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Abstract

This study investigated the impact of different modes of scaffolding on students who are learning science through a web-based collaborative inquiry project in authentic classroom settings and explored the interaction effects with students’ characteristics. The intervention study aimed to improve domain-specific knowledge and metacognitive awareness during online information problem solving (IPS) as part of an online inquiry project. Three experimental conditions (teacher-enhanced scaffolding, technology-enhanced scaffolding, and both forms of scaffolding) were compared with a control condition in a two-by-two factorial quasi-experimental design. Moreover, gender and prior knowledge were examined as two factors which may have a significant impact on Web-based learning. In a four-week field study in secondary science education, pretest-posttest differences were measured. In total 347 students from 18 secondary school classes were involved and the classes were randomly distributed over the 4 conditions. Our findings support the notion of multiple scaffolding as an approach to enhance both knowledge acquisition and metacognitive awareness with respect to IPS-processes and to meet a mix of students with different needs within the context of a web-based inquiry learning project.

Keywords: web-based inquiry, information problem solving, scaffolding, secondary science education, individual differences
1. Introduction

Information and computer technologies and more specific the World Wide Web are receiving increased attention in education because of their potential to support new forms of (collaborative) inquiry (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). When the World Wide Web is used as a source within inquiry learning this supports the development of higher-order skills such as critical thinking and problem solving (Linn, Clark, & Slotta, 2003). But, although learning in such dynamic learning environments is much more engaging, learning is also much more challenging (Kuiper, Volman, & Terwel, 2009). Many students experience difficulties when receiving learning tasks that require them to find answers on the Internet or to retrieve information for the construction of arguments that can be used in scientific debates (Raes, Schellens, & De Wever, 2010). This set of activities, conceptualized as Information Problem Solving (IPS) on the Web (Brand-Gruwel, Wopereis, & Walraven, 2009), is only a part of what web-based inquiry learning can include but it can be seen as a prerequisite for successful web-based inquiry learning.

Since the World Wide Web is an extensive source of information, strong self-regulation ability and metacognitive awareness are necessary in order to be successful in web-based learning (Brand-Gruwel et al., 2009). However, contemporary cognitive and educational research has shown that most students have difficulty regulating their learning as well as performing metacognitive activities spontaneously (Lazonder & Rouet, 2008). In this context the mechanism of scaffolding, offering students an adaptable support system during the learning process, is put forth as a condition for acquiring the self-regulatory skills that IPS entails (Lazonder, 2001). Yet, while traditional scaffolding research focused on one type of scaffolding, particularly computer-embedded prompting (Azevedo & Hadwin, 2005; Reiser, 2004), few studies have documented interactions among multiple modes of scaffolding in real classroom settings (Kim & Hannafin, 2011). To help fill this gap, this study provides insight
into the unique value of two different modes of scaffolds, technology-enhanced and teacher-enhanced scaffolding, to support knowledge acquisition and information problem solving as part of a web-based collaborative inquiry project. Before explaining the methodology of this study, the two key concepts ‘information problem solving on the web’ and ‘the notion of scaffolding’ will be described.

2. Information Problem Solving on the Web

The concept of Information Problem Solving (IPS) combines the skills needed to access and use information, whether or not found on the Internet (Brand-Gruwel et al., 2009; Eisenberg & Berkowitz, 1990). Yet, within this study, we only focus on IPS while using the Web. Within web-based inquiry learning students are often confronted with problems for which information is required to solve it (Brand-Gruwel et al., 2009). Understanding how students engage in the IPS-process is becoming an increasingly important area of research in library and information sciences (Eisenberg & Berkowitz, 1990; Kuhlthau, 2004) and in learning and educational sciences (Kuiper et al., 2009; Walraven, Brand-gruwel, & Boshuizen, 2009; Wecker, Kohnlet, & Fischer, 2007).

Within this research, the model of Brand-Gruwel and colleagues (2009) is used as a comprehensive framework to conceptualize students’ IPS while using the Web. Moreover it is used as an external script that guided the design of the scaffolding during the intervention which is described below. This model, depicted in Figure 1, describes the main skills, regulation skills, and conditional skills needed to solve information problems. Based on this model, it is assumed that students need to master the following main skills: ‘Define the information problem’, ‘Search information’, ‘Scan information’, ‘Process information’, and ‘Organize and present information’. Second, to be successful in IPS, a strong appeal to peoples’ regulation ability is made during the execution of all skills. Regulatory aspects such as orientation, monitoring, steering, and evaluation, are crucial in the execution of the skill.
Finally, students are assumed to have the adequate reading, evaluating, and computer skills, which are the conditional skills.

Figure 1

*The Information Problem Solving using Internet model (IPS-I-model)*

Numerous studies on IPS have found that when attempting to self-regulate their learning, students predominantly use ineffective strategies and rarely engage in help-seeking behavior (Azevedo, Cromley, & Seibert, 2004). Teenagers, for instance, use information that can solve their information problem without thinking about the purpose of a website (Fidel et al., 1999) and they hardly evaluate information results and information sources (Walraven et al., 2009).

A state-of-the art study of Chen and Macredie (2010) reviewed the empirical studies that examined how human factors affect user’s interactions with the web, accounting for gender differences and prior knowledge. Regarding gender, some studies (e.g. Koohang & Durante, 2003) found that there are no gender differences in navigation patterns and attitudes toward web-based interaction, but the majority of studies (e.g. Large, Beheshti, & Rahman, 2002; Liu & Huang, 2008; Roy, Taylor, & Chi, 2003) indicated that females and males showed different behavior and demonstrated different attitudes. In particular, females encountered more disorientation problems, they generally felt themselves unable to find their way around effectively and they were more likely to get lost compared to males (Ford, Miller, & Moss, 2001). With regard to different levels of prior knowledge, several studies argue that this factor can play a substantial role in Internet searching. User’s prior knowledge can include system experience and domain knowledge. The former refers to user’s knowledge of the system being used whereas the latter refers to user’s understanding of the content area.
(Lazonder, 2000). Only the latter is taken into account in this study. Regarding domain knowledge, it is found that domain experts issued longer queries and used many more technical query terms compared to domain non-experts (White, Dumais, & Teevan, 2009). Moreover, it is found that novices used significantly fewer meta-cognitive strategies than intermediates or experts (Tabatabai & Shore, 2005) found.

