection of the scaffold (calibration) that either supports the current focus or guides the learner to a different focus. Finally, scaffolds are only sent when the student seems to need the support (fading).

An intervention model was defined based on self-regulated learning theory to select appropriate scaffolds. This model formulated metacognitive, cognitive and motivation scaffolds. The selection of metacognitive scaffolds was based on the cyclical model of Zimmerman (2002), which indicates when different metacognitive activities are used to control and monitor students’ learning: orientation and planning before commencing the task, monitoring and evaluation during the task. The selection of cognitive scaffolds is largely dependent on students’ own ability to ask for help using the help button in the interface. Finally, the selection of motivation scaffolds is related to the groups’ motivational input using interface buttons. AtgentSchool is a combination of an attention management system and the learning environment Ontdeknet. In AtgentSchool the scaffolds are communicated to the learner by a 3D embodied agent. The first test runs confirmed that the system provides dynamic scaffolds and students appreciated the scaffolding. This gave the green light for the first study.

In the third chapter, we presented the results of the first experimental study with the AtgentSchool system. The second sub-question was addressed: What is the effect of computerized scaffolding of self-regulated learning on learning outcomes and perception of collaborating students? A control group (n=54) was compared to an experimental group receiving scaffolds (n=56) working with the AtgentSchool system for 6 lessons (4.5 hours). The assignment was to learn about another country from an inhabitant of that country to decide if you want to live there and to write a group paper. We measured the effect of dynamic computerized scaffolding of self-regulated learning on dyads’ performance (the quality of the paper the dyads wrote), individual domain knowledge (knowledge test) and the dyads’ perception of the learning environment (questionnaire). The results showed that dynamic scaffolding had a significant small to medium effect on the performance of dyads, which is in line with other research on scaffolding of self-regulated learning (Azevedo & Hadwin, 2005; Azevedo, et al., 2008). However, no effects of scaffolding were found on the students’ domain knowledge. The absence of effects of scaffolding on the students’ domain knowledge is in line with other scaffolding studies, which also failed to find an effect of scaffolding on domain knowledge (Bannert, 2006; Bannert et al., 2009; Lin & Lehman, 1999).
The dyads’ perception of the learning environment was measured in the middle of the assignment and at the end. Dyads in the experimental group reported more positive perceptions of their teacher and of the collaboration, both during and at the end of the learning sequence. Conversely, with respect to the perception of the software and of the 3D-agent, students in the control and experimental group did not differ significantly at the same measurement. There was an interaction effect, dyads receiving scaffolds perceived the software and 3D-agent as more useful in the middle than at the end of the lesson sequences compared to the control group. A possible explanation could be that dyads give more positive evaluations of the environment at the beginning, possibly because they are surprised by its reactivity. However, as time passes they become used to it, they probably do not “see” the system anymore but they concentrate on the learning task. Another explanation might be that during the first two lessons students received many metacognitive scaffolds which were reduced during the later lessons. The fact that students received less scaffolds over time could also explain their shift in perception.

Overall, the findings indicated that dynamic scaffolding of self-regulated learning can be supported based on our conceptual model making use of an attention management system. Dynamic scaffolding positively contributed to dyads' performance on the learning task. Analysis of the log files did, however, indicate that the AtgentSchool system had a limited capability to provide cognitive scaffolds without the help-questions of learners. The system seemed especially effective for metacognitive scaffolds following the cyclical model of Zimmerman (2002). For this reason our second experimental study focused on the effects of metacognitive scaffolds.

Part II. The effects of metacognitive scaffolding and different forms of scaffolds

In this section the results of the second study focusing on the effects of metacognitive scaffolding and different forms of scaffolds were discussed. This study was different from the first in a number of ways. First, it only focused on metacognitive scaffolds, whereas in the first study cognitive scaffolds were also used. Second, this study had an elaborate design, measuring students’ activities during learning, group performance, and individual students’ domain and metacognitive knowledge. Third, instead of dyads we used triads, because in a pre-pilot we found that students in triads verbalized their learning activities more than students in dyads. Fourth, we only provided the triads with scaffolds during the first two lessons (2 hours), in the remaining four lessons (4 hours) students worked without support. Finally, we used two different forms of scaffolds, namely structuring and problematizing scaffolds. Structuring scaffolds supported the groups by providing guidelines and examples to support the groups’ metacognitive activities (i.e. providing the students with an example of a plan for the assignment), whereas problematizing scaffolds elicited metacognitive activities from the group (i.e. asking students to make their own plan for the assignment).
Chapter four focused on the effects of metacognitive scaffolding on learning. The research question was: What is the effect of metacognitive scaffolding and different forms of scaffolds on students’ learning? A control group (n=48) was compared to an experimental scaffolding group (n=106). Half of the triads received structuring scaffolds (n=51) and the other half received problematizing scaffolds (n=57). The triads worked on a similar assignment as in the first study for six lessons (6 hours) plus 1 hour pre-test and 1 hour post-test. The goal was to understand the effects of scaffolding on the triads’ learning performance (quality of the paper), individual students’ domain knowledge (knowledge test), the transfer of domain knowledge (application test) and metacognitive knowledge (open questions). The results showed, in contrast with our previous study, that metacognitive scaffolding had no significant effect on group performance. Nevertheless, the trend was in the expected direction. There also was no effect on the domain knowledge students acquired. The absence of effects of metacognitive scaffolding on the students’ domain knowledge was in line with our previous study and as stated above with other scaffolding studies (Bannert, 2006; Bannert et al., 2009; Lin & Lehman, 1999). We did find a significant effect of dynamic scaffolding on students’ metacognitive knowledge, which was in line with other research (Veenman, Blote & Kok, 2005).

With respect to the form of scaffolds, there was a significant medium effect of the form of scaffolds on group performance, the transfer of domain knowledge and on metacognitive knowledge. These findings indicate that problematizing scaffolds were more effective for learning than structuring scaffolds. Bannert (2006) stated that even though metacognitive scaffolding does not affect the quantity of domain knowledge, it does enhance the quality of domain knowledge. This was confirmed for problematizing scaffolds that led to higher transfer of knowledge than structuring scaffolds in our study.

We expected these results to be explained by the fact that problematizing scaffolds stimulated more metacognitive activities than structuring scaffolds. Furthermore, we wanted to examine two widely held assumptions, namely that scaffolds stimulate the students’ activities that they are directed at and lead to lasting changes in the students’ behavior (Pea, 2004). In chapter four, we investigated the effects of scaffolding on the groups' metacognitive activities during and after scaffolding. The sub-question addressed was: Does scaffolding and different forms of scaffolds stimulate metacognitive activities and develop metacognitive skills in small groups? We expected to explain the differential effects of problematizing and structuring scaffolds on learning with quantitative differences in metacognitive activities. We analyzed the learning activities of the 18 triads (n=54) with discourse analysis (6 triads from each condition). In total 108 hours of discourse and 51,339 turns were analyzed. We examined the stimulation hypothesis looking at the triads’ metacognitive activities during the 2 lessons that students received scaffolds and the developmental hypothesis during lessons 3 to 6 after the scaffolding had stopped.
We found that metacognitive scaffolding had a significant positive effect on the quantity of metacognitive activities performed by the triads. These findings confirmed the stimulation hypothesis: scaffolding supported triads to engage in more metacognitive activities. We also found that metacognitive scaffolding had a significant positive effect on the quantity of metacognitive activities performed by the triads after scaffolding stopped. This confirmed the development hypothesis: scaffolding did indeed continue to have a lasting effect on the triads' metacognitive activities after scaffolding stopped. This was important as scaffolding studies often refrain from creating lasting changes in behavior even within the same setting (Pea, 2004).

