Examining the Effects of Metacognitive Scaffolding on Students' Design Problem Solving and Metacognitive Skills in an Online Environment

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Abstract

Complex, ill-structured problem solving is not a linear, straightforward process. Rather it is an iterative and cyclical process and involves ongoing monitoring and evaluation. Therefore, metacognition is critical for successful problem solving. Although there is no question about the importance of scaffolding in complex, ill-structured problem solving, relatively little attention has been given to metacognitive scaffolding. Using mixed-methods research, this study investigated the effects of metacognitive scaffolding on students' complex problem solving processes and outcomes in the domain of instructional design as well as on their metacognitive skills in an online environment. Both qualitative and quantitative data were collected from multiple sources, including online surveys, planning sheets, technology-enhanced lessons, and reflection papers. The results of the study revealed that metacognitive scaffolding had positive effects on students' design problem solving processes but did not have a significant effect on design outcomes. Regarding metacognitive skills, the experimental group showed significant improvement in the planning subscale.

Key Words: metacognition, metacognitive scaffolding, ill-structured problem solving, complex problem solving, design problems, metacognitive skills, online learning, instructional design

Introduction

Problems vary in terms of their structuredness, situatedness, complexity, dynamicity, and domain specificity (Jonassen, 2011). Problem complexity is "a function of external factors, such as the number of issues, functions, or variables involved in the problem; the number of interactions among those issues, functions, or variables; and the predictability of the behavior of those issues, functions, or variables" (Jonassen, 2011, p. 9). Complex problems require more cognitive operations than do simpler ones, and they impose more cognitive load on the problem solver. As Jonassen (2000, 2011) noted, complexity and structuredness overlap. Although ill-structured problems tend to be more complex, well-structured problems can be extremely complex. Likewise, ill-structured problems can be fairly simple (Jonassen, 2000). Design problems are among the most complex, ill-structured kinds of problems that require greater metacognitive skills (Jonassen, 2000, 2011). Research studies show that students are unfamiliar with the ill-structured problem solving process (An, 2010) and do not always engage in metacognitive activities (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004; Ge & Land, 2004). Despite the apparent importance of metacognition in complex, ill-structured problem solving, relatively little attention has been given to metacognitive scaffolding. Focusing on instructional design problems, this study aimed to investigate the effects of metacognitive scaffolding on students' complex problem solving in an online environment.

Design Problem Solving

Jonassen (2000) identified eleven kinds of problems: (1) logic problems, (2) algorithms, (3) story problems, (4) rule-using/rule-induction problems, (5) decision making, (6) troubleshooting, (7) diagnosis-solution problems, (8) strategic performance, (9) policy-analysis problems, (10) design problems, and (11) dilemmas. Design problems are usually among the most complex and ill-structured kinds of problems. They usually have ambiguous goals and possess multiple solutions, multiple solution paths, and multiple criteria for evaluating solutions. The criteria for evaluating design solutions are often unknown. Design problems require the problem solver to integrate knowledge from multiple domains. They also require greater metacognitive or self-regulation skills (Jonassen, 2000, 2011).

Design is a ubiquitous activity. In numerous fields, including education, engineering, computer science, art, music, architecture, and business, professionals design products, processes, models, activities, and other outcomes. Many jobs and tasks involve design problem solving. The largest body of research on design comes from engineering design (Jonassen, 2011). According to Dym and Little (2004), the engineering design process includes the following five phases: (1) problem definition, (2) conceptual design, (3) preliminary design, (4) detailed design, and (5) final design. Most disciplines attempt to define their own design models. Instructional design is one of the prominent design venues. The core elements to all instructional design models are summarized in the ADDIE model (analysis, design, development, implementation, and evaluation (Gustafson & Branch, 1997). That is, instructional designers first engage in analysis, design instruction by assembling content and instructional strategies, develop instructional materials, implement the developed instruction, and evaluate its effectiveness. However, instructional design is not a linear process as implied by the ADDIE and other instructional design models. Rather it is a cyclical and iterative process (Jonassen, 2011).