Since the development of metacognitive awareness is considered to be the key to successful learning (Flavell, 1976), it is important to focus on how we can improve this metacognitive awareness. Metacognition is classically divided into two major components that are metacognitive knowledge and metacognitive regulation. The former can be simply explained by knowledge about cognition while the latter can be referred as the way for regulation of cognition (Schraw & Moshman, 1995). Knowledge about cognition on the one hand is defined as an awareness of one’s strengths and weaknesses, knowledge about strategies and why and when to use those strategies. Regulation of cognition on the other hand is defined as a number of sub processes that facilitates the control aspect of learning, i.e. planning, information management, comprehension monitoring, and evaluation (Schraw & Dennison, 1994). Subsequently, to improve this metacognitive awareness is has been found that students need activities that incorporate reflection, thinking about what they are going to do and why. To develop thinking implicit, explicit scaffolding is needed.

3. The notion of Scaffolding

The notion of scaffolding comes from the socio-constructivist model of learning (Vygotsky, 1978) and was traditionally introduced by Wood, Bruner, and Ross (1976) who believed that learning occurs in one-on-one interactions in which a more knowledgeable person guides a learner’s emerging understanding. In accordance with Vygotsky’s zone of proximal development, the scaffold should provide just enough information so that the learner may make progress on his or her own (Hogan & Pressley, 1997). However, the modern
classroom does not allow that privilege, since a teacher cannot interact with every child or small group individually. Consequently, teacher’s help is usually not based on what any individual requires at the moment, but rather on what the teacher believes the class needs in order to be successful (Davis & Miyake, 2004). In recent project-based approaches to learning, ways to use various forms of support provided by software tools have therefore been explored (Davis & Miyake, 2004; Reiser, 2004).

In the most common approach to technology-enhanced support, embedded computer-based scaffolds guide and support individuals or small groups through their inquiry processes (Morris et al., 2010). However, these embedded tools cannot include the dynamics of face-to-face interactions, they are more static which means that the amount and type of support is fixed. Dynamic scaffolding, however, is based on observation and ongoing diagnoses and provides support in a personal way (Puntambekar & Hubscher, 2005).

Based on these findings, it is assumed that supporting multiple students in a technology-enhanced classroom requires a rethink of the notion of scaffolding (Luckin, Looi, Chen, Puntambekar, & Stanton Fraser, 2011). In this respect, distributed scaffolding with multiple modes of support with each its own unique affordances is put forth as an approach to support learning in complex classrooms (McNeill & Krajcik, 2009; Puntambekar & Kolodner, 2005; Tabak, 2004). However, as indicated by Kim and Hannafin (2011), research that explores everyday classroom interactions between multiple modes of scaffolding is still limited.

3.1 Multiple modes of scaffolding

Within this research two modes of scaffolding, depicted in Table 1, are examined and further explained below.
Table 1

Two modes of scaffolding described according the three dimensions of scaffolding problem solving inquiry (Kim & Hannafin, 2011): purpose, interaction, and source.

3.1.1 Technology-enhanced scaffolding

Prompting to support (self-regulated) learning is gaining recognition as an important instructional scaffolding 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 to questions (Morris et al., 2010). Within technology-enhanced learning environments, these can be displayed on screen at certain times in the learning process. 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). Research provides evidence that it is possible to improve individual learning in a technology environment by implementing appropriate question 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 of IPS does not always 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 & Fischer, 2010) or human guidance (Azevedo, Moos, Greene, Winters, & Crornley, 2008) which is taken into account as a second mode of support.
3.1.2 Teacher-enhanced scaffolding

According to Crawford (2000) teachers play multiple roles in inquiry classes. Moreover, when the inquiry classes are technology-enhanced, teachers’ roles become even more crucial. The teacher needs to first help students understand the inquiry practice before they can effectively use the computer-based scaffolds embedded in the project (Pea, 2004). Moreover, the teacher needs to acts as an adaptive scaffold that facilitates students’ IPS by prompting students to deploy certain key processes and strategies during web-based learning. Providing students with an external regulating agent, i.e. the teacher or a human tutor, is proved to be more beneficial than when students only need to self-regulate their learning (Azevedo et al., 2008). Consistently, research on metacognitive tools has underlined the significance of adaptive, human scaffolding in facilitating science learning with technologies (Kim & Hannafin, 2011).

3.2 Interaction between scaffolding and students’ characteristics

Since it has been found that gender and prior knowledge may have a significant impact on web-based learning and Internet searching (Chen & Macredie, 2010), it can be questioned to what extent the effect of scaffolding web-based IPS-processes is also influenced by those individual differences. Previous research indicated that learners who lack adequate prior knowledge may be more limited – or even fail - to adequately perform problem solving processes; consequently these students especially need a teacher or human tutor who can scaffold or model inquiry (Kim & Hannafin, 2011, Kirschner, Sweller, & Clark, 2006). According to Zohar and Peled (2008) explicit teaching of metastrategic knowledge is a vital instructional method especially for supporting the progress of students with low-academic achievements.

Although web-based inquiry learning is demanding for students, it has been indicated that students often refrain from seeking help from the sources (e.g. teacher, peer learners,

Moreover, there are indications that help-seeking behavior is influenced by gender since it have been found that females are more willing to seek help in the classroom when they need it (Ryan, Pintrich, & Midgley, 2001).

Chen and Marcredie (2010) put forth that it is important to be aware of such differences since offering appropriate support to each individual may result in the improvement of student performance. Yet, in most scaffolding research these individual differences are not taken into account (e.g. Wang, Kollar, Stegmann, & Fischer, 2011).