With respect to the effect of different forms of scaffolds, we predicted that problematizing scaffolds would elicit more metacognitive activities than structuring scaffolds. This expectation was based on the fact that problematizing scaffolds elicit students' metacognitive activities and could consequently have a greater effect on the interaction between the group members. Contrary to our expectation, we did not find that problematizing scaffolds stimulated more metacognitive activities than structuring scaffolds, nor did we find that they stimulated more metacognitive activities after scaffolding ceased. Again the trend was in the expected direction, but the differential effect on learning could not be explained by the quantity of groups’ metacognitive activities.

These results demand an explanation: why do problematizing scaffolds yield better group performance, transfer of domain knowledge and more metacognitive knowledge than structuring scaffolds, even though they do not stimulate significantly more metacognitive activities? We cannot answer this question before we know the exact relationship between scaffolding and different forms of scaffolds, metacognitive activities and students’ learning. We assumed that students learn from scaffolding through activities that scaffolds stimulate, but this has not been properly tested. Moreover, there could be qualitative differences in the metacognitive activities stimulated by different scaffolds. In chapter six, we addressed these issues with an additional discourse analysis, looking at the groups' responses to the scaffolds and a statistical analysis combining the learning outcome data from chapter four with the data on metacognitive activities from chapter five. The main question to be answered was: To what extent do metacognitive activities mediate the effects of metacognitive scaffolding and different scaffolds (structuring vs. problematizing) on students’ domain and metacognitive knowledge?

The discourse analysis suggested that structuring scaffolds encouraged students to discuss the application of the example while problematizing scaffolds stimulated them to construct metacognitive activities in interaction with their group members. Hence, structuring scaffolds might foster active metacognitive activities from the students, whereas problematizing scaffolds might trigger more constructive activities embedded in intensive interaction. Constructive activities are likely to be more effective than active activities at aiding knowledge acquisition (Chi, 2009). Thus, this qualitative difference in the student interactions might help explain why problematizing scaffolds were associated
with greater learning, while structuring scaffolds were not. This is an important finding, because it suggests that the effect of metacognitive scaffolds on learning operates through both a greater number of metacognitive activities within the group and the individual students' involvement in the metacognitive activities.

The statistical analysis assessed the relationship between scaffolding and different forms of scaffolds, the individual students' own and the other group members’ metacognitive activities and students’ domain and metacognitive knowledge, while controlling for other learning activities (cognitive, relational and off-task activities). The results of this analysis confirmed previously reported results that students receiving either form of metacognitive scaffolds (structuring or problematizing) displayed more metacognitive activities, and that students receiving metacognitive scaffolds had more metacognitive knowledge than students who did not receive any scaffolding. Furthermore, we found that metacognitive activities mediated the effects of the scaffolding on students’ metacognitive knowledge. However, only individual students’ own metacognitive activities significantly influenced their metacognitive knowledge. Additionally, students performing proportionately more cognitive activities and proportionately fewer off-task activities scored higher on the metacognitive knowledge test.

With respect to domain knowledge, this analysis showed that students in the problematizing condition did have more domain knowledge than those in the structuring and control condition. The difference in results compared to chapter four was probably due to a different sample: due to the labor intensive nature of the research we could only use the subsample of 18 triads for which we coded the learning activities. Again the individual students' own metacognitive activities mediated the effects of the problematizing scaffolds on their domain knowledge. Additionally, students performing proportionately more cognitive activities scored higher on the domain knowledge test. Furthermore, when a student’s group mates performed proportionately more relational activities, that student scored higher on the domain knowledge test. Contrary to our previous suggestion and Bannerts' statement (2009) that metacognitive scaffolding does not influence the quantity of domain knowledge, this seems to indicate that when scaffolding influences metacognitive activities in a certain way, it does increase domain knowledge.

These findings indicate that the effects of scaffolding on students’ knowledge were indeed mediated by the metacognitive activities the scaffolds stimulated. Moreover, the discourse analysis indicated that problematizing scaffolds stimulated stronger student involvement embedded in more intensive interaction. This conclusion needs to be treated with caution, because the discourse analysis only looked at the responses of the triads to the scaffolds and did not determine whether these qualitative difference in metacognitive activities continued throughout the assignment. Additionally, even though interaction is likely to enhance the quality of the groups’ metacognitive activities, up until now there is little empirical evidence that confirms this proposition. In part III, we elaborate on these issues.
Part III. Social metacognition, interaction and scaffolding

Until now there has been very little knowledge about metacognitive activities during collaborative learning (Dillenbourgh, Jarvala & Fischer, 2009). It has been proposed that different forms of metacognitive activities occur at various points along the social spectrum in groups, namely individual, other and social metacognitive activities (Iskala, Vauras & Lehtinen, 2004, Iiskala et al., 2011; Hadwin & Oshige, 2011). Moreover researchers differentiate between different types of interaction in which cognitive activities are embedded (Chi, 2009; Webb, 2009; Weinberger & Fischer, 2006). Cognitive activities embedded in more transactive interaction have been found to influence students’ learning more (Weinberger & Fischer, 2006). So far this distinction has not been applied to metacognitive activities during collaborative learning. In chapter seven, therefore, we focused on the question: How are metacognitive activities embedded in interaction during collaborative learning? To examine this issue, we selected the collaborative discourse from six control groups (n=18) from the second study, who engaged in 996 metacognitive episodes.

The majority of metacognitive activities were social metacognitive activities, but there was a small proportion of individual and other metacognitive activities in the groups’ interactions. This analysis indicated that the groups’ social metacognitive activities were indeed embedded in different types of interaction. We found ignored, accepted, shared and co-constructed metacognitive activities in our sample. Most metacognitive activities were shared, as they were embedded in episodes in which the group members related to each other’s metacognitive contributions with new metacognitive remarks. There was also a substantial amount of accepted metacognitive activities that were immediately engaged in by the group members’ cognitive activities. There were quite a number of ignored metacognitive activities that were not taken up by the group members at all. Finally, we only found a small number of co-constructed metacognitive activities.

As expected we found that metacognitive activities in more transactive interaction were more likely to facilitate the group process. This confirms that interaction in which group members relate to and engage in each other’s contributions adds to the quality of metacognitive activities. This verifies that findings from collaborative learning research (Chi, 2009; Webb, 2009; Weinberger & Fischer, 2006) are also applicable to metacognitive activities. Moreover, shared attention among the group members at the start of a metacognitive episode supported transactive interaction. Overall these findings indicate that for the analysis of metacognitive activities in small groups, it is important to take into account the type of interaction these activities are embedded in.