In addition, successful design must address the constraints imposed by the context. Constraints in instructional design include learner characteristics, learning goals, resources available, environmental factors, and physical context in which instruction is delivered. Constraints are rarely identified at the beginning of the design process. They emerge throughout the design process, and designers need to make decisions based on the constraints as they emerge (Jonassen, 2011).

Complex Problem Solving and Metacognition

In order to be successful in complex, ill-structured problem solving, the problem solver needs both domain-specific knowledge and structural or structured knowledge. Domain-specific knowledge refers to content knowledge in a specific discipline. Structural or structured knowledge, on the other hand, refers to the knowledge of how concepts within a domain are interrelated. It is often described as schemata or cognitive structure (Chi & Glaser, 1985; Ge & Land, 2004; Jonassen, 2000; Voss & Post, 1988; Voss et al., 1991). Due to the lack of sufficient domain-specific and structural knowledge, novices tend to interpret complex problems in simplified ways by overlooking critical factors, have difficulty identifying relevant information, and often fail to consider alternative solutions (Powell & Willemain, 2007; Voss & Post, 1988).

In addition to domain-specific knowledge and structural knowledge, metacognition is also important because complex, ill-structured problem solving involves ongoing monitoring and evaluation. The term metacognition, coined by Flavell (1979), is often simplified as “thinking about thinking” or “cognition about cognition.” Although there are many different definitions of metacognition, there is a general agreement that metacognition consists of both metacognitive knowledge and metacognitive regulation (Flavell, 1979; Hacker, Dunlosky, & Glaesser, 1998; McCormick, 2003; Zimmerman & Schunk, 2011). Metacognitive knowledge refers to declarative knowledge about and awareness of one’s own cognitive processes. On the other hand, metacognitive regulation refers to one’s procedural knowledge for regulating cognitive processes and consists of the following four components (See Figure 1): (1) planning, (2) monitoring, (3) evaluating, and (4) revising (Brown, 1987), all of which are required for complex, ill-structured problem solving. Metacognition is necessary for solving complex, ill-structured problems, including design problems, especially when domain-specific knowledge and structural knowledge are absent or limited. Wineburg (1998, 2001) found that metacognition could compensate for absence of relevant domain knowledge.

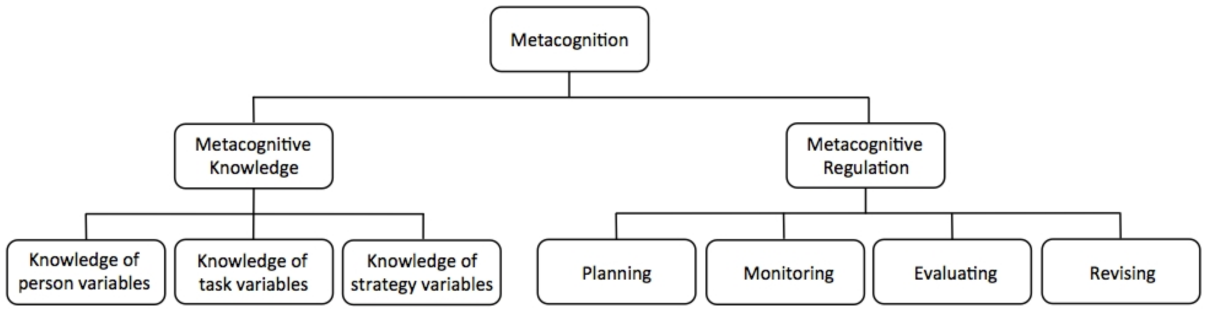


Figure 1. Components of Metacognition

Scaffolding

Scaffolding refers to temporary support provided by the teacher, more capable peers, or computer tutors to help students solve a problem or carry out a task that they cannot accomplish independently (Vygotsky, 1978; Wood et al., 1976). Scaffolds can take a variety of forms, including expert modeling, expert advice, prompts, learner guides, and tools. Saye and Brush (2002) distinguished between hard scaffolds and soft scaffolds. Hard scaffolds refer to “static supports that can be anticipated and planned in advance based on typical student difficulties with a task” (p. 81). In contrast, soft scaffolds provide dynamic and spontaneous support based on learner responses. Further, Hannafin et al. (1999) identified four types of scaffolding: conceptual, metacognitive, procedural, and strategic. First, conceptual scaffolding guides learners regarding what to consider and helps them reason through complex problems. Second, metacognitive scaffolding facilitates metacognitive thinking and supports metacognitive processes, including planning, monitoring, and evaluating. Third, procedural scaffolding emphasizes how to utilize resources and tools. Finally, strategic scaffolding provides guidance on how to approach learning tasks or problems.

