Dynamic scaffolding of socially regulated learning in a computer-based learning environment

Inge Molenaar a, *, Claudia Roda b, Carla van Boxtel a, Peter Sleegers c

a University of Amsterdam, Department of Child Development and Education, Postbus 94208, 1090 GE Amsterdam, The Netherlands
b American University of Paris, Department of Computer Science, France
c University of Twente, Department of Educational Organization and Management, The Netherlands

ABSTRACT

The aim of this study is to test the effects of dynamically scaffolding social regulation of middle school students working in a computer-based learning environment. Dyads 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 dyads’ progress with an attention management system. The scaffolds support two aspects of socially regulated learning namely the metacognitive and cognitive activities. We analyzed the effects of dynamic scaffolding on dyads’ performance, their perception of the learning environment and students’ knowledge acquisition. We found that scaffolding had a positive effect on the dyads’ learning performance, but did not affect students’ domain knowledge. The repeated measurements of perception of the learning environment showed that dyads 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 appreciation over time in the scaffolding condition compared to the control condition.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Self-regulation is important for learning in complex Computer-Based Learning Environments (CBLEs), such as hypermedia and computer-based learning environments (Azevedo & Hadwin, 2005; Bannert & Mengellkamp, 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 & Hadwin, 2005; Azevedo, Moos, Johnson, & Chauncey, 2010). 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). Moreover, students are often learning collaboratively in CBLEs and research indicates that students in small groups also have problems regulating their learning (Hadwin & Oshige, 2007; Iskala, Vauras, & Lehtinen, 2004; O’Donnell, 2006).

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, & Burkett, 2010) and Atgentive (Molenaar, van Boxtel, & Sleegers, 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 et al., 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, Moos et al., 2010; Molenaar & Roda, 2008).
In our study, we used an attention management system to attain dynamic scaffolding (Molenaar, van Boxtel, & Sleegers, 2011). The aim of this study is to assess the effects of computerized dynamic scaffolding on middle school students’ learning in small groups. The students worked in dyads and the effect of scaffolding were determined on the dyads’ performance, their perception of the learning environment and students’ knowledge acquisition. This analysis allows us to identify if the AgentSchool system supports students’ socially regulated learning and consequently influence their performance, perception and 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 of self and socially regulated learning on learning and motivation.

2. Computerized dynamic scaffolding

Scaffolding is defined as providing assistance to students when needed, fading the assistance when the competence of the student increases (Wood et al., 1976). Within the scaffolding paradigm, a distinction can be made between different types of scaffolding, namely static and dynamic scaffolding (Molenaar & Roda, 2008; Puntambekar & Hubscher, 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 particular 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, we are just beginning to develop computer systems that can monitor students’ behavior to provide dynamic scaffolds (Molenaar, van Boxtel, & Sleegers, 2011; Woolf, 2009). Moreover, attempts to develop programs that assess students’ knowledge have only been successful in structured domains such as mathematics, science and chemistry. In ill-structured domains, it is difficult to build models of the student’s knowledge, because students’ answers are difficult to interpret (Lynch, Ashley, Pinkwart, & Aleven, 2009).

Therefore, we took a different approach in this study. 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 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), which forms the basis for computerized dynamic scaffolding (Molenaar, van Boxtel, Sleegers, & Roda, 2011).

3. Scaffolding self-regulated learning

Cognitive and metacognitive activities are key to self-regulating one’s learning in complex Computer-Based Learning Environments (CBLEs) such as the Internet, electronic learning environments and games (Azevedo & Hadwin, 2005; Azevedo et al., 2010). 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, & Cromley, 2008; Bannert & Mengelkamp, 2008). However research has abundantly shown that students insufficently regulate their learning in CBLEs. 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).

In a similar vein, students in small groups need to regulate their learning, which is referred to as socially regulated learning (Hadwin & Oshige, 2007; Iiskala et al., 2004; O’Donnell, 2006). In small groups learners have to use the appropriate cognitive activities to attain their learning goals and use metacognitive activities to control and monitor their learning (Hadwin & Oshige, 2011; Iiskala, Vauras, Lehtinen, & Salonen, 2011; Vrole, Vauras, & Salonen, 2009). Thus group members should 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 order to support students’ socially regulated learning, scaffolding should focus on supporting the group’s 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).

4. Effects of scaffolding on learning

As discussed above, scaffolding differs with respect to the types of scaffolds (static vs. dynamic vs. adaptive). 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 also discuss studies that were directed at individual students due to a lack of studies directed at small groups. We emphasize the type, modality and focus of scaffolding.

First, we report on static scaffolding studies. Veenman, Kok, and Blote (2005) analyzed the effects of a paper list of 6 metacognitive questions on the performance of 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, and 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 dyads’ problem solving on the near and far transfer performance on biology tasks. They found increased far transfer on contextually different problems when dyads’ were supported with the scaffolds. However, no effects of scaffolding were found on near transfer problems.