Finally, we wanted to take a close look at how scaffolding during collaborative learning influenced the way metacognitive activities were embedded in the interaction among the students. We also wanted to confirm our previous proposition about qualitative differences between metacognitive activities stimulated by different scaffolds. In chapter
Discussion and Conclusion

eight, we addressed the sub-question: What is the effect of metacognitive scaffolding on the way metacognitive activities are embedded in interaction? We examined the effect of scaffolding and different scaffolds on the relative frequency of the different types of metacognitive activities embedded in the interaction of 18 triads (n=54) from study 2. We tested the transactivity hypothesis that states that scaffolding increases transactive interaction and the shared attention hypothesis that proposes that scaffolding stimulates shared attention among group members.

We found that students receiving scaffolding showed significantly more co-constructed metacognitive activities than groups that did not receive scaffolding. This indicates that scaffolding positively influenced students' uptake of metacognitive activities. This is in line with earlier findings (Barron, 2000; 2003) that indicate that the difference between successful and unsuccessful groups in problem-solving is not caused by the quantity of possible solutions, but by the uptake of those solutions by the group. Moreover, groups receiving problematizing scaffolds showed significantly fewer ignored metacognitive activities and more co-constructed metacognitive activities than groups receiving structuring scaffolds. These findings suggest that scaffolding had a differentiating effect on the groups' interaction and different forms of scaffolding seemed to influence the groups’ interaction differently. Scaffolding was not found to have an effect on the students’ shared attention. These findings indicate that under the right circumstances scaffolding can support collaborative learning. Thus the relation between scaffolding and collaboration needs further research, but it could be a promising combination to enhance students' metacognitive knowledge and skills for future learning in complex computer-based environments.

Developing metacognitive knowledge with scaffolding during collaborative learning

Answering our main research question – What are the effects of computerized scaffolding of self-regulated learning on the learning of collaborating students? – we established that computerized scaffolding of self-regulated learning has a small to medium positive effect on group performance and also positively influenced the groups’ perception of their collaboration, their teacher, their initial opinion of the software and the agent. Metacognitive scaffolding also showed a similar small to medium effect on group performance but this was not significant. We did not find an effect of scaffolding on domain knowledge. We did find that metacognitive scaffolding had a small positive effect on students’ metacognitive knowledge. Finally, looking at the groups’ activities during learning, we found that metacognitive scaffolding had a medium to large positive effect on the groups’ metacognitive activities and a large positive effect on co-constructive metacognitive activities. Thus our scaffolding systems stimulated groups’ metacognitive activities, enhanced the way metacognitive activities were embedded in interaction and consequently improved students’ metacognitive knowledge.

Reflecting on the goal of our computerized program, namely to support small groups in complex computer-based learning environments to enhance the regulation of
their learning, the findings suggest that we succeeded in stimulating students’ metacognitive activities and knowledge. Although this seemed to support group performance, we did not find an effect on domain knowledge. It is important to note that the assignment was not directly focused on acquiring domain knowledge and that all students in both studies showed more domain knowledge on the post-test. In the light of the results, it is important for practical purposes to determine whether there were any lasting changes of scaffolding on the groups’ metacognitive activities. We established that groups receiving scaffolds continued to apply more metacognitive activities after the scaffolding stopped. Moreover, we found that problematizing scaffolds outperformed structuring scaffolds on a number of issues. Problematizing scaffolds resulted in better group performance, more transfer of domain knowledge and more metacognitive knowledge. These differential effects on learning could not be explained by quantitative differences in metacognitive activities. We did find students in the problematizing condition showed fewer ignored metacognitive activities and more co-constructed metacognitive activities than those in the structuring condition. The combination of quantitative and qualitative differences seems likely to explain the differential learning effects of problematizing scaffolds.

Our studies increased our understanding of how scaffolding in collaborative settings influences learning. First, small groups receiving metacognitive scaffolds showed more metacognitive activities and continued to show more metacognitive activities after scaffolding stopped. Second, the effect of scaffolding on students’ knowledge was mediated by the metacognitive activities. Third, students’ own activities influenced their learning significantly, whereas other students’ activities had less impact. Fourth, qualitative differences in the way activities were embedded in interaction (more or less transactive) seemed to influence the students’ learning from scaffolding. Finally, different forms of scaffolds can have differential effects on students’ transactive interaction. These findings indicate that scaffolding in small groups was strengthened by the interaction among the group members. This means that scaffolds could be designed in ways that are more attuned toward eliciting students' interaction. Future research needs to test the proposition further but if it were to be confirmed, scaffolding during collaborative learning could be a powerful mechanism to enhance students’ metacognitive knowledge and skills.

Limitations

As in all research, there are a number of limitations to take into account. This study was very specific with respect to its sample, the context and the learning task, and therefore generalization of the results is should be carefully considered. The sample in our studies consisted of young learners in elementary education aged 8-12. Young learners are likely to have less developed metacognitive knowledge and skills than older learners, and so studies with learners from different age groups would be needed to validate the results for other groups. The context in our studies was a computer-based e-learning environment with mostly text and pictures. Future research would need to determine whether this
scaffolding system could also facilitate learning in other computer-based learning environments, for instance games, immersive environments or mobile learning environments. Moreover, the assignment was a research task in the geography domain with a writing assignment. Future work should assess whether a task with a stronger focus on domain knowledge and in different domains could also be supported in this way. Furthermore, the sample size of measurements at the group level was restricted. In the process analysis the sample size was even smaller, though this was partially compensated by the large volume of analyzed coded utterances (51,399). This limited the power of our analysis and non-significant results should be treated with caution.

With respect to the measurement of metacognitive knowledge, we used a self-designed context-specific metacognitive knowledge questionnaire. This questionnaire correlated with the measurement of metacognitive activities performed by the students, which indicates that it solved some of the issues around the measurement of metacognitive knowledge (Veenman, 2011). However, this questionnaire was not suitable for a pre-test. We were therefore unable to measure the students' existing metacognitive knowledge, which makes it impossible to say anything about the students’ development or the differential effects of initial metacognitive knowledge. Another limitation is that we measured the groups’ metacognitive activities after scaffolding within the same setting and context. This allows us to conclude that, within the same task and context, scaffolding did lead to lasting changes in behavior, we do not know whether these effects will be confirmed in other assignments in another learning environment, group or learning domain. Moreover, it can be argued that some metacognitive activities are not explicit, but implicit in the occurrence of higher cognition (Veenman et al., 2006). For these reasons the measurement of metacognitive activities was not exhaustive for all metacognitive activities occurring within the triads. Future research needs to address the transfer issue and find a solution to adequately pre-test metacognitive knowledge.