There is no question about the importance of scaffolding in complex, ill-structured problem solving. Many students are accustomed to traditional teacher-centered instruction, unfamiliar with the ill-structured problem solving process, and overwhelmed by the complexity and ambiguity of the problem presented to them (An, 2010). Also, students do not always engage in the planning activities and rarely use metacognitive monitoring processes (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004). They do not necessarily monitor and evaluate their problem solving (Ge & Land, 2004). Researchers have increasingly emphasized the need to provide external support to facilitate students’ cognitive and metacognitive processes during complex, ill-structured problem solving.

Effects of Metacognitive Scaffolding

Only a small number of studies have investigated the effects of metacognitive scaffolding in the context of complex, ill-structured problem solving. Research shows that metacognitive scaffolding supports metacognitive activities and facilitates problem-solving processes. For example, Ge and Land (2003) found that students who received metacognitive question prompts performed significantly better than those who did not receive question prompts in all four problem-solving processes, including problem representation, generating solutions, making justification, and monitoring and evaluation. Specifically, students who closely followed the question prompts demonstrated significantly better problem solving skills in metacognitive activities, such as planning for the problem solving process, monitoring the problem solving progress, evaluating the effectiveness of the solutions, and justifying the viability of the proposed solution against alternatives. Bulu and Pedersen (2010) investigated the effects of domain-general and domain-specific scaffolds on learning and problem-solving outcomes during ill-structured problem solving. Their findings revealed that domain-general scaffolds facilitated monitoring and evaluation better than domain specific ones and helped students transfer problem-solving skills when they were faded, while domain-specific scaffolds facilitated learning of the scientific content and problem representation better than domain-general scaffolds. In the domain-general conditions, students evaluated their solutions more effectively and provided alternative solutions to the problem. These results suggest that domain-general scaffolds are effective for fostering students' monitoring and evaluation skills.

Using Hannafin et al.'s (1999) scaffolding classification, An (2010) designed conceptual, metacognitive, procedural, and strategic scaffolds and examined their effectiveness in supporting students' wiki-based, ill-structured problem solving in an online graduate-level course. She found that metacognitive scaffolds helped students effectively develop problem-solving plans, monitor and evaluate their progress, make necessary changes to improve their problem solving processes, and avoid procrastination. More recently, Chen and Chan (2011) reported that process prompts facilitate students' problem-solving efforts and support self-monitoring and metacognitive thinking. These research findings indicate that metacognitive scaffolds are effective in supporting students' metacognitive processes, including planning, monitoring, and evaluation.

The literature also reveals that metacognitive scaffolding facilitates students' content learning and knowledge construction as well as metacognitive processes. In Bulu and Pedersen's (2010) study, sixth grade students were randomly assigned to one of the four scaffolding conditions: domain-general continuous (DG-C), domain-general faded (DG-F), domain-specific continuous (DS-C), and domain-specific faded (DS-F). Students in all four conditions improved their content knowledge significantly from pretest to posttest. Although the students in the continuous domain-specific (DS-C) condition outperformed those in the other conditions on the posttest, the results show that domain-general scaffolds have a positive effect on students' content learning. In a similar vein, An (2010) found that metacognitive scaffolds not only supported student groups' planning, monitoring, and evaluation in the ill-structured problem solving process, but also helped the instructor better understand students' conceptual needs. By making the student groups' plans, strategies, progress, reflections, and evaluations visible, the metacognitive scaffolds provided in her study enabled the instructor to understand what was going on in each group and to provide tailored conceptual scaffolding.

Roll and his colleagues (2012) examined the effect of metacognitive scaffolding, domain-independent instructional prompts, on students' invention behaviors and outcomes. One hundred thirty-four undergraduate students were assigned to one of the two conditions: Guided Invention (treatment) and Unguided Invention (control) conditions. Students in both conditions were asked to invent methods for calculating uncertainties in best-fitting lines. The Guided Invention condition differed from the Unguided Invention condition in that it included metacognitive scaffolding. The results of the study revealed that students in the Guided Invention condition developed better conceptual understanding and invented methods that included more conceptual features. The study suggests that metacognitive scaffolding facilitates students' conceptual understanding and increases the quality of solutions.

