Instr Sci (2011) 39:785–803
DOI 10.1007/s11251-010-9154-1

Metacognitive scaffolding in an innovative learning arrangement

Inge Molenaar · Carla A. M. van Boxtel · Peter J. C. Sleegers

Received: 9 February 2009 / Accepted: 8 October 2010 / Published online: 30 October 2010

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. The experimental groups differed in the form of scaffolding used: structuring scaffolds versus problematizing 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 no effect of scaffolding on group performance, nor on the acquired individual domain knowledge, but a small effect on acquired individual metacognitive knowledge. With respect to the effects of different forms of scaffolds, we found a small effect on group performance, on transfer of individual domain knowledge and on the individual metacognitive knowledge acquired.

Keywords Metacognition · Scaffolding · Innovative learning arrangements · Virtual agents · Elementary education

I. Molenaar (✉)
Research Institute Child Development and Education, University of Amsterdam,
Postbus 94208, 1090 GE Amsterdam, The Netherlands
e-mail: i.molenaar@uva.nl

C. A. M. van Boxtel
Research Institute Child Development and Education, University of Amsterdam,
Amsterdam, The Netherlands

P. J. C. Sleegers
Department of Education Organization and Management, University of Twente,
Enschede, The Netherlands

Introduction

Many students have difficulties learning successfully in innovative learning arrangements, which in turn have an impact on their performance and achievement (Azevedo and Cromley 2004; Azevedo and Hadwin 2005; Bannert and Mengelkamp 2008; Hannafin and Land 1997; Land and 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 et al. 2000). In these learning arrangements students are given the responsibility to specify topics to be learned and to decide upon the learning strategies to be followed (Kalyuga et al. 2001; Kirschner et al. 2006). As a consequence, these environments draw heavily on the 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 et al. 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 and Hadwin 2005; Azevedo et al. 2008; Bannert 2006, Bannert et al. 2009; Lin and 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 and Oshige 2007; Iiskala et al. 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 et al. 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 and Hadwin 2005; Luckin and 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). 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 are 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 et al. 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 procedural knowledge for regulating 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 and Roda 2008; Puntambekar and 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 been 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 and Hadwin 2005; Azevedo et al. 2008; Bannert 2006, Bannert et al. 2009; Lin and 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 and 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, 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 and 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 training metacognitive knowledge or 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 to 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 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 drew on the socio-cognitive perspective of learning (Hadwin and Oshige 2007; Iiskala et al. 2004; Vauras et al. 2003; Volet et al. 2009). This perspective focuses on how peers play a mediating role in the learning of others through reciprocial 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 and Oshige 2007). Members of the group are conceptualized as multiple regulating agents who co-regulate each others 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 the individuals' 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 a 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 individuals' 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. For instance, 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 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 innovative learning arrangements?
2. What is the effect of different forms of scaffolds (structuring vs. problematizing) supporting metacognition on learning outcomes of collaborating students in innovative learning arrangements?

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 of 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 also therefore 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 students' 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 students' 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 paper 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 "The scaffolding system and the conditions" 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 three 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 the students with specialized information. The assignment is divided into smaller sub-assignments to support the 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 and 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 eight lessons of 1 h. 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 h). In six 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 four 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 h 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 the 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 the students' attention from the students' environment. Currently, input information is derived from the keyboard strokes, mouse movements and event information about the students' activities in the e-learning environment. The reasoning level selected the scaffold that is sent to the learner. Different software agents assessed the 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 the students' attention focus. This attention focus was established based on the input information that the system acquired from the 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 and Roda 2008). 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 1 for an overview of all scaffolding messages).

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 students' metacognitive activities. The triads in the problematizing condition were obliged to answer the agent's questions in an answer box on the screen, see Fig. 1 for an example of both forms of scaffold. Screenshots in Appendix 2 show how the messages are integrated into the electronic learning environment. Table 1 shows the messages of the orientation, planning and monitoring scaffolds in

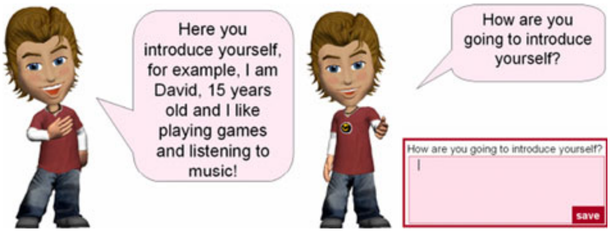

Fig. 1 An example of a structuring and problematizing scaffold

Table 1 Example of structuring and problematizing scaffolds for the assignment introduction

Situation	Structuring scaffold	Problematizing scaffold
Orientation on introduction	Before we start, I would like to know who you are, please introduce yourselves	Why are you going to introduce yourselves?
Planning of introduction	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	How are you going to introduce yourselves?
Monitoring of introduction	Thank you, I will send your introduction to the expert	Did you introduce yourselves as planned?

structuring and in problematizing form for the introduction assignment (Appendix 1 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 and Kaul 1978).