Finally, we raise the question of how dynamic our scaffolding system really is. The development of computerized scaffolding systems is driven by the positive effects of scaffolding with human tutors and the infeasibility of personalized scaffolding in schools. Other examples of such recently developed systems are MetaTutor for college students learning in hypermedia (Azevedo et al., 2010a,b, in press) and Betty’s Brain for middle school children learning science topics (Biswas, Jeong, Kinnebrew, Sulcer & Roscoe, 2010). These systems successfully foster students’ self-regulation and facilitate learning doing this. Inspired by human tutors who determine their scaffolding based on the diagnosis of students’ behavior and reduce it when the students’ competences increase (Wood, Bruner & Ross, 1976; Scharma & Hannafin, 2007), computerized scaffolding systems track and trace students’ activities to diagnose current behavior and select scaffolds that adjust to each student's progress (Azevedo et al., 2010a; Molenaar & Roda, 2008). However, the system’s awareness and interpretation of the students' behavior is still restricted to making localized decisions for scaffolding and feedback, depending on time thresholds for various system- and learner-initiated behaviors. This means that the
scaffolding is dynamically adjusting itself to the students' progress, but it does not fully adapt to their development.

Adaptive metacognitive scaffolding demands the measurement of students’ metacognitive activities during learning. Metacognitive activities are identified based on their manifestation during learning with concurrent thinking-aloud protocols (Azevedo, et al., 2008; 2010a; van der Stel & Veenman, 2010). These measurements are very labor intensive, not concurrent with learning, nor applicable for computer systems. Consequently there is an active debate about new approaches to measure metacognitive activities during learning (Greene & Azevedo, 2010). Multiple data-stream analysis can be used to establish indicators of metacognitive activities using analyzed think-aloud protocols together with data-streams that are measured during learning, for example computer log files, eye tracking, psychological or sensor data. For example, scrolling in the computer log file is found to be an indicator of monitoring (Veenman, Wilhelm & Beishuizen, 2004). Finding valid and reliable indicators of metacognitive activities during learning should therefore be pursued both for system development and to advance research about metacognition and its development.

Apart from measuring metacognitive activities during learning, we suggested in chapter two that the current input into our system was too limited to support the diagnosis of both the cognitive and motivational processes of students. Registering more and different information from the students' environment would allow us to accumulate a better representation of the individual learner’s attentional focus. This could enhance our ability to position interventions in relation to cognitive and motivational processes. For example, the effectiveness of cognitive scaffolds could be enhanced using eye tracking, which would provide a better diagnosis of the learner’s current focus and related cognitive activities. The use of a webcam to assess the emotional state of a student could provide better input to the system to support the diagnosis of the learner’s motivation and provide scaffolds supporting this.

**Future research directions**

In this thesis, we elaborated extensively on the effects of scaffolding on students' activities and learning. However, we have still not analyzed all of the data-sets we collected. For example, students’ epistemological beliefs about the nature and sources of learning could interplay with their willingness to engage in learning in open complex computer-based learning environments. This could also affect their response to scaffolding and their willingness to engage in active construction of their own metacognitive activities. Moreover, the data-sets we did analyze could benefit from further analysis. Our process analyses looking at students' metacognitive activities were on a holistic level (Reimann, 2009). Holistic analyses consider the process as one unit without aiming to understand the temporal or sequential aspects within the process (Azevedo et al.,2010; Reimann, 2009;
Wampold, 1992). Attention for temporal aspects could help us understand how scaffolding influences the positioning of metacognitive activities over time. For instance, does scaffolding support more planning at the beginning of a task? Concentration on sequential aspects could support more insights into the effect of scaffolding on the pattern of the learning activities. For example, does scaffolding affect the position of the metacognitive activities in relation to cognitive activities? Thus process analysis looking at the temporal and sequential effects of scaffolding could produce further evidence in support of our understanding of how scaffolding influences learning in collaborative settings.

Taking a broader perspective, the results of our research provide a number of suggestions for new research. Our research showed that metacognitive activities are important for regulating group learning in Computer-Based Learning Environments (CBLEs). Students who orientate, plan, monitor and evaluate perform better than students who do not engage in these metacognitive activities as shown in this thesis and by others (Azevedo, Cromley, Winters, Moos & Greene, 2008; Bannert, Hildebrand & Mengelkamp, 2008). We showed that scaffolding can support the development of metacognitive knowledge. Moreover, other research indicates that metacognitive skills (i.e. the ability to apply metacognitive activities to regulate one’s learning) are a significant predictor of students’ learning performance, possibly even more important than intelligence (van der Stel & Veenman, 2010). Although the importance of metacognitive knowledge and skills is recognized and there is abundant research evidence showing that students do not regulate their learning in CBLEs sufficiently, little attention has been given to how to develop students’ metacognitive knowledge and skills to foster learning in these complex environments (Azevedo et al., 2008). Until now, most research has concentrated on scaffolding to stimulate regulation to enhance domain knowledge acquisition (Azevedo, et al., 2008; Land & Greene, 2000).

We know very little about the development of metacognitive skills and knowledge of young students in elementary education. This is partly due to difficulties measuring metacognitive activities and to the belief that the development of metacognitive knowledge starts when students are older (Azevedo 2010; Schraw, 2010; Veenman, 2011). We found that computerized scaffolding supported the development of metacognitive knowledge by stimulating students’ metacognitive activities. Interaction among peers also seemed to support the development of young students’ metacognitive knowledge. Moreover, initial stimulation of the scaffolds seemed to be taken over by the group. Further research is therefore needed to examine under what conditions scaffolding during collaborative learning could support the development of students’ metacognitive knowledge and skills.

**Future directions for development of scaffolding systems**

In the limitation section, we emphasized the need to measure metacognitive activities concurrently during learning to enhance our scaffolding system. There have been some interesting findings for scaffolding with a 3D virtual agent as used in our system. Research has established the so-called *mere belief* effect, which demonstrates that the
belief one is having of social interaction (believing that you are interacting with a human) leads to higher arousal, attention, and learning (Okita, Bailerson & Schwartz, submitted). Additionally the protégé effect asserts that even though young learners know the embodied agent is not real, they still show strong social responses that improve learning when working with these agents (Chase, Ching, Opperzo & Schwartz, in press). Hence, the communication and presentation of the scaffolds to the learner seems to be an important issue. The effects of the usage of modalities are largely unknown; for example, one can use modalities used such as text messages, agents or even robots. With respect to the embodied agent, we know very little with respect to the usage of its emotions, appearance, animations and their effects on fostering student activities and learning. This emphasizes the need for further research into modality effects and the usages of the embodied agent.
Summary

Young students in elementary education often have problems effectively controlling and monitoring their learning in complex computer-based environments. In the Atgentive project, we developed a computerized scaffolding system to support students’ self-regulated learning to overcome that problem. This thesis addresses the research question: What are the effects of computerized scaffolding of self-regulated learning on learning of collaborating students? To answer this question seven sub-questions were formulated, which were answered in seven chapters in this thesis. The questions and their answers are grounded in the theoretical constructs: self-regulated learning, scaffolding and the socio-cognitive perspective on collaborative learning.

