Multiple Modes of Scaffolding to Enhance Web-based Inquiry

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Abstract: This study investigated the impact of different scaffolding conditions on students who are learning science through a web-based collaborative inquiry project. This project aimed to improve domain-specific knowledge, as well as strategy use on the internet, and metacognitive awareness. Three experimental conditions (human tutor as an external regulating agent, embedded question prompts (EQP), and both forms of support) were compared with a control condition. Findings revealed that providing students with EQP and a human tutor leads to significant higher performances comparing to the other conditions. Only with regard to strategy use and regulation of cognition, EQP alone is as effective as the condition with EQP and human tutor. Providing students with only a human tutor, however, didn't seem to provide enough help by itself, i.e. without incorporation of the embedded prompts. In this respect, our findings support the notion of multiple scaffolding as an approach to enhance web-based inquiry learning for a mix of students.

Theoretical Background

Scaffolding Web-based Inquiry

Science inquiry on the Web can be seen as a specific case of learning from multiple sources (Wiley et al., 2009). Although hypermedia learning is much more engaging, learning is also much more challenging (van Joolingen, de Jong, & Dimitrakopoulou, 2007). Strong regulation and metacognitive skills are needed (Azevedo, Moos, Greene, Winters, & Cromley, 2008; Bannert, 2009). Yet, previous research has shown that most students have poor self-regulatory skills and use ineffective strategies. These findings stress the need to effectively scaffold web-based inquiry processes.

The term scaffolding was traditionally introduced by Wood and colleagues (1976) in the context of one-on-one interactions in which the more knowledgeable adult tutors the child to complete a task that the child would be unable to do on his or her own. However, the modern classroom does not allow that privilege, since a teacher cannot interact with every child or every small group individually. Recent project-based learning approaches have therefore explored ways to use various forms of support provided by software tools (Davis & Miyake, 2004; Reiser, 2004). In the most common approach to computer-based support, both scripts and prompts can be embedded as scaffolds to individuals or small groups (Morris et al., 2009). However, because embedded tools that guide and support students through their inquiry processes cannot always include the dynamics of adult–child or even peer interactions, they also can be seen as limited. Embedded computer-based support is static which means that the amount and type of support is fixed and not adjusted based on an observation and a diagnosis of a learning (Puntambekar & Hubscher, 2005). Dynamic scaffolding on the other hand is based on observation and diagnosis and provides support in a personal way.

Consequently, recent studies claim that supporting multiple students in a classroom requires to rethink the notion of scaffolding. In this respect, the notion of distributed scaffolding with multiple modes of support is put forth as an approach to support inquiry learning in a classroom (McNeill & Krajcik, 2009; Puntambekar & Kolodner, 2005; Tabak, 2004). It is suggested that when support is distributed, integrated, and multiple, there are more opportunities for students to notice and take advantages of the environment's and activity's affordances (Puntambekar & Kolodner, 2005).

Multiple Modes of Scaffolding

Prompting

Prompting to support learning is gaining recognition as an important instructional method, and an increase in usage is most evident in the field of computer-based learning environments (Bannert, 2009). Prompts are defined as measures to induce and stimulate cognitive, metacognitive, motivational, and/or cooperative activities during learning, which vary from hints, suggestions, reminders, sentence openers or questions (Morris et al., 2009). Generally, they are based on the central assumption that students already possess some procedural knowledge about specific tasks, but do not recall or execute them spontaneously (Bannert, 2009). Previous research provides evidence that it is possible to improve individual learning in a technology environment, by implementing appropriate questioning strategies and reflection prompts that trigger students to activate their cognitive processes (Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008). However, studies have found that simply prompting students to use strategies is not enough to lead to improvements in learning outcomes and web literacy (Lazonder & Rouet, 2008; Stadtler & Bromme, 2007). Learners may need further support to take advantage of the opportunity to self-regulate their performance, e.g. by means of distributed monitoring (Wecker, Kollar, & Fisher, 2010) or human guidance (Azevedo et al., 2008). Therefore, the current study also takes into account a second mode of support.

Human Tutor

Providing students with an external regulating agent, i.e. teacher or a human tutor, is another method for improving learning outcomes and students' regulation of their web-based learning (Azevedo & Hadwin, 2005; Azevedo et al., 2008). This method is proved to be more beneficial than when students only need to self-regulate their learning (Azevedo et al., 2008). In this case, the teacher/human tutor acts as an adaptive scaffold that facilitate students' web inquiry by prompting students to deploy certain key processes and strategies during web-based learning.

Research Questions

Accordingly, this study focused on the following research questions:

1. What are the effects of different scaffolding conditions on students' *domain-specific knowledge*?
2. How do different scaffolding conditions influence learner's *strategy use* on the web?
3. Do different scaffolding conditions influence learners' *metacognitive awareness*?