4. Research questions

Two main research question drove this study:

1. Was is the impact of multiple modes of scaffolding on students’ domain-specific knowledge and students’ metacognitive awareness during information problem solving?

2. Does the way students are scaffolded interact with students’ personal characteristics, i.e. gender and students’ level of prior knowledge?

The multiple modes of scaffolding were investigated in a two-by-two factorial quasi-experimental design with three experimental conditions (teacher-enhanced scaffolding, technology-enhanced scaffolding, and both forms of scaffolding) and a control condition.

5. Method

5.1 Study participants

The participants in this study were 347 students from 18 secondary school classes, grade 9 and 10 from 10 Flemish secondary schools. The average age of these students was 16 years (SD = 0.56); 178 of them were girls (51.3%), 169 were boys (48.7%). A group of 17 science teachers were involved in the research project. Teacher participation in the
intervention was voluntary and teachers agreed to dedicate four lessons of 50 minutes for
involvement in the research project.

5.2 Instructional context and curriculum project

This study was conducted in the context of a web-based inquiry science project in
secondary education. Consistent with a previous study (Raes et al., 2010) global warming and
climate change was chosen as the topic under investigation. This is an issue that students have
heard about, but because of the uncertainty and controversy in the scientific community about
the scientific issues associated with climate change, global warming and climate change can
be considered as a complex topic. The web-based inquiry project that spanned four regular
science lessons was implemented during a four-week field study in secondary education.

The Web-Based Inquiry Science Environment (WISE) (Slotta & Linn, 2009) was used
in this study to design our project. WISE is developed to provide a solid online platform that
allows teachers to adopt new forms of inquiry-based instruction. For students, on the other
hand, it is a powerful learning environment where they examine in dyads real world evidence
from the web and analyze current scientific controversies. The project was learning goal
driven, which means that learning goals identified from the national science standards have
guided all phases of the project design. Besides the science content, other learning goals
strongly focused on information problem solving (i.e. search, select, gather, and use web info
as evidence to support their claims and answers). The design of this project is in accordance
with previous research suggesting that a whole-task approach with embedded instruction that
promote IPS within inquiry activities is effective for teaching the highly interrelated
constituent skills and sub skills involved in IPS (Lazonder & Rouet, 2008). Moreover,
valuable insights from the notion of scaffolding, i.e. the growing body of opinion that fading
is a fundamental and intrinsic component of scaffolding (Pea, 2004; Puntambekar &
Hubscher, 2005), were applied within the overall project. Table 2 gives an overview of how
the notion of fading was operationalized within the designed project.

Table 2

<table>
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<th>Operationalization of the notion of fading within the WISE-project</th>
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During the project, students navigated through the sequence of inquiry activities using
the inquiry map in the WISE environment and they were asked to write their answers down in
input boxes embedded in the web-based project. Students also worked in the same dyads
during the whole intervention since collaborative inquiry has been found to positively relate to
self-regulation, as well as yielding higher learning outcomes during web search compared to
individual work (Lazonder, 2005).

5.3. Study Design

As shown in Figure 2, three experimental conditions were compared with a control
condition in a two-by-two factorial quasi-experimental design. Participating classes were
randomly assigned to one of the four conditions, but we ensured that teachers with multiple
classes were assigned to the same condition to avoid confusion and conflicts.

Figure 2

Quasi-experimental 2 x 2 factorial design

5.4 Procedure

Forty master’s students in Educational Sciences were involved in this study to support
the implementation of the web-based collaborative inquiry project and to act as
teachers/human tutors during the project. The master’s students were randomly divided over
the 18 classes participating in this study. To be fully prepared, all master’s students went through a thorough training depending on the condition to which they belong. First, different interaction patterns were proposed and discussed based on video excerpts of previous field studies. Second, master’s students practiced their tutoring skills while exercising with their classmates during the test phase of the WISE-project. The instruction for intervention differed from condition to condition and in each condition a strict protocol had to be followed.

Although all master’s students were instructed to provide technical and organizational help, the master’s students in the conditions with teacher-enhanced scaffolding (3 and 4), needed to act additionally as external regulating agents. In these conditions extra support was given through metacognitive interventions. Master’s students were instructed to interact with groups of students to monitor their IPS process, e.g. asking questions that stimulate students’ reflection, probe students’ thinking and asking students questions that push them to clarify and elaborate on their ideas, prompting students to focus on particular issues, asking tentative questions to suggest alternative perspectives, without giving the solution procedure. They were instructed to avoid giving answers and providing students with content knowledge. In the conditions without teacher-enhanced scaffolding (1 and 2), master’s students were instructed to avoid providing the pupils with metacognitive and strategic prompting.

Because this adaptive behavior task is extremely complex for teachers, especially since they have to closely monitor group and individual progress (Schwarz & Asterhan, 2010), the master’s students were provided with a tutoring script, a predefined protocol designed to help them manage and scaffold information problem solving during web-based inquiry. The IPS-framework (Brand-Gruwel et al., 2009) presented in the conceptual framework was used to script the scaffolds provided by the master’s students and was also used for designing the technology-enhanced embedded scaffolds. As shown in Table 3, the
IPS framework describes as an external script how to fulfill the series of steps for successful information problem solving.

Table 3

IPS tutoring script and corresponding hints & prompts with regard to each constituent skill and sub-skill involved in Information Problem Solving

To warrant - as far as possible- for controlled circumstances, manipulation checks were included to assess whether the conditions were successful put into practice. First, the real classroom teachers – without knowing to which condition they belong – were asked to observe the master’s students and fill out an evaluation form evaluating the overall web-based project, as well as the quality of the intervention of the master’s students. This form of manipulation check informed us on how the master’s interacted in the classroom. Second, the master’s students were required to keep a logbook and additionally they were invited individually for an evaluation talk.