Students’ ability to steer and regulate their learning is considered important for learning in complex computer-based learning environments. Self-regulating learners are those learners who successfully use cognitive activities (read, process, elaborate) to study a topic, control and monitor their learning with metacognitive activities (orientate, plan, monitor and evaluate their actions) and are able to motivate themselves (Zimmerman, 2002, Azevedo et al., 2008, Winne & Hadwin, 2010). Students’ self-regulated learning can be supported with scaffolding, which refers to providing assistance to a student on an as-needed basis, fading the assistance as the competence of the student increases (Wood, Bruner & Ross, 1976). Students often learn collaboratively in complex computer-based environments. Under the right circumstances collaborative learning enhances group performance and individual learning (Cohen, 1994; Johnson & Johnson, 1999; Lou, 2001; Slavin, 1996; Dillenbourg et al., 2009). In this thesis, we use the socio-cognitive perspective on collaborative learning to explain how individuals learn in interaction with others. This perspective emphasizes the student’s individual development as well as the group development as a result of the collaboration between group members (Hadwin & Oshige, 2007; liskala, Vauras, & Lehtinen, 2004; Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen, 2003; Volet, Vauras, & Salonen, 2009).

In part I, the conceptual framework that supported the development of the scaffolding system AtgentSchool is described, as well as the results of the first study on scaffolding self-regulated learning. Chapter 1 describes the theoretical foundation and rationale for the design of our scaffolding system. This chapter specifies how an attention management system can support dynamic scaffolding for self-regulated learning. Attention management systems capture information from the students’ environment about the students’ attentional focus. This information is interpreted to select scaffolds for the learners. The essential elements for selecting appropriate scaffolds are diagnosis, calibration and fading. The appropriate scaffold is selected from an intervention model with scaffolds that support the components of self-regulated learning, namely cognition,
metacognition and motivation. Based on the test-runs, we concluded that the system functioned according to the conceptual framework.

Chapter 2 reports on the results of the first study that assessed the effects of scaffolding of self-regulated learning on the groups’ performance, perception of the learning environment and individual students’ acquisition of domain knowledge. This study was performed in the Czech Republic with students aged 11 years, who worked collaboratively in dyads on a task in AtgentSchool. Students in the scaffolding condition (n=56) were supported with computer-generated scaffolds and students in the control condition (n=54) did not receive scaffolds. The scaffolds were dynamically adjusted to the students’ progress with the attention management system. The scaffolds supported students’ metacognitive and cognitive activities. We found that scaffolding had a positive effect on the students’ group performance, but did not affect individual students’ domain knowledge. The repeated measurement of perceptions of the learning environment showed that students in the experimental condition were more positive about their teachers and their peer-collaborators than students in the control condition. With respect to their perception of the software and the 3D embodied agent delivering the scaffolds, we found a stronger decrease in appreciation over time in the scaffolding condition compared to the control condition.

Part II focuses on the effects of metacognitive scaffolding and different forms of scaffolds (structuring and problematizing scaffolds) on learning. In chapter 3, we discuss the effects of metacognitive scaffolding and different forms of scaffolds on the groups' performance and individual students' domain and metacognitive knowledge. This study was performed in the Netherlands with students aged 9 to 12 years who worked collaboratively in triads on a task in AtgentSchool. In an experimental design the two experimental groups receiving scaffolds were compared with a control group (n=48). The experimental groups differed in the form of scaffolding used: structuring scaffolds which entailed context-specific examples (n=51) vs. problematizing (n=57) scaffolds which were context-specific questions. We analyzed the effects of metacognitive scaffolding and of different forms of scaffolds on the learning outcomes at group and individual level. The results showed no effect of scaffolding on group performance nor on acquired individual domain knowledge and a significant effect on acquired individual metacognitive knowledge. Students in the scaffolding condition gained higher scores on the metacognitive knowledge test than students in the control condition. With respect to the effects of different forms of scaffolds, we found a small significant effect on group performance, on transfer of individual domain knowledge and on the individual metacognitive knowledge acquired. Students receiving problematizing scaffolds gained better learning results than students receiving structuring scaffolds and students in the control group.

In order to explain the differential results of different forms of scaffolds, we investigated the effect of scaffolds on the groups' metacognitive activities on the data set
from the second study. This study, described in Chapter 4, examined the effects of scaffolds on groups’ metacognitive activities in a complex computer-based learning environment. We used discourse analysis to analyze students’ metacognitive activities. Due to the labor intensiveness of discourse analysis, we only used a randomly drawn subsample from the second study: 6 control groups (n=18), 6 structuring groups (n=18) and 6 problematizing groups (n=18). We analyzed the effects of scaffolding and the different forms of scaffolds on the amount of metacognitive activities of triads, making a distinction between the two lessons triads received scaffolds and the four lessons they did not. The results showed that scaffolding had a significant effect on metacognitive activities; triads receiving scaffolds performed significantly more metacognitive activities. Additionally, scaffolding also had a significant development effect; triads continued to show more metacognitive activities after the scaffolding ceased. Finally, no significant differences between the two forms of scaffolding were found; triads receiving problematizing scaffolds did not show more metacognitive activities during or after the scaffolding than triads receiving structuring scaffolds.

Chapter 4 did not explain the differential learning results of different forms of scaffolds. To further unravel this puzzle, we analyzed the mediated role of metacognitive activities on the effects of scaffolding and different forms of scaffolds on students’ learning. The findings of these analyses are described in chapter 5. Multivariate, multilevel analysis of the 51,339 conversation turns from the 54 students from the second study showed once again that scaffolding had an effect on students’ learning. Students receiving structuring or problematizing metacognitive scaffolds displayed more metacognitive knowledge than students in the control group. We found that students’ own metacognitive activities mediated the effects of scaffolding and that increased metacognitive activities supported students’ metacognitive knowledge. Moreover, students that were engaged in proportionately more cognitive activities or fewer off-task activities also outperformed other students on the metacognitive knowledge test. In this sample, contrary to the findings in chapter 3, problematizing scaffolds did lead to more domain knowledge and again students’ own metacognitive activities mediated the effects of the problematizing scaffolds. Moreover, students in the problematizing condition that were engaged in more cognitive activities or whose group mates used more relational activities had greater domain knowledge acquisition than other students. We proposed that the differential effects of problematizing scaffolds could be explained by qualitative differences in the students’ metacognitive activities. This proposition was explored in part III.

Part III focuses on how students collaboratively regulated their learning and investigates the effects of scaffolding on students’ metacognitive activities embedded in interaction. Chapter 6 investigates how metacognitive activities were embedded in interaction between the group members during collaborative learning. Research indicates that the quality of cognitive activities is positively influenced by transactive interaction in which group members relate to and engage in each other’s contributions (Roschelle, 1996, Teasley, 1997; Weinberger, Stegemann & Fischer, 2007). We examined whether
metacognitive activities embedded in different types of interaction were more likely to facilitate the group process and the provisional role of shared attention on interaction. We analyzed 996 metacognitive episodes embedded in the interaction of 6 triads from the control condition (n=18) collaborating on a research task in a computer-based learning environment. The findings show that metacognitive activities in small groups occurred in four different types of interaction which were accompanied with an increasing level of transactivity, namely ignored, accepted, shared and co-constructed among the group members. Shared attention did indeed support more transactive interaction. Moreover, metacognitive activities embedded in more transactive interaction were more likely to facilitate the group process than those embedded in less transactive interaction. These findings confirm that interaction between the group members can positively influence the quality of metacognitive activities and that in collaborative settings it is important to look at how metacognitive activities are embedded in interaction.