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. Finally, the 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 et al. 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

Table 2 Overview of measurements

Learning outcome	Group measurement	Individual measurement
Performance	Quality of the paper	
Domain knowledge		Free recall
		Knowledge test
		Near transfer test
Procedural knowledge		Procedural knowledge test

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 min 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, the *metacognitive knowledge* of the students 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 2.

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 ANOVAs 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.

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) see, Table 3. 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.

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 9(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.

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 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 (Table 3).

Table 3 The effect of scaffolding on learning outcomes; comparing the control group to the two scaffolding conditions

Conditions	Control M (SD)	Scaffolding M (SD)	t	*p*	r
Quality of group paper	3.31 (1.35)	3.98 (1.41)	1.39	0.08	0.19
Recall domain knowledge	8.89 (3.37)	9.15 (3.59)	0.42	0.34	0.03
Domain knowledge New Zealand	19.56 (5.70)	19.25 (9.14)	−0.17	0.43	0.01
Domain knowledge Iceland	15.78 (6.39)	17.06 (5.39)	0.79	0.22	0.08
Transfer of domain knowledge	6.42 (2.32)	6.27 (2.23)	−0.37	0.35	0.03
Procedural knowledge*	4.51 (1.96)	5.21 (2.15)	1.63	0.05*	0.16

* indicates significant at $p < 0.05$

Table 4 The effect of the form of scaffolds on learning outcomes; comparing the structuring condition to the problematizing condition

Conditions	Structuring M (SD)	Problematizing M (SD)	t	*p*	r
Quality of group paper	3.41 (1.46)	4.37 (1.34)	2.07	0.02*	0.28
Recall domain knowledge*	9.25 (3.53)	9.05 (3.62)	−0.28	0.39	0.02
Domain knowledge New Zealand	19.61 (9.03)	18.88 (9.23)	−0.35	0.37	0.03
Domain knowledge Iceland	17.77 (5.99)	16.35 (4.80)	−0.83	0.21	0.11
Transfer of domain knowledge*	5.90 (2.05)	6.65 (2.41)	1.64	0.05*	0.13
Procedural knowledge*	4.81 (2.31)	5.61 (1.99)	1.67	0.05*	0.16

* indicates significant at $p < 0.05$

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; $p < 0.02$ (one tailed) see Table 4. 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 significantly affect the 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 forms 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 9 (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.

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 (Table 4).

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 increase learning outcomes more 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 no significant effect on group performance nor 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 or to the acquisition of more domain knowledge. These results concur with findings of other studies. In another study, we found a medium effect of scaffolding on the quality of group papers (Molenaar et al. 2010), which had a similar magnitude to the effect found in this study. The absence of effects of metacognitive scaffolding on the 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 and 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. 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 significantly 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 modeling effect hypothesis of 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 improved their group product 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 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.

Acknowledgments 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 would like to thank Joost Meijer for his contribution to the statistical analysis.

Appendix 1: all scaffolding messages

See Table 5.

Table 5 All scaffolding messages

Situation	Structuring scaffold	Problematizing scaffold
Introduction of the group		
Orientation on introduction	Before we start, I would like to know who you are, please introduce yourselves	Why are you going to introduce yourselves?
Planning of introduction	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	How are you going to introduce yourselves?
Monitoring of introduction	Thank you, I will send your introduction to the expert	Did you introduce yourselves as planned?
Writing the goal statement		
Orientation on goal statement	I would like to know what you want to learn, please explain that in your goal statement	Why are you going to write a goal statement?
Planning of goal statement	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	How are you going to write a goal statement?
Monitoring of goal statement	I will send your learning goal to your expert to explain to him what you want to learn	Did you write your goal statement as planned?
Selecting the country		
Orientation on selection	Please select the country you would like to learn more about	Why are you going to choose the country?
Planning of selection	Please explore the environments of the experts to decide which country you would like to learn more about	How are you going to choose the country?
Monitoring of selection	You have now selected the country to learn more about	Did you make your choice as planned?
Specifying topics of interest in a mind map		
Orientation on mind map	The expert would like to know what you want to learn; let's make a mind map	Why are you going to make a mind map?
Planning of mind map	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?	How are you going to make a mind map?
Monitoring of mind map	I will send the topics you would like to learn more about to the expert	Did you make your mind map as planned?

Appendix 2: screen shots

See Figs. 2 and 3.

Fig. 2 Structuring condition

Fig. 3 Problematizing condition

References

Azevedo, R., & Cromley, J. G. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia? *Journal of Educational Psychology, 96*(3), 523–535.

Azevedo, R., & Hadwin, A. F. (2005). Scaffolding self-regulated learning and metacognition—implications for the design of computer-based scaffolds. *Instructional Science, 33*(5–6), 367–379.

Azevedo, R., Moos, D. C., Greene, J. A., Winters, F. I., & Cromley, J. G. (2008). Why is externally-facilitated regulated learning more effective than self-regulated learning with hypermedia? *Educational Technology Research and Development, 56*(1), 45–72.

Bannert, M. (2006). Effects of reflection prompts when learning with hypermedia. *Journal of Educational Computing Research, 35*(4), 359–375.