5.5 Measurements

In this study, the effects of multiple scaffolding conditions were measured through a pretest-posttest design. During the first session, secondary students completed the individual pretest and started in dyads the first introductory activity of the WISE-project. The whole project consisted of four main activities considering global warming issues. At the end of the project all students completed the individual posttest. In our analysis of students’ learning, we examined domain-specific knowledge of the subject global warming and metacognitive awareness during IPS, which are the two targeted learning outcomes of the intervention.
5.5.1 Domain-specific knowledge

The pre and post achievement test to investigate the learning effect on domain-specific knowledge consisted of eight assessment items (see Appendix A). It was a combination of four open-ended knowledge questions (rubric 0-3) and four multiple-choice items, in which students were asked for explanation and connecting scientific ideas in their arguments (rubric 0-4). The items were scored using an adapted version of the knowledge integration rubric that rewards both accurate and connected ideas, created by the Technology Enhanced Learning in Science Community (TELS, 2010). The rubrics which are displayed in Appendix B and C contain a number of proficiency levels; the higher the proficiency level, the more complex the skills are that the students have to master to tackle the scientific problems. The eight assessment items were added up to form the scale for domain-specific knowledge with a possible range from 0 to 28. The fourth author was trained to use the rubrics and coded all students’ answers. 20% of students’ performance was re-coded by a second rater to check for interrater reliability by means of Krippendorff’s alpha (Hayes & Krippendorff, 2007). Regarding all the items, Krippendorff’s alpha ranged from 0.65 to 1 which indicates good to excellent agreement.

5.5.2 Metacognitive awareness

Because we aimed to improve students’ metacognitive awareness during IPS-processes students in pretest and posttest were faced with an unfamiliar information problem, more specifically a scientific controversy (i.e. “Mobile phone radiation: harmful or nonsense?” and “Is nuclear power a good alternative?”). They were assigned to take up a particular position that they needed to justify with appropriate evidence from the web to support their claim. After performing this IPS-task students were asked to fill out an adapted version of the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994). This self-report inventory was used to measure students’ perception about their metacognitive and
strategic activities while performing the task. The original MAI inventory developed by Schraw and Dennison (1994) consisted of 52 items supporting the two-component view of metacognition, i.e., knowledge of cognition and regulation of cognition. Because the available time was limited, we decided to reduce the number of items. In line with the research of van Schooten (2008), the items with a factor loading on both factors or without factor loading were excluded. This resulted in the adapted inventory which consisted of 40 items. Moreover, the items were transformed to task-specific items related to the information problem solving task on the web. Instead of a 100-mm bi-polar scale, we used a 4-point Likert scale that forced students to indicate whether they agree or not with the items concerning the task they previously performed.

The instrument was afterwards evaluated using factor analyses. The forced oblique two-factor solution resulted in loadings on factor 1: knowledge of cognition and factor 2: regulation of cognition. Items with loadings of less than 0.30 and items with cross loadings were excluded. Finally this resulted in 17 items for the knowledge of cognition scale (Cronbach’s alpha in pretest 0.845, in posttest 0.849) and 15 items for the regulation of cognition scale (Cronbach’s alpha in pretest 0.847, in posttest 0.844). See Appendix D for example items of the two components of the Metacognitive Awareness Inventory (Schraw & Dennison, 1994).

5.6 Statistical analysis

One-way analyses of covariance (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. Moreover, the between-subjects factors gender (female versus low based on prior knowledge based on pretest scores) (high versus low based on

mean 7/160 split) are included in the model as independent variables. The Bonferroni test.
which corrects for the number of pairwise tests, was used to compare main effects. The significance level was .05 for all analyses.

6. Results

6.1 Students’ domain-specific knowledge about global warming and climate change

First, the effects of different scaffolding conditions on students’ domain-specific knowledge were explored. An overall increase between pretest and posttest was found with respect to students’ domain-specific knowledge about climate issues (F(1,302) = 773.94, \(p < .001\)). Yet, ANCOVA confirmed that the four conditions significantly differ on the posttest scores, after adjustment for pretest scores (F(3,332) = 12.59, \(p < .001\)). Pairwise comparisons indicated that both the condition with teacher-enhanced scaffolds (mean difference = 2.02, \(p < .001\)) and the condition with teacher-enhanced scaffolds in combination with technology-enhanced scaffolds (mean difference = 1.97, \(p < .001\)) significantly differ from the control condition. This means that students in these conditions significantly outperform students from the control condition without scaffolds. The difference between the control condition and the condition with technology-enhanced scaffolds was not significant (mean difference = 0.88, \(p = .551\)).

Moreover we examined how the different scaffolding conditions interact with gender and students’ prior knowledge. The posttest scores were analyzed using a factorial analysis of covariance with three between-participant factors: scaffolding condition, gender and prior knowledge. This analysis revealed that the main effect due to the scaffolding condition was significant (\(F(3,286) = 5.77, p = .001\), partial \(\eta^2 = .057\)). Moreover a significant main effect was found due to gender (\(F(1,286) = 4.48, p = .035\), partial \(\eta^2 = .015\)), whereas the main effect of prior knowledge was not significant (\(F(1,286) = 1.29, p = .257\), partial \(\eta^2 = .004\)). Nevertheless, the analysis revealed a significant interaction between prior knowledge and scaffolding condition (\(F(3,286) = 2.66, p = .048\), partial \(\eta^2 = 0.027\)) which suggest differential
effects depending on students’ prior knowledge. Additionally, the interaction between gender and scaffolding condition is found to be marginally significant ($F(3,286) = 2.47, p = .063$, partial $\eta^2 = .025$). No significant interaction was found between prior knowledge and gender ($F(1,286) = 0.24, p = .625$, partial $\eta^2 = .001$). The three-way interaction was not significant ($F(3,286) = 0.63, p = .591$, partial $\eta^2 = .007$). The interactions with gender and prior knowledge are further explained with reference to the plots presented below.