Method

Participants and Design

During a four-week field study, students had to work in pairs on an inquiry based science project about climate change (for a description of context and project see Raes, Schellens, & De Wever, 2010). The project was designed in partnership with science teachers and in accordance with the Knowledge Integration framework (Slotta & Linn, 2009). The total project consisted of four main inquiry learning activities spread over 4 sessions of 50 minutes each. Pretest-posttest differences in students' domain-specific knowledge, strategy use and metacognitive awareness were measured. The participants in this study were 347 students from 18 secondary school classes, grade 9 and 10 from 10 Flemish secondary schools. The classes were randomly distributed over the 4 conditions. Three experimental conditions were compared with a control condition in a two-by-two factorial quasi-experimental design (see Figure 1). The conditions differed in the provided type and amount of scaffolding during online inquiry.

		HUMAN TUTOR AS AN EXTERNAL REGULATING AGENT	
		Present	Absent
EMBEDDED QUESTION PROMPTS	Present	**Condition 1: human tutor and embedded question prompts (EQP)** N = 101 from 5 classes	**Condition 2: embedded question prompts (EQP)** N = 72 from 4 classes
	Absent	**Condition 3: human tutor** N = 97 from 5 classes	**Condition 4: no scaffolds** N= 63 from 4 classes

Figure 1. Quasi-experimental 2 x 2 Factorial Design.

Measurements

The pre and post achievement test consisted of eight assessment items, 4 open-ended knowledge questions and 4 multiple-choice items, in which students were asked for explanation. To measure students' strategy use, they were faced with a scientific controversy. They were asked to take a stand and justify their position with appropriate evidence from the web. Students were asked to describe in detail their strategy for searching for evidence and formulating their position. Finally metacognitive awareness was measured by means of an adapted version of the Metacognitive Awareness Inventory (Schraw & Dennison, 1994), which supports the two-component view of metacognition, i.e. knowledge about cognition and regulation of cognition.

Statistical Analysis

ANCOVA's were conducted with posttest scores as dependent variable, Condition as independent factor, and pretest scores as covariate to discover whether there are differences between conditions on the posttest measure, after adjustment for the pretest scores. The Bonferroni test, which corrects for the number of pairwise tests, was used to compare main effects. The significance level was set up to 5% for all analyses.

Results

RQ 1: Effects of Different Scaffolding Conditions on Students' Domain-specific Knowledge

An overall increase is found with respect to students' domain-specific knowledge about climate issues. Students from the condition with multiple scaffolds made the highest learning gain. ANCOVA confirms that the four conditions significantly differ on the adjusted means ($F(3,332) = 12.592$, $p < .001$). Pairwise comparisons (see Table 1) shows that students in condition 1 (EQP + Human Tutor) significantly outperform students from the conditions 2 and 3 with a single mode of support as well as students from condition 4 (no scaffolds). These three conditions, however, do not significantly differ from each other.

Table 1: Pairwise comparisons for domain-specific knowledge as dependent variable.

Condition (I)	Condition (J)	Mean Difference (I-J)	*SE*	p^a
1 EQP + Human Tutor	2 EQP	2.15*	0.57	.002
	3 Human Tutor	3.23*	0.55	<.001
	4 No scaffolds	2.55*	0.61	<.001
2 EQP	1 EQP + Human Tutor	-2.15*	0.59	.002
	3 Human Tutor	1.08	0.58	.380
	4 No scaffolds	0.40	0.65	1.000
3 Human Tutor	1EQT + Human Tutor	-3.23*	0.55	<.001
	2 EQP	-1.08	0.58	.380
	4 No scaffolds	-0.68	0.61	1.000
4 No scaffolds	1 EQT + Human Tutor	-2.55*	0.61	<.001
	2 EQP	-0,40	0.65	1.000
	3 Human Tutor	0,68	0.61	1.000

a Adjustment for multiple comparisons: Bonferroni * $p < .05$

RQ 2: How Do Different Scaffolding Conditions Influence Learner's IPS Skills

Regarding strategy use, students reported to conduct more strategies during their online search in the posttest. This increase was found in all conditions, however, students in condition 2 (EQP) realize the highest learning gain compared to the other conditions. ANCOVA revealed that the four conditions do not significantly differ on the posttest measure, after adjustment for the pretest scores ($F(3,325) = 0.495$, $p = .686$).

RQ 3: Do different Scaffolding Conditions Influence Learners' Metacognitive Awareness?