Chapter 7 explores the effect of computerized scaffolding with different scaffolds (structuring vs. problematizing) on the way metacognitive activities were embedded in the interaction among group members during collaborative learning. In this study, we investigated the different types of interaction around metacognitive activities of 18 triads (6 control groups (n=18) and 12 scaffolding groups (6 structuring (n=18) and 6 problematizing (n=18)). We found that groups receiving scaffolding showed significantly more co-constructed metacognitive activities than groups in the control condition. Groups receiving problematizing scaffolds showed significantly less ignored and more co-constructed metacognitive activities than groups receiving structuring scaffolds. These findings indicate that scaffolding positively influenced the way metacognitive activities were embedded in the interaction between group members. Moreover, these findings seem to explain the differential learning effects of different forms of scaffolds. Future research should therefore consider how to design scaffolds that support metacognitive activities embedded in more transactive interaction.

Reflecting on the goal of the AtgentSchool computer program, namely to support small groups in complex computer-based learning environments to enhance the regulation of their learning, the findings show that it succeeded in stimulating students’ metacognitive activities and knowledge. Although this seemed to support group performance, it did not affect individual students’ domain knowledge. Moreover, we found that problematizing scaffolds were superior to structuring scaffolds, generating better effects on learning. Our findings contributed to our understanding of how scaffolding in collaborative settings influenced learning. First, small groups receiving metacognitive scaffolds performed more metacognitive activities and continued to show more metacognitive activities after scaffolding was stopped. Second, the effect of scaffolding on students’ metacognitive knowledge was mediated by these metacognitive activities. Third, students’ own activities influences their learning significantly, whereas other students’ activities had less impact, though there is an exception in the case of other students’ relational activities. Fourth, different forms of scaffolds can have differential effects on students’ transactive
interaction. Finally, qualitative differences in the way activities are embedded in interaction (more or less transactive) seemed to influence students’ learning from scaffolding.

Our research findings suggest that scaffolding in small groups is strengthened by the interaction among the group members. This means that scaffolds could be designed in ways that are more attuned toward eliciting students’ interaction. Future research needs to test the proposition, but it seems that scaffolding during collaborative learning could be a powerful mechanism to enhance students’ metacognitive knowledge and skills.
Leerlingen in het basisonderwijs hebben vaak problemen met het sturen, controleren en monitoren (reguleren) van hun leren in complexe computer leeromgevingen. Om dit probleem te verhelpen is er, binnen het Atgentive project, computer ondersteuning (scaffolding) ontwikkeld om leerlingen te helpen bij het reguleren van hun leren. Dit proefschrift behandelt de onderzoeksvraag: Wat zijn de effecten van computer ondersteuning van zelfregulerend leren op het leren van samenwerkende leerlingen? Om deze vraag te beantwoorden zijn er zeven subvragen geformuleerd, die in zeven hoofdstukken in dit proefschrift worden behandeld. De vragen en de antwoorden zijn gebaseerd op de theoretische constructen, zelfregulerend leren en scaffolding en het socio-cognitieve perspectief op samenwerkend leren.

De vaardigheid om je eigen leren te sturen, controleren en monitoren is heel belangrijk voor succesvol leren in open computer leeromgevingen. Om een onderwerp te bestuderen gebruiken zelfregulerende leerlingen cognitieve activiteiten (lezen, verwerken, verbreden) op de juiste wijze. Daarnaast controleren en monitoren zijn hun leren met metacognitieve activiteiten (oriënteren, plannen, monitoren, evalueren en reflecteren) en zij ze in staat zichzelf te motiveren (Zimmerman, 2002; Azevedo et al, 2008; Winne & Hadwin, 2010). Zelfregulerend leren kan worden ondersteund met zogenaamde scaffolding. Scaffolding is het ondersteunen van leerlingen, wanneer zij hulp nodig hebben. Deze steun wordt afgebouwd, zodra de vaardigheden van de leerlingen toenemen (Wood, Bruner & Ross, 1976).

Samenvatting

Aandacht van de leerling op gericht is. Deze informatie wordt geïnterpreteerd en op basis daarvan wordt de juiste ondersteuning (scaffolds) voor de leerling geselecteerd. De juiste hulp wordt geselecteerd uit een interventiemodel. Hierin is ondersteuning opgenomen voor de verschillende componenten van het zelfregulerend leren, namelijk cognitieve, metacognitieve en motivatie activiteiten. Verschillende gebruikerstesten met het systeem hebben aangetoond dat het systeem functioneert zoals beschreven in het conceptuele model.

Hoofdstuk 2 behandelt de resultaten van de eerste studie. De eerste studie onderzoekt de effecten van het ondersteunen (scaffolden) van zelfregulerend leren op de groepsprestaties, de perceptie van leerlingen op de leeromgeving en de acquisitie van domein kennis. Deze studie werd uitgevoerd in Tsjechië met 11 jarige leerlingen die in tweetallen samenwerkten aan een taak in de computer leeromgeving AtgentSchool. Leerlingen in de ondersteuningsconditie (n=56) kregen hulp van het computer systeem, leerlingen in de controleconditie (n=54) kregen geen hulp. De ondersteuning werd aangepast aan de voortgang van de leerlingen met behulp van het aandachtsmanagement systeem. De ondersteuning was gericht op de cognitieve en metacognitieve activiteiten van de leerlingen. De resultaten tonen aan dat de ondersteuning wel een positief effect heeft op de groepsprestaties maar niet op de domeinkennis van de leerlingen. De herhaalde metingen van de perceptie van de leerlingen op de leeromgeving laten zien dat leerlingen die ondersteuning ontvlagen positiever oordelen over hun leerkraghten en de samenwerking met hun medeleerlingen. De waardering van de leeromgeving en de 3D agent, die de ondersteuning aan leerlingen communiceerde, werd naarmate de tijd verstreek, minder positief bij de leerlingen in de ondersteuningsconditie in vergelijking met die van leerlingen in de controle conditie.