6.1.1 Interaction with gender

The observed means for posttest scores, after adjustment for the pretest, for boys and girls in the four scaffolding conditions are presented in Figure 3. According to the main effect of gender, it is found that female students significantly outperform male students regarding domain-specific knowledge after the WISE-project (mean difference $= 0.78, p = .035$). However, this outperformance of girls doesn’t count in every scaffolding condition. When students are provided with teacher-enhanced scaffolds, boys and girls perform equally. The combined condition, however, seems to result in higher posttest performance for female students.

Figure 3

Line graph illustrating the interaction between gender and the scaffolding condition with regard to posttest scores after adjustment for pretest scores

Through pairwise comparison, with respect to girls, a significant mean difference (mean difference $= 2.56, p = .021$) between the combined scaffolding condition and the control condition is found. The other conditions do not significantly differ from each other. This means that the combined condition is most beneficial for girls. With respect to boys, however, it is the teacher-enhanced scaffolding condition which seem to be the most
beneficial with a significant mean difference (mean difference = 2.05, \(p = .002\)) between the teacher-enhanced scaffolding condition and the control condition. No significant difference is found between the combined condition or the technology-enhanced scaffolding condition and the control condition.

### 6.1.2 Interaction with level of prior knowledge

Figure 4 shows the observed means for posttest scores, after adjustment for the pretest, for the interaction between prior knowledge and scaffolding condition. There was no main effect for prior knowledge, but there was a significant interaction between scaffolding condition and prior knowledge. The interaction was further investigated using ANCOVA’s to explore to what extent the scaffolding condition matters either for students with high or low prior knowledge.

![Figure 4](image)

*Figure 4: Line graph illustrating the interaction between level of prior knowledge and the scaffolding conditions with regard to posttest scores after adjustment for pretest scores*

Regarding students with high prior knowledge, ANCOVA suggested that the four conditions do not significantly differ on the adjusted means (\(F(3,155) = 0.37, p = .774\), partial \(\eta^2 = .007\)). Regarding students with low prior knowledge, however, ANCOVA confirms that the four conditions do significantly differ on the adjusted means (\(F(3,138) = 9.49, p < .001\), partial \(\eta^2 = .171\)). Students with low prior knowledge significantly outperform in the condition with teacher-enhanced scaffolds (mean difference = 3.57, \(p < .001\)) or in combination with technology-enhanced scaffolds (mean difference = 3.49, \(p < .001\)) in comparison with the condition without scaffolds.
Based on these results, we can conclude that with regard to the acquisition of domain-specific knowledge especially teacher-enhanced scaffolding seems to affect learning outcomes, particularly for students with low prior knowledge. According to gender, boys benefit the most when provided with teacher-enhanced scaffolding, whereas girls perform the best teacher-enhanced scaffolds in combination with technology-enhanced scaffolds.

6.2 Students’ metacognitive awareness in relation to information problem solving

Second, the effects of multiple modes of scaffolding on students’ metacognitive awareness were explored. This metacognitive awareness was according to Schraw and Dennison (1994) split up in knowledge about cognition and regulation of cognition.

6.2.1 Knowledge about cognition

The scale knowledge about cognition aimed to measure students awareness of one’s strengths and weaknesses during a web-based inquiry project and their knowledge about strategies and why and when to use those strategies. It was questioned if students’ knowledge about cognition improved after a web-based project and more important if this improvement is determined by the way students’ Information Problem Solving was scaffolded through embedded instruction. 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 an ANCOVA confirmed that conditions did significantly differ regarding the posttest adjusted means ($F(3,321) = 4.36, p = .005$, partial $\eta^2 = .039$).

Pairwise comparisons suggest that the condition with a combination of teacher-enhanced and technology-enhanced scaffolding significantly outperformed the control condition without scaffolds (mean difference = 0.17, $p = .006$). The differences between the other conditions were not significant.

6.2.2 Regulation of cognition
Finally, the scale *regulation of cognition* aimed to measure whether students could apply the IPS-strategies that were scaffolded in different ways during the web-based inquiry project. Students were asked to what extent they performed the subprocesses of IPS that facilitates self-regulated learning, i.e. planning, information management, comprehension monitoring, and evaluation. All students reported performing more regulation after the intervention than before. Particularly, the condition with combined scaffolds and the condition with technology-enhanced scaffolds realized a high learning gain.

Figure 5
*Line graph illustrating pre- and posttest descriptives for regulation about cognition*

ANCOVA indicated that the four conditions did significantly differ on the posttest measure, after adjustment for the pretest scores ($F(3,321) = 5.70, p = .001$). Pairwise comparisons showed that both the condition with technology-enhanced scaffolds (mean difference 0.22, $p = .004$) and the condition with teacher- and technology-enhanced scaffolds (mean difference 0.20, $p = .004$) significantly differ from the control condition. No significant differences were found between the other conditions. From these results we can conclude that with regard to improvement in IPS-skills technology-enhanced scaffolding seems to affect more transfer than teacher-enhanced scaffolding. No interaction effects were found according to gender and students’ prior knowledge.

7. Discussion and conclusion

Despite the widespread recognition of the need to scaffold students during web-based inquiry learning, the understanding of how students’ metacognitive awareness can be supported in authentic classroom settings is rather limited. Especially, more insight is needed in how to foster students’ web-based information problem solving skills, a pivotal 21st
century skill which is required in everyday life in and out of the classroom. The Internet brings up-to-date scientific findings in the reach of everyone, yet searching and finding relevant, credible, and scientifically substantiated information on the Internet is a challenging task. Consequently, an important question that arises is how to support the information problem solving skills of a variety of students. This question drove our research and practice. We implemented a web-based inquiry project with embedded instruction in real classroom settings.

