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

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Introduction

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<th>Student</th>
<th>Turns</th>
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<tr>
<td>Tim</td>
<td>What are we supposed to do?</td>
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<tr>
<td>Elise</td>
<td>I do not know, do you know Linda?</td>
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<tr>
<td>Linda</td>
<td>No, we have to write a paper</td>
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<tr>
<td>Tim</td>
<td>Ok, but how?</td>
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<tr>
<td>Linda</td>
<td>On the computer with this program</td>
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<td>Elise</td>
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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

\(^1\) 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, analyzes 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, Alexender & 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
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
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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 (liskale 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.
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.