Knowledge about Cognition

Concerning the scale *knowledge about cognition* which measures an awareness of one's strengths and weaknesses, knowledge about strategies and why and when to use those strategies, students from the four conditions did not significantly differ from each other on the pretest. After the intervention, however, all students reported a higher knowledge of cognition and conditions do significantly differ on the posttest adjusted means ($F(3,321) = 4.361$, $p = .005$).

Pairwise comparisons (see Table 2) shows a significant difference between condition 1 (EQP + Human Tutor) and condition 4(no scaffolds). Condition 1 also differs from conditions 2 and 3, but the differences are not significant. The differences between conditions 2, 3 and 4 are minimal.

Table 2: Pairwise comparisons for knowledge about cognition as dependent variable.

Condition (I)	Condition (J)	Mean Difference (I-J)	*SE*	p^a
1 EQP + Human Tutor	2 EQP	0.11	0.05	.133
	3 Human Tutor	0.11	0.04	.071
	4 No scaffolds	0.17*	0.05	.006
2 EQP	1 EQP + Human Tutor	-0.11	0.05	.133
	3 Human Tutor	0.01	0.05	1.000
	4 No scaffolds	0.06	0.05	1.000
3 Human Tutor	1EQT + Human Tutor	-0.11	0.04	.071
	2 EQP	-0.01	0.05	1.000
	4 No scaffolds	0.06	0.05	1.000
4 No scaffolds	1 EQT + Human Tutor	-0.17*	0.05	.006
	2 EQP	-0.06	0.05	1.000
	3 Human Tutor	-0.06	0.05	1.000

a Adjustment for multiple comparisons: Bonferroni * $p < .05$

Regulation of Cognition

Concerning the scale *regulation of cognition* which measures a number of sub processes that facilitates the control aspect of learning, i.e. planning, information management, comprehension monitoring, and evaluation, all students report to perform more regulation after the intervention than before. Particularly, the condition with multiple scaffolds and the condition with EQP realize a high learning gain.

The four conditions do significantly differ on the posttest measure, after adjustment for the pretest scores ($F(3,321) = 5.702$, $p = .001$). Pairwise comparisons (see Table 3) show that the difference between condition 1 (EQP + Human Tutor) and 2 (EQP) is negligible. Both EQP conditions do however differ significantly from the control condition (no scaffolds). No significant differences are found between condition 3 (Human Tutor) and the other conditions.

Table 3: Pairwise comparisons for regulation of cognition as dependent variable.

Condition (I)	Condition (J)	Mean Difference (I-J)	*SE*	p^a
1 EQP + Human Tutor	2 EQP	-0.02	0.06	1.000
	3 Human Tutor	0.11	0.05	.210
	4 No scaffolds	0.20*	0.06	.004
2 EQP	1 EQP + Human Tutor	0.02	0.06	1.000
	3 Human Tutor	0.13	0.06	.158
	4 No scaffolds	0.22*	0.06	.004
3 Human Tutor	1EQT + Human Tutor	-0.11	0.05	.210
	2 EQP	-0.13	0.06	.158
	4 No scaffolds	0.10	0.06	.696
4 No scaffolds	1 EQT + Human Tutor	-0.20*	0.06	.004
	2 EQP	-0.22*	0.06	.004
	3 Human Tutor	-0.10	0.06	.696

a Adjustment for multiple comparisons: Bonferroni * $p < .05$

Discussion

Our results indicate that learning science by means of a web-based inquiry project is effective to enhance learners' knowledge construction and to enhance their strategy use and metacognitive awareness. We can conclude this based on evidence for an overall increase in students' performances. However, pairwise comparisons show that benefits significantly differ based on the scaffolds students are provided with. Providing students with embedded question prompts and a human tutor whose role is to facilitate the use of online search strategies and self-regulatory processes leads to statistically significant higher performances compared to the other conditions. Providing students with only embedded question prompts is as effective as the condition with EQP and human tutor with regard to regulation of cognition and strategy use. Providing students with a human tutor but without incorporation of the embedded prompts, however, does not provide enough help. In this respect, our findings support the notion of multiple, distributed scaffolding (Puntambekar & Kolodner, 2005; Tabak, 2004) as an approach to enhance web-based inquiry learning in complex classroom environments and are in line with previous research (McNeill & Krajcik, 2009).

However, a limitation of the present study is that strategy use during web inquiry was measured by means of self-report. Additional research is needed to get more insight in the strategies students are using. Further research will make use of thinking aloud protocols (Azevedo et al., 2008) and logfile recording (Perry & Winne, 2006) in order to find out in more detail how students actually perform the metacognitive and strategic learning activities during web-based collaborative inquiry. Given the fact that not all dyads collaborate in the same way and this might have an effect on the regulation of the search task (Lazonder & Rouet, 2008), future research could also pay more attention to the collaboration processes that are inherent to the research design and approach of this study.

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