During this project, students were faced with several information problems to be solved by means of evidence from the web. The purpose of this study was to investigate whether the presence of metacognitive and strategic scaffolds improved students’ domain-specific knowledge and their metacognitive awareness of their IPS-processes. While most studies within the context of web-based inquiry learning focus on technology-enhanced scaffolding, this study also took into account the role of the teacher with respect to scaffolding IPS. Consequently, the effectiveness of technology-enhanced, teacher-enhanced scaffolding, and the combination of both forms of scaffolding, together with the way they interact with students’ gender and prior knowledge were examined. The three experimental conditions (teacher-enhanced scaffolding, technology-enhanced scaffolding, and the combination of both modes) were compared with a control condition in a two-by-two factorial quasi-experimental design.

Our results indicate that learning by means of a web-based inquiry project with embedded scaffolding contributes to enhancing learners’ domain-specific knowledge and to enhancing their metacognitive awareness. This conclusion is based on evidence to an overall increase in students’ performances. However, the question is which scaffolding condition is most beneficial for a mix of students (i.e. boys and girls with different levels of prior
knowledge) and regarding the learning objectives (i.e. knowledge acquisition and metacognitive awareness).

With regard to knowledge acquisition, teacher-enhanced scaffolding is found to be a determining factor. Students provided with teacher-enhanced scaffolds that facilitate the information problem solving skills and metacognitive processes, reach statistically significant higher knowledge performances scores compared to students in classes without teacher-enhanced scaffolding. Moreover, when we questioned to what extent the effectiveness of scaffolding is influenced by students’ characteristics, a significant interaction was found between the scaffolding conditions and prior knowledge. Although students with high prior knowledge performed equally on the knowledge posttest irrespective of the way they were scaffolded, the performances of students with low prior knowledge significantly differed with regard to the scaffolding condition. Students with low prior knowledge performed significantly better in the condition with teacher-enhanced scaffolds or in combination with technology-enhanced scaffolds in comparison with the condition without teacher-enhanced scaffolds. As a consequence, human interactions with the teacher or human tutor may prove to be important especially for more disadvantaged students because the teacher can dynamically monitor the information processes and help them to overcome their lack of domain knowledge. On the other hand, it seems that more advantaged students are able to perform successfully regardless of the scaffolding condition.

These findings are consistent with previous research that stressed that students with insufficient prior knowledge can suffer from minimal guidance (Kirschner et al., 2006). Moreover, Kim and Hannafin (2011) have suggested that learners who lack adequate prior knowledge need a teacher or human tutor who can scaffold or model information problem solving.
Subsequently, with regard to gender, a marginally significant interaction was found with the scaffolding condition. A remarkable finding was the fact that whereas the combined condition was the most beneficial one for girls, it was not so for boys for whom the teacher-scaffolded condition was the most beneficial. Based on these results, the combination of both modes of scaffolding may produce for boys an “over-scripting effect” as conceptualized by Dillenbourg (2002). In this respect, the technology-enhanced scaffolds guided students IPS, but if the learner already has an internal script of how to fulfill the task, the performance of the learner might decrease (Stegmann, Mu, Gehlen, Baum, & Fischer, 2011). The finding that the combined condition was not effective for boys might be related with the fact that in other research (e.g. Large et al., 2002; Roy et al., 2003; Liu & Huang, 2008, Ford et al., 2001) boys were found to encounter less disorientation problems, they generally feel themselves able to find their way around effectively and they do feel more in control compared to girls.

Although teacher-enhanced scaffolding is found to be a determining factor regarding knowledge acquisition, with regard to metacognitive awareness, technology-enhanced scaffolding seem to be more beneficially. Our results indicate that by providing technology-enhanced scaffolds, students’ metacognitive awareness improved. Consequently, providing prompts as part of an external script may support the internalization of the strategic knowledge so that learners can apply the acquired knowledge to self-prompt actions in similar situations (Wang et al., 2011). With regard to metacognitive awareness, only providing students with these fixed scaffolds is as effective as the combined condition. No significant interactions with students’ characteristics were found. Providing students with teacher-enhanced scaffolds but without incorporation of the embedded prompts, however, ends in significantly lower results.

In conclusion, if we want adequately support a diversity of students during web-based inquiry learning, which is aiming at knowledge acquisition as well as at improving
information problem skills, multiple modes of scaffolding are needed to take into account individual differences between students. In this respect, our results support the notion of multiple, distributed scaffolding (McNeill & Krajcik, 2009; Puntambekar & Kolodner, 2005; Tabak, 2004) as an approach to enhance students’ information problem solving during web-based inquiry learning. Consequently, our study produced promising results which may be of value for educational practice. Multiple scaffolding gives teachers the opportunity to differentiate between students by gender and with different prior knowledge. Moreover, this study provided new insight in ways to improve learning environments and scaffolding in order to reduce gaps between learners.

8. Limitations and implications for future research

This study took place in real classrooms and is conducted on large scale - 347 students from 18 secondary school classes were involved in this intervention. Research in authentic settings is advantageous because they are highly ecologically valid, however they have some drawbacks. Due to the intervention on large scale and in real context, the available time and facility to measure learning processes was limited. In this study, IPS skills and strategy use were only measured by means of self-report. Additional research is needed to get more insight in the strategies students use during information processes on the web to reach more accurate conclusions about interaction with and the effect of scaffolding during the learning process. Further research can make use of thinking aloud protocols (Azevedo et al., 2008), log file recording (Perry & Winne, 2006), and/or eye-movement methods (Nüssli, Jermann, Sangin, & Dillenbourg, 2009) in order to find out in more detail how students actually perform the metacognitive and strategic learning activities during web-based collaborative inquiry.