There are few studies with computerized dynamic or adaptive 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 students’ self-regulated learning and facilitates learning of complex science topics (Azevedo et al., 2010). Finally, Azevedo and colleagues performed several studies (Azevedo et al., 2008) assessing students learning in a hypermedia 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.

5. Our study

The aim of our study is to explore the effects of dynamic scaffolding with an attention management system on dyads’ performance, their perception of the learning environment and student’s knowledge acquisition. Research has shown effects of static scaffolding on problem solving and transfer of domain knowledge and dynamic scaffolding also improved students’ domain knowledge. However, to our knowledge no studies have been conducted so far into the effects of computerized dynamic scaffolds supporting dyads 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 assess dyads’ perception and how this fluctuates during learning.

The following research questions are addressed:

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

In an experimental design a dynamic scaffolding condition is compared with a control condition. The students in the scaffolding condition are supported with dynamic cognitive and metacognitive scaffolds that are adjusted to the dyads’ progress. Dyads in the control condition did not receive dynamic scaffolds that were adjusted to their progress. The agent communicated to all students that he was monitoring their progress and dyads in both conditions could indicate how they felt to the agent with smiley’s in the interface. Based on earlier scaffolding research the expectation is that dynamic scaffolding will positively affect dyads’ performance, their perception and the acquisition of students’ domain knowledge.

6. 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. Teachers rated students as low or high achievers based on their reading, writing and computer abilities and then created dyads containing one low and one high achiever, and combining one boy and one girl. The dyads 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 blocking for class and school effects. 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 Fig. 1). The dyads in the control condition did see the virtual agent, but did not receive any metacognitive or cognitive scaffolds from the agent. This was to prevent a hawthorn effect (Franke & Kaul, 1978). The agent did communicate to all students including those in the control group that he was monitoring their activities. Moreover all students could indicate how they felt to the agent with the smiley’s in the interface (happy, neutral and unhappy). The agent mirrored their feelings, for instance when students indicated they were happy the agent would smile too or make a small joke.

The total duration of the experiment was 6 lessons of 45 min 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. During the lessons 2 through 5 the dyads worked on the assignment (4 h). In the final lesson, students finished the assignment and the domain knowledge of individual students was measured.

7. 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, van Boxtel, & Sleegers, 2011). The attentional focus was monitored at three levels: the input level, the reasoning level and the intervention level. At the input level, the system collected environmental information about students' attention including for example, the keyboard strokes, mouse movements and students' activities in the e-learning environment. This allowed the system to know which task students were working on (active task), how long they worked on this task and if they finished the task successfully. At the reasoning level the system determined what was in the focus of the students' attention using the input information. The ongoing registration of students' active tasks and events (e.g. the students has filled in 6 items in the mind map), allowed the system to make a judgment of the students' progress. Based on this diagnosis of the students' attention and progress, scaffolds were selected that could be useful to support the students at this particular moment. Dynamic scaffolding was therefore achieved through a process of continuous students' monitoring and consequent dynamic adaptation of the scaffold. In the next paragraph, we discuss how different types of scaffolds were selected. At the intervention level it was decided how to communicate the selected scaffold. Our 3D agent David communicated the scaffolds to the learners with a particular expression, for example happy, sad or angry and particular behavior, for example pointing, sitting or walking.

The dyads in the scaffolding condition received scaffolds supporting their cognitive and metacognitive learning activities. The cognitive scaffolds were given 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 current task. For example a cognitive support scaffold when the learner is working on 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 (2002) model for self-regulated learning. For the three preparation assignments and at the start of the main task, all dyads

Fig. 1. Example of the embodied agent in the learning environment providing a scaffold to the learner.
in the scaffolding condition received orientation, planning and monitoring scaffolds. 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 when students are about to select this task is: “You can write a goal statement to explain to the expert why you chose 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 was given when students were about to start the learning goal task: “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 a sub-task, 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”. Students in the scaffolding conditions received a minimum of 12 metacognitive scaffolds, which were implemented at the beginning of the three preparation assignments and the main assignment. The system had no information to judge the entry level of the students and therefore it was designed to assume that the dyads had low skills at entry time. This assumption was based on previous research that indicated that small groups often have problems regulating their learning (Hadwin & Oshige, 2011). Following this initial state, the system dynamically tracked the activities of the students over time and, based on that, it inferred their progress and need for help. Students would only receive metacognitive scaffolds when their progress was hampered, which was indicated by unfinished tasks and monitoring of idle users without an active task.