Bannert, M., Hildebrand, M., & Mengelkamp, C. (2009). Effects of a metacognitive support device in learning environments. *Computers in Human Behavior, 25*(4), 829–835.

Bannert, M., & Mengelkamp, C. (2008). Assessment of metacognitive skills by means of instruction to think aloud and reflect when prompted. Does the verbalisation method affect learning? *Metacognition and Learning, 3*(1), 39–58.

Ericsson, K., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist, 49*(8), 725–747.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*(10), 906–911.

Franke, R. H., & Kaul, J. D. (1978). The Hawthorne experiments: First statistical interpretation. *American Sociological Review, 43*, 623–643.

Hadwin, A., & Oshige, M. (2007). *Self-regulation, co-regulation and socially shareed regulation: Examining many faces of social in models of of SRL.* Paper presented at the EARLI.

Hannafin, M. J., & Land, S. M. (1997). The foundations and assumptions of technology-enhanced student-centered learning environments. *Instructional Science, 25*(3), 167–202.

Igo, L. B., Bruning, R., & McCrudden, M. T. (2005). Exploring differences in students' copy-and-paste decision making and processing: A mixed-methods study. *Journals of Education Psychology, 87*, 103–116.

Janssen, J. (2008). Using visualizations to support collaboration and coordination during computer-supported collaborative learning. UU Universiteit Utrecht, doctoral thesis.

Kalyuga, S., Chandler, P., & Sweller, J. (2001). Learner experience and efficiency of instructional guidance. *Educational Psychology, 21*(1), 5–23.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational psychologist, 41*(2), 75–86.

Land, S. M., & Greene, B. A. (2000). Project-based learning with the World Wide Web: A qualitative study of resource integration. *Educational Technology Research and Development, 48*(1), 45–67.

Lin, X., & Lehman, J. D. (1999). Supporting learning of variable control in a computer-based biology environment: Effects of prompting college students to reflect on their own thinking. *Journal of Research in Science Teaching, 36*(7), 837–858.

liskala, T., Vauras, M., & Lehtinen, E. (2004). Socially-shared metacognition in peer learning? *Hellenic Journal of Psychology, 1*(2), 147–178.

Luckin, R., & Boulay, B. d. (2002). Construction and abstraction: Contrasting methods of supporting model building in learning science. In P. Brna, M. Baker, K. Stenning, & A. Tiberghien (Eds.), *The role of communication in learning to model* (pp. 99–125). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Molenaar, I. (2003). *Knowledge exchange from citizens to learners through online collaboration*. Paper presented at the Edmedia.

Molenaar, I., & Roda, C. (2008). Attention management for dynamic and adaptive scaffolding. *Pragmatics & Cognition, 16*(2), 224–271.

Molenaar, I., Van boxtel, C., Sleegers, P., & Roda, C. (2010). Atgentschool; dynamic scaffolding with attention management. In C. Roda (Ed.), *Human attention in digital environments*. Cambridge: Cambridge University Press.

Nelson, T. O. (1996). Consciousness and metacognition. *American Psychologist, 51*, 102–116.

O'Donnell, A. M. (Ed.). (2006). *Introduction: Learning with technology*. Mahwah, NJ: Lawrence Erlbaum Associates.

Pea, R. D. (1993). Practices of distributed intelligences and design for education. In G. Salomon (Ed.), *Distributed cognitions; psychological and educational considerations*. Cambridge: Cambridge University Press.

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational psychologist, 40*(1), 1–12.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *Journal of the Learning Sciences, 13*(3), 273–304.

Rosenthal, R. (1991). *Meta-analytic procedures for social research (revised)*. Newbury Park, CA: Sage.

Salomon, G. (1993). *Distributed cognitions; psychological and educational considerations*. Cambridge: Cambridge University Press.

Simons, P. R. J. (2000). *Leren en Instructie*. Den Haag: NWO/PROO.

Vauras, M., Iiskala, T., Kajamies, A., Kinnunen, R., & Lehtinen, E. (2003). Shared-regulation and motivation of collaborating peers: A case analysis. *Psychologia: An International Journal of Psychology in the Orient, 46*(1), 19–37.

Veenman, M. V. J. (2005). The assessment of metacognitive skills: What can be learned from multimethod designs? In C. Artelt & B. Moschner (Eds.), *Lernstrategien und Metakognition: Implikationen für Forschung und Praxis*. Berlin: Waxmann.

Veenman, M. V. J., Kok, R., & Blote, A. W. (2005). The relation between intellectual and metacognitive skills in early adolescence. *Instructional Science, 33*(3), 193–211.

Veenman, M. V. J., Van Hout-Wolters, B. H. A. M., & Afflerbach, P. (2006). Metacognition and learning: conceptual and methodological considerations. *Metacognition Learning, 1*(1), 3–14.

Volet, S., Vauras, M., & Salonen, P. (2009). Self- and social regulation in learning contexts: An integrative perspective. *Educational Psychologist, 44*(4), 215–226.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*, 89–100.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into Practice, 42*(2), 64–70.