Deel II richt zich op de effecten van metacognitieve ondersteuning en de verschillende vormen van ondersteuning (structurerende en problematiserende ondersteuning) op het leren. In hoofdstuk 3 worden de effecten onderzocht van metacognitieve ondersteuning en de verschillende soorten ondersteuning op de groepsprestaties. Tevens wordt de domein en metacognitieve kennis van leerlingen onderzocht. Deze studie werd uitgevoerd in Nederland met leerlingen van 9 tot 12 jaar die in drietallen samenwerkten aan een taak in de computer leeromgeving AtgentSchool. In een experimentele opzet werden leerlingen die ondersteuning ontvingen in twee verschillende groepen (structurerende (n=51) en problematiserende ondersteuning (n=57)) vergeleken met een controle groep (n=48). De experimentele groepen verschillen in de vorm van ondersteuning. In de conditie met structurerende ondersteuning werden context specifieke voorbeelden van metacognitieve activiteiten gegeven, in de conditie met problematiserende ondersteuning werden context specifieke vragen over metacognitieve activiteiten gesteld. De effecten van metacognitieve ondersteuning en verschillende soorten ondersteuning werden bestudeerd op groeps- en individueel niveau. De resultaten laten zien dat ondersteuning geen effect heeft op de groepsprestaties en de individuele domein kennis van leerlingen. Er is wel een effect op de metacognitieve kennis van leerlingen.
Leerlingen die ondersteuning ontvangen hebben meer metacognitieve kennis dan leerlingen die geen ondersteuning ontvangen. Daarnaast blijkt dat problematiserende ondersteuning in vergelijking tot structurerende ondersteuning een effect heeft op groepsprestaties, het hergebruik van domein kennis en metacognitieve kennis van de leerlingen. Leerlingen die problematiserende ondersteuning ontvangen hebben betere leerresultaten dan leerlingen die structurerende ondersteuning danwel geen ondersteuning ontvangen.

Om de effecten van verschillende vormen van ondersteuning te verklaren hebben we nader onderzocht hoe de ondersteuning de metacognitieve activiteiten van de groepen beïnvloedt. Deze studie wordt beschreven in hoofdstuk 4 en onderzoekt het effect van ondersteuning op de metacognitieve activiteiten van de groep in een open computer leeromgeving. We hebben de gesprekken van de leerlingen geanalyseerd om de metacognitieve activiteiten te onderzoeken. Door het arbeidsoptimistische karakter van gespreksanalyse was het niet mogelijk alle groepen uit de bovenstaande studie te analyseren. Voor deze studies is een aselecte steekproef genomen van 6 controle groepen (n=18), 6 groepen met structurerende ondersteuning (n=18) en 6 groepen met problematiserende ondersteuning (n=18). De effecten van ondersteuning en verschillende vormen van ondersteuning op de hoeveelheid metacognitieve activiteiten in de groepen tijdens 6 lessen werd onderzocht. Hierbij werd een onderscheid gemaakt tussen de metacognitieve activiteiten die werden uitgevoerd als de groepen ondersteuning kregen tijdens de eerste 2 lessen en de metacognitieve activiteiten die werden uitgevoerd als de groepen geen ondersteuning meer kregen tijdens de laatste 4 lessen. De resultaten laten zien dat ondersteuning een significant effect heeft op de metacognitieve activiteiten van de leerlingen. Groepen die ondersteuning krijgen voeren significant meer metacognitieve activiteiten uit. Daarnaast zien we ook een significant ontwikkelingseffect, groepen blijven meer metacognitieve activiteiten uitvoeren ook wanneer ze geen ondersteuning meer ontvangen. Echter we vinden geen significante verschillen tussen de twee verschillende soorten ondersteuning. Groepen die problematiserende ondersteuning krijgen voeren niet significant meer metacognitieve activiteiten uit als groepen die structurerende ondersteuning krijgen.

Aangezien de studie in hoofdstuk 4 niet de verschillen in leeropbrengsten tussen de verschillende soorten ondersteuning kan verklaren gaan we in hoofdstuk 5 een stapje verder om deze puzzel op te lossen. We hebben geanalyseerd wat de medierende rol is van de metacognitieve activiteiten op de effecten van de ondersteuning en verschillende soorten van ondersteuning op het leren van individuele leerlingen. Hiervoor gebruiken we een Multi-variatie, Multi-level analyse waarin de 51.339 beurten in de gesprekken van de leerlingen (n=54) uit de bovenstaande studie nader worden bestudeerd. Hieruit blijkt dat ondersteuning een effect heeft op het leren van de leerlingen. Leerlingen die ondersteuning kregen hebben meer metacognitieve kennis dan leerlingen in de controle groep die geen ondersteuning ontvingen. De metacognitieve activiteiten medieren de effecten van de ondersteuning op het leren en meer metacognitieve activiteiten leiden tot meer
metacognitieve kennis. Daarnaast blijkt dat leerlingen die meer cognitieve activiteiten en minder niet taak gerelateerde activiteiten uitvoeren hogere resultaten behalen op de metacognitieve kennistoets. In deze steekproef leidt problematiserende ondersteuning wel tot meer domein kennis in tegenstelling tot de resultaten in hoofdstuk 3. Ook hier mediëren de metacognitieve activiteiten de effecten van de problematiserende ondersteuning. Daarnaast blijkt dat leerlingen die meer cognitieve activiteiten uitvoeren en/of die groepsgenoten hebben die meer relationele activiteiten (betrekken, bevestigingen, ontkennen) uitvoeren hogere resultaten behalen op de domein kennistoets. Deze analyse lijkt erop te duiden dat de verschillen in leeropbrengsten tussen de verschillende vormen van ondersteuning verklaard kunnen worden door kwalitatieve verschillen in de metacognitieve activiteiten van de leerlingen. Deze veronderstelling wordt nader onderzocht in deel III.

Deel III onderzoekt hoe leerlingen in groepen hun leren samen controleren en monitoren. Daarnaast wordt het effect van ondersteuning op de wijze waarop groepen hun metacognitieve activiteiten vorm geven in interactie onderzocht. In hoofdstuk 6 wordt onderzocht hoe metacognitieve activiteiten ingebed zijn in de interactie tussen de groepsleden. Onderzoek heeft aangetoond dat de kwaliteit van cognitieve activiteiten positief wordt beïnvloed door de mate van transactieve interactie tussen de groepsleden. In transactieve interactie relateren leerlingen aan elkaars uitspraken en bouwen voort op elkaars bijdragen (Weinberger & Fischer, 2006). Daarom is onderzocht of metacognitieve activiteiten die ingebed zijn in meer transactieve interactie een faciliterende bijdrage aan het groepsproces leveren. Daarnaast blijkt gedeelde aandacht bij te dragen aan de mate van transactiviteit in de interactie van leerlingen (Barron, 2000; 2003). Dus er is ook gekkeken of gedeelde aandacht de transactiviteit van de interactie beïnvloedt. 996 metacognitieve episoden zijn geanalyseerd uit de gesprekken van de 6 controle groepen (n=18). Deze analyse laat zien dat metacognitieve activiteiten in vier verschillende soorten interactie voorkomen in kleine groepen leerlingen met een oplopende mate van transactieve interactie. Metacognitieve activiteiten kunnen worden genegeerd, geaccepteerd, gedeeld en samen geconstrueerd door de groepsleden. De analyses tonen aan dat metacognitieve activiteiten, ingebed in een hogere mate van transactieve interactie tussen de groepsleden, een hogere kans hebben om het groepsproces te faciliteren dan metacognitieve activiteiten met een lagere mate van interactie. Daarnaast lijkt gedeelde aandacht aan het begin van een metacognitieve episode de mate van interactie tussen de leerlingen te bevorderen. Deze bevindingen bevestigen dat meer transactieve interactie tussen de groepsleden een positieve bijdrage kan leveren aan de kwaliteit van de metacognitieve activiteiten. Dit betekent dat het belangrijk is om tijdens het samenwerkend leren aandacht te besteden aan de wijze waarop metacognitieve activiteiten zijn ingebed in de interactie tussen de leerlingen.