Moreover, more research is needed to get insight in what really happens in the context of the classroom during the scaffolding process to deepen the questions: Who searches for help? Who needs help? Who used the support that is offered?
Also the second limitation is due to the authentic research context in which several master’s students acted as teachers in different classrooms. Because of the large scale, it was hard to keep the intervention parameters completely under control. Nevertheless, a number of actions were undertaken to ensure that the intervention took place as intended (described above). The real classroom teachers – without knowing to which condition they belong – were asked to observe the master’s students and fill out an evaluation form evaluating the overall web-based project, as well as the quality of the intervention of the master’s students. This form of manipulation check informed us on how the master’s students interacted in the classroom. A teacher who was involved in the condition without teacher-enhanced scaffolding reported for example that from her opinion the master’s students could provide more profound help. On the other hand, a teacher from the condition with combined scaffolding, mentioned that the pacing of the project was to slow due to interruptions during the process. Many master’s students indicated their role in the classroom as a hard one to realize. Secondary students often gave the impression that they did not need help, but once they started to interact with those students they realized they could make a difference. However, to get more insight in teachers’ role and in student-teacher interactions further research with a focus of the process of scaffolding is needed.

A final limitation of this study is the fact that all the measurements were conducted on the individual level. In accordance with previous research ((Lazonder, 2005; Lazonder & Rouet, 2008) suggesting that student dyads are generally better to apply (information) problem solving strategies and yield higher learning outcomes comparing with students who work individually, the web-based inquiry project was performed through collaborative work. Yet, regarding the fact that collaboration might have an effect on the regulation of the search task but considering that not all dyads collaborate in the same way (Rummel & Spada, 2005) the collaboration processes need to be taken into account as a factor. Further research needs to
be conducted to identify and examine student interactions during web-based collaborative inquiry.
References


10.1016/j.compedu.2007.09.012


### Table 1

*Two modes of scaffolding described according the three dimensions of Scaffolding Problem Solving Inquiry (Kim & Hannafin, 2011): source, interaction, and purpose.*

<table>
<thead>
<tr>
<th>Technology-enhanced scaffolds</th>
<th>Teacher-enhanced scaffolds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source:</strong> Embedded hints and question prompts which appeared on screen associated with each information problem task</td>
<td><strong>Source:</strong> Cues en prompts given by the teacher or human tutor who circulated in the classroom</td>
</tr>
<tr>
<td><strong>Interaction:</strong> Static and fixed, faded over time</td>
<td><strong>Interaction:</strong> Dynamic and adaptive based on students’ needs while working on the task</td>
</tr>
<tr>
<td><strong>Purpose:</strong> Metacognitive and strategic: regulating their information-problem solving processes</td>
<td></td>
</tr>
</tbody>
</table>
Table 2

*Operationalization of the notion of fading within the WISE-project*

<table>
<thead>
<tr>
<th></th>
<th>Start of the project</th>
<th>End of the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Task Definition</td>
<td>Straightforward e.g.: What’s the difference between weather and climate?</td>
<td>More complex e.g.: Why are the sun, atmosphere, oceans and the earth surface the main protagonists of the climate?</td>
</tr>
<tr>
<td>#2 Information Seeking Strategies</td>
<td>The search space is restricted by providing a list of pre-selected websites (max. 3) on which students can find the answers</td>
<td>Only one important and reliable source is provided, students need to add information they search on the WWW.</td>
</tr>
<tr>
<td>#3 Location &amp; Access</td>
<td>Students need to judge the relevance of the sources to answer the question.</td>
<td>Students need to judge the relevance of the provided source and judge the relevance and reliability of found sources</td>
</tr>
<tr>
<td>#4 Use of Information</td>
<td>Due to a more simple information problem, students can find the answer on the provided websites.</td>
<td>A more complex information problem require students to add information from different websites.</td>
</tr>
<tr>
<td>#5 Synthesis of information</td>
<td>A sentence opener is provided in the body of the answer input box: e.g. ‘The difference between weather and climate is…’ and the given sources are already mentioned</td>
<td>No sentence opener is provided, but students are prompted within the answer input box to formulate their sources.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No scaffolds were provided within the answer input box to remind students about the information problem and about mentioning the used sources.</td>
</tr>
</tbody>
</table>
Table 3

IPS tutoring script and corresponding hints & prompts with regard to each constituent skill and sub-skill involved in Information Problem Solving

<table>
<thead>
<tr>
<th>IPS-skill decomposition</th>
<th>Corresponding scaffolds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>#1 Task Definition</strong></td>
<td>- What does your teacher want you to do?</td>
</tr>
<tr>
<td>1.1 Define the information problem</td>
<td>- Restate/rewrite the assignment in your own words</td>
</tr>
<tr>
<td>1.2 Identify information needed</td>
<td>- Activate prior knowledge</td>
</tr>
<tr>
<td><strong>#2 Information Seeking Strategies</strong></td>
<td>- Consider the possible sources of information that will help you answer the question</td>
</tr>
<tr>
<td>2.1 Determine all possible sources</td>
<td>- Think about relevant keywords and specify search terms</td>
</tr>
<tr>
<td>2.2 Select the best sources</td>
<td>- Evaluate/judge the list of sources</td>
</tr>
<tr>
<td><strong>#3 Location &amp; Access</strong></td>
<td>- Figure out where you will find these sources, read information global</td>
</tr>
<tr>
<td>3.1 Locate sources (intellectually and physically)</td>
<td>- Try to find <strong>relevant</strong> and <strong>useful</strong> sources:</td>
</tr>
<tr>
<td>3.2 Find information within sources</td>
<td>Look at the title, index and date. Scan the information using your keywords from step 2</td>
</tr>
<tr>
<td><strong>#4 Use of Information</strong></td>
<td>- Try to find <strong>reliable</strong> sources: what is the aim of the website? Who is the writer of the website? Do you find information that confirm the information?</td>
</tr>
<tr>
<td>4.1 Engage</td>
<td>- Read, view, or listen to the sources you located during step 3.</td>
</tr>
<tr>
<td>4.2 Extract relevant information</td>
<td>- Compare information from multiple sources</td>
</tr>
<tr>
<td><strong>#5 Synthesis</strong></td>
<td>- Take notes to answer the questions you formulated in the first step</td>
</tr>
<tr>
<td>5.1 Organize from multiple sources</td>
<td>- Try to paraphrase or summarize ideas instead of just copying information word-for-word from your sources.</td>
</tr>
<tr>
<td>5.2 Present the information</td>
<td>- Be sure to give credit to your sources.</td>
</tr>
<tr>
<td></td>
<td>- Structure relevant information and outline your answer.</td>
</tr>
<tr>
<td></td>
<td>- Is your answer more than just a summary of other people’s ideas?</td>
</tr>
</tbody>
</table>
| | - If you paraphrased or summarized information found on the Internet, or from other people, did you cite the source at point of use in your answer (using a footnote or parenthetical reference)?
Appendix A
Exemplary test items