8. Measurements

8.1. Group performance

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. The paper was assessed on the richness of the text and the amount of processing of the provided information. The number of different topics about the country covered, for example the language, the climate and the native population, was an indication of the richness of the paper (Janssen, 2008). Therefore the richness of the text was evaluated by counting the number of topics covered in at least a paragraph in the paper. The assignment was to write a paper that compares New Zealand to Czech Republic to determine if you want to live in New Zealand. Thus a certain level of richness is innate for a good paper that supports that goal. The amount of self-formulated text was an indication of the amount of processing students had done in relation to the information provided (Igo, Bruning, & McCrudden, 2005). The students received information about the country written by the inhabitant in the computer-based learning environment. This information was compared to the student’s text to determine to what extent students formulated the text themselves. This resulted in a processing score. This criteria was added to prevent copy and past behavior. Both criteria were communicated to the students. The paper was assessed evaluating the richness and the amount of processing to assign final paper scores: bad paper (1 point), medium paper (2 points) and a good paper (3 points). The papers were scored by a researcher and the dyads’ teacher. The interrater reliability was measured with Cohen’s kappa, κ = 0.63, which is considered adequate. Two researchers were asked to reach mutual agreement on the papers that were scored differently by the teacher and the first researcher.

Student’s domain knowledge was measured individually by a curriculum-based knowledge test with 15 true/false items related to New Zealand. For example, “It is winter in New Zealand when it is summer in the Czech Republic” true or false. 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 0.18 for the pre-knowledge test and 0.76 for post-knowledge test. The same test was used as pre-test and as post-test with 6 weeks in between the two measurements.

8.2. Perception questionnaire

The dyads’ 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 alpha of 0.72. The perception of the software measured the students’ ideas about the software and consisted of 8 items with a Cronbach’s alpha 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 alpha 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 alpha of 0.83. The answer options were 1 through 5 with 5 indicating very good and 1 indicating very bad. See Appendix A for an overview of the questions. The dyads filled in one questionnaire together, they were asked to come to a agreement about the answers.

9. 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 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 (Honzza), 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.1

10. Results

10.1. 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 (Mdn = 2) wrote significantly better papers compared to the control condition (Mdn = 1), $U = 268.5$, $p < .05$, $r = 0.26$. 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 (Mdn = 1) asked significantly more questions compared to the control condition (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 relevant in this case $F(1,55) = 0.42$, $p > .05$ not significant and the interaction between time and condition was also not significant, $F(1,55) = 2.93$, $p > .05$. 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-test ($m = 6.61$) and post-test ($m = 10.57$), indicating that all students gained more domain knowledge.

10.2. 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, $F(1,38) = 3.01$, $p > .05$ 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 Fig. 2). Overall, all students reported a good perception of the agent, but over time this reduced to a neutral attitude.

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, $F(1,38) = 0.22$, $p > .05$ 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 then students in the control condition (see Fig. 3). 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 $F(1,38) = 0.79$, $p > .05$, 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, $F(1,38) = 1.64$, $p > .05$. 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

---

1 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 $r = z/\sqrt{N}$. The $r$ for the parametric data is calculated on the basis of the data from the repeated ANOVA $r = \sqrt{F(1, dfr)}/F(1, dff) + dfR$. 

Fig. 2. Perception agent at time 1 and time 2 of the control group and the experimental group.
of their collaboration was not significant, $F(1,38) = 1.59, p > .05$ 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 $F(1,38) = 2.62, p < .05$. 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.

11. Conclusion and discussion

This study contributes to the existing body of knowledge on scaffolding socially regulated learning by showing the effects 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 better papers 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. We believe this could possibly be explained by the fact that the focus of the assignment was not on acquiring new knowledge, but on writing the paper comparing the Czech Republic with New Zealand and acquiring new information by asking questions. Closer qualitative analysis of the dyads’ papers seemed to indicate that the fact that they were better could be explained by a greater effort of students in the scaffolding condition in processing the information about New Zealand. Moreover, these students seemed better able to distinguish the relevant information necessary to compare two countries. Based on these findings, we suggest that students in the experimental condition had a better understanding of the task.

Yet, our expectation with respect to domain knowledge was not confirmed. All students had gained significantly more domain knowledge after the learning sequence, which indicated that they learned. However, the fact that we did not find effects of scaffolding metacognitive activities on domain knowledge is in line with the results from other computerized scaffolding studies (Bannert, 2006; Bannert et al., 2009). An argument provided for these findings is that metacognitive scaffolding does not affect the quantity of domain knowledge, but only leads to enhanced quality of this knowledge. As in Bannert’s studies the dyads mostly received metacognitive scaffolds in this study, cognitive scaffolds were only provided upon help asking behavior of the students. More research is needed to validate our findings of the effects of dynamic scaffolding on domain knowledge. In future studies, researchers should also focus on long term effects of dynamic scaffolding and the transferability of the effects to other domain knowledge. Findings from these studies can contribute to a deeper understanding of differential effects of dynamic scaffolding on several student outcomes.

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 many mainly 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 toward dynamic computerized scaffolding.

Acknowledgments

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 Agtive IST 4–027529–STP. We acknowledge the contribution of all project partners to the development of the AgtentSchool scaffolding system.

Appendix A

Table 1A
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</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 immediate 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>

References