In hoofdstuk 7 wordt het effect van de verschillende soorten ondersteuning op de wijze waarop metacognitieve activiteiten zijn ingebed in de interactie tussen de
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groepsleden tijdens het samenwerkend leren bestudeert. Deze studie onderzocht of groepen in de verschillende condities (6 controle groepen (n=18), 6 structurerende groepen (n=18) en 6 problematiserende groepen (n=18)) variëren in de verschillende soorten interactie waarin metacognitieve activiteiten zijn ingebed. De resultaten laten zien dat groepen die ondersteuning ontvangen significant meer samen geconstrueerde metacognitieve activiteiten uitvoeren dan groepen in de controle groepen. Daarnaast blijkt dat groepen die problematiserende ondersteuning ontvangen minder metacognitieve activiteiten negeren en dat ze meer samen geconstrueerde metacognitieve activiteiten uitvoeren in vergelijking met groepen die gestructureerde ondersteuning ontvangen. Deze bevindingen laten zien dat ondersteuning een positieve invloed heeft op de wijze waarop metacognitieve activiteiten zijn ingebed in de interactie tussen de leerlingen. Aangezien de transactieve interactie tussen de groepsleden een positief bijdrage lijkt te leveren aan het groepsproces kan dit mogelijk een verklaring zijn voor de verschillende leerprestaties en de verschillende soorten ondersteuning. Daarom adviseren we om in de toekomst meer onderzoek uit te voeren naar de wijze waarop ondersteuning kan worden ontwikkeld die transactieve metacognitieve interactie tussen leerlingen bevorderd.

Reflecterend op het doel van het computer programma AtgentSchool, namelijk het ondersteunen van leerlingen in computer leeromgevingen bij het reguleren van hun leren, laten de bevindingen zien dat we erin zijn geslaagd om metacognitieve activiteiten te stimuleren en metacognitieve kennis te ontwikkelen. Dit lijkt een positieve invloed te hebben op groepsprestaties, maar het beïnvloedt niet de domein kennis van de leerlingen. Daarnaast hebben we gevonden dat problematiserende ondersteuning leidt tot betere leerresultaten dan structurerende ondersteuning. In het algemeen geven de resultaten inzicht in hoe ondersteuning leerresultaten beïnvloedt tijdens het samenwerkend leren. Ten eerste, kleine groepen leerlingen die metacognitieve ondersteuning ontvangen voeren meer metacognitieve activiteiten uit als ze worden ondersteund en blijven meer metacognitieve activiteiten uitvoeren als de ondersteuning is gestopt. Ten tweede, de effecten van de ondersteuning op het leren van leerlingen worden gemediërd door metacognitieve activiteiten. Ten derde, de activiteiten die worden uitgeoord door de leerling zelf hebben een significante invloed op zijn leren terwijl activiteiten van andere leerlingen minder effect lijken te hebben. De relationele activiteiten van mede leerlingen zijn hierop een uitzondering. Ten vierde, verschillende vormen van ondersteuning hebben verschillende effecten op de mate van interactie tussen de leerlingen. Ten vijfde, de kwalitatieve verschillen in de wijze waarop activiteiten zijn ingebed in de interactie tussen de leerlingen lijken het leren van de leerlingen te beïnvloeden.

Onze onderzoeksbevindingen suggereren dat ondersteuning aan kleine groepen wordt verstrekt door de interactie tussen de groepsleden. Dit betekent dat moet worden onderzocht hoe ondersteuning kan worden ontwikkeld die is afgestemd op het stimuleren van de interactie tussen leerlingen. Toekomstig onderzoek zou deze veronderstelling verder moeten onderzoeken. Het lijkt erop dat ondersteuning tijdens het samenwerkend
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leren een krachtig mechanisme is om de metacognitieve kennis en vaardigheden van leerlingen te versterken.
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possibly ever develop, but let’s continue our work together. Jan, the journey is what matters and I chose to travel with you. Sophie and Max, I will see to it that you develop excellent metacognitive skills, collaboratively!
Bio Inge Molenaar

Inge Molenaar (1975) was born in Son en Breugel and finished her secondary education in 1994. She started to study International Business at the University of Maastricht in 1994, adding Psychology to her study program in her second year. In 1999 she obtained her Master's in International Business Studies with specializations in Innovation Management and Information Systems. Inspired by psychological topics, she wrote her master's thesis on organizational learning. In 2001 she completed her Master's in Cognitive Psychology with a specialization in Educational Psychology and a thesis on corporate learning in virtual communities of practice.

In 2000 she took up the position of researcher at the SCO Kohnstamm Institute at the University of Amsterdam, working on various national and international technology enhanced learning projects. One year later she founded the company Ontdeknet, that designed, developed and implemented an e-learning environment that enables students in primary and secondary school to collaborate with experts in a virtual learning environment. She won several national and international awards for this innovative idea and the learning environment has been used successfully in over 200 schools.

In the meantime, she maintained her association with the University of Amsterdam and wrote a funding proposal for a PhD project with dr. Marianne Elshout-Mohr. The national science foundation of the Netherlands funded the proposal entitled “Effects of Innovative Learning Arrangements on the Acquisition of Knowledge” on which Inge started to work on in 2005. The same year Ontdeknet was awarded the European project Atgentive to develop attentive agents for collaborating students. Both projects influenced Inge’s research and this thesis is the result.

Over time the focus of Ontdeknet was slowly transferred from developing and implementing the e-learning environment to consultancy and developing new technology enhanced learning solutions, such as the repository service behind the national repository Wikiwijs and a tool for creating adaptive learning materials. Inge’s professional career reflects both her strong interest in learning and her quest to design and develop technology enhanced learning solutions that help practitioners to implement new ways of learning in schools.
Publication list

Refereed Journal Articles and Book Chapters


Manuscripts under review


Articles in preparation


**Presentations**


Molenaar, I., van Boxtel, C. A.M, & Sleegers, P. J. C. (2010). Analyzing the Metacognitive Process from Different Angles; Three Methods of Process Analysis Compared. *In Symposium New Methods to Analyze Metacognitive and Self Regulation Processes, 4th Biennial Meeting of the EARLI Special Interest Group 16 “Metacognition”: Munster, Germany*


Molenaar, I., van Boxtel, C. A.M, & Sleegers, P. J. C. (2008). Scaffolding Metacognition in Collaborative Learning with a Virtual Agent; Measuring Social Metacognition. *In proceedings onderwijs research dagen*, Eindhoven, the Netherlands


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**Workshops**


**Symposia**

*New Methods to Analyze Metacognitive and Self Regulation Processes, 4th Biennial Meeting of the EARLI Special Interest Group 16 “Metacognition”: Munster, 2010, Germany*

*Metacognition in Collaborative Learning, 4th Biennial Meeting of the EARLI Special Interest Group 16 “Metacognition”: Munster, 2010, Germany*

**Posters**


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