<table>
<thead>
<tr>
<th>Knowledge items</th>
<th>What is the difference between weather and climate?</th>
<th>What is the IPCC?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation items</td>
<td>Which part of figure B is comparable with the glass on figure A. Thick the right answer and explain your answer.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>□ The sun</td>
<td></td>
</tr>
<tr>
<td></td>
<td>□ The cosmos</td>
<td></td>
</tr>
<tr>
<td></td>
<td>□ The atmosphere</td>
<td></td>
</tr>
</tbody>
</table>

![Figure A](image1.png)

![Figure B](image2.png)
## Appendix B
Scoring Rubric for knowledge items

<table>
<thead>
<tr>
<th>Grade / score</th>
<th>Response description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Students have no or incorrect and irrelevant ideas in the given context.</td>
</tr>
<tr>
<td>1</td>
<td>Students have some relevant and correct ideas but do not connect them in a given context. There are still incorrect and irrelevant ideas included in the answer.</td>
</tr>
<tr>
<td>2</td>
<td>The answer is correct, but rather isolated. Students still fail to connect the relevant ideas.</td>
</tr>
<tr>
<td>3</td>
<td>Scientific concepts are explained correct and coherent as a token of a systematic understanding.</td>
</tr>
</tbody>
</table>
Appendix C
Scoring Rubric for explanation items

<table>
<thead>
<tr>
<th>Grade / score</th>
<th>Response description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Students have no or incorrect and irrelevant ideas in the given context.</td>
</tr>
<tr>
<td>1</td>
<td>Correct multiple choice answer, but without further explanation.</td>
</tr>
<tr>
<td>2</td>
<td>Correct multiple choice answer with further explanation, but rather isolated and still some incorrect and irrelevant ideas are included.</td>
</tr>
<tr>
<td>3</td>
<td>Students have correct and relevant ideas but do not fully elaborate links between them in the given context. They still fail to connect the relevant ideas.</td>
</tr>
<tr>
<td>4</td>
<td>Students recognize connections between scientific concepts and understand how they interact. They have a systematic understanding and apply this in their explanation and argumentation.</td>
</tr>
</tbody>
</table>
Appendix D
Exemplary items of the two components of the adapted version of the Metacognitive Awareness Inventory (Schraw & Dennison, 1994) and the associated Cronbach's alpha’s

<table>
<thead>
<tr>
<th>Scale</th>
<th>Items</th>
</tr>
</thead>
</table>
| Knowledge of cognition   | ・When searching the Internet for information I tried to use a method that had worked well in the past.  
                             ・When I finished searching the Internet, I knew how good I had solved the information problem.  
                             ・I knew what information was most important to solve the information problem.  
                             ・I was good at presenting the information I had found on the Internet.  
                             ・While searching the Internet for information, I deliberately turned my attention to important information.  
                             Consisted of 17 items  
                             Pretest ($\alpha = 0.845$)  
                             Posttest ($\alpha = 0.849$)  
                                                                                                                                                                                                                                                                                                |
| Regulation of cognition  | ・While searching the Internet for information, I often asked myself if my strategy would result in a good answer for the information problem.  
                             ・I compared information from different Websites before I solved the information problem.  
                             ・I asked myself questions about the subject before I started searching for information on the Internet  
                             ・I asked for help when I did not understand anything when searching for information on the Internet  
                             ・Once I finished searching the Internet, I asked myself how well I had answered the information problem.  
                             Consisted of 15 items  
                             Pretest ($\alpha = 0.847$)  
                             Posttest ($\alpha = 0.844$)  
                                                                                                                                                                                                                                                                                                |
Figure 1
The information problem solving using internet model (IPS-I-model)*

### Figure 2

**Quasi-experimental 2 x 2 factorial design**

<table>
<thead>
<tr>
<th></th>
<th>TECHNOLOGY-Enhanced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absent</td>
</tr>
<tr>
<td>TEACHER-Enhanced</td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>Condition 1:</td>
</tr>
<tr>
<td></td>
<td><em>Without scaffolds</em></td>
</tr>
<tr>
<td></td>
<td><em>(N=63)</em></td>
</tr>
<tr>
<td>Present</td>
<td>Condition 3:</td>
</tr>
<tr>
<td></td>
<td><em>Teacher-enhanced scaffolds</em></td>
</tr>
<tr>
<td></td>
<td><em>(N=97)</em></td>
</tr>
</tbody>
</table>
Figure 3
*Line graph illustrating the interaction between gender and the scaffolding conditions with regard to posttest scores after adjustment for pretest scores*
Figures: Scaffolding Information Problem Solving

Figure 4
Line graph illustrating the interaction between prior knowledge level and the scaffolding conditions with regard to posttest scores after adjustment for pretest scores.
Figure 5
*Line graph illustrating pre- and posttest descriptives for regulation about cognition*

![Line graph](image-url)
Highlights:

- Effects of scaffolding on knowledge acquisition and metacognition are examined.

- Technology-enhanced scaffolding and teacher-enhanced scaffolding are compared.

- Teacher-enhanced scaffolding is important to increase knowledge acquisition.

- Providing technology-enhanced scaffolds improves students’ metacognitive awareness.

- Girls and low-achievers benefit more from teacher-enhanced scaffolding.