Despite the increasing research efforts, there is still a lack of understanding of how metacognitive scaffolding affects students' complex problem solving processes and outcomes and their metacognitive skills, particularly in online learning environments.

Purpose of the Study

The purpose of this study was two-fold: (1) to investigate the effects of metacognitive scaffolding on students' complex problem solving processes and outcomes in the domain of instructional design in an online environment, and (2) to examine how metacognitive scaffolding influences students' metacognitive skills. Specifically, the following research questions were addressed:

1. What are the effects of metacognitive scaffolding on students' design problem solving processes and outcomes in an online environment?
2. How does metacognitive scaffolding affect students' metacognitive skills (planning, monitoring, and evaluation skills)?

We expected students receiving metacognitive scaffolds to acquire more metacognitive skills than students in the group that did not receive metacognitive scaffolds. We also expected that the group supported by metacognitive scaffolds would outperform the group not supported by metacognitive scaffolds on the quality of the design outcomes.

Method

Participants.

Participants in this study were 49 students enrolled in two sections of an online graduate course in the Instructional Technology program at a public university in the southeastern United States. They were all graduate students in the College of Education. The majors of the participants included Instructional Technology, Special Education, School Counseling, School Library Media, and Business Education. Seventy percent of the participants were female and thirty percent were male. Their age ranged from 23 to 58 years old. Approximately 70% of the participants did not have prior experience in creating technology-enhanced lessons. Standard IRB procedures were followed. The students returned consent forms and agreed to participate in the study. Participants' background information is summarized in Table 1.

Table 1.

Participant Demographic Information

Class	*N*	Age	Gender		Prior experience in creating technology-enhanced lessons	
		M (*SD*)	Female	Male	Yes	No
Section 1	25	31.2 (8.77)	16	9	7	18
Section 2	24	35.3 (10.7)	18	6	8	16
Total	49	33.2 (9.89)	34	15	15	34

Procedures.

This study focused on two instructional design assignments: (1) creating a WebQuest (Dodge, 1995) and (2) developing a technology-enhanced, design-based lesson that requires students to collaboratively design digital objects. They were individual assignments. Two sections of the Instructional Technology course were offered online in Spring 2012. The first section was an experimental group, and the second section was a comparison group. For the two design assignments, the students in the experimental group were given metacognitive scaffolding in addition to content-specific scaffolding (e.g., WebQuest template, sample lessons). On the other hand, the students in the comparison group did not receive metacognitive scaffolding. They were given content-specific scaffolding only.

Table 2.

Metacognitive Scaffolding

Metacognitive Scaffolds	
Planning	• Planning Sheet Templates (Hard scaffolding) • Feedback on Planning Sheets (Soft scaffolding)
Monitoring & Evaluating	• Question Prompts (Hard scaffolding)

Metacognitive scaffolding was designed to facilitate planning, monitoring, and evaluating processes during design problem solving (See Table 2). Specifically, the instructor first provided the experimental group with planning sheet templates (hard scaffolding), in which directions and prompts for facilitating planning were embedded. The planning sheet template for the WebQuest assignment consisted of the following four sections: (1) Topic/subject, (2) Grade level, (3) Learning issues, and (4) Timeline (See Figure 2). The template for the design-based lesson assignment consisted of the following four sections: (1) Target learners, (2) Design task, (3) Learning issues, and (4) Timeline (See Figure 3).

Planning Sheet

Name:
Date:

1. **Topic/Subject**: Consider several different topics and choose the best one. Make sure that it is appropriate for WebQuest.
2. **Grade Level**:
3. **Learning Issues**: What do you need to learn to create a WebQuest? Read the assignment instructions and evaluation criteria carefully to identify learning issues.
4. **Timeline**: Identify the steps or activities involved in creating a WebQuest and determine how much time to spend on each activity. Use the following table format.

Steps or activities to be completed	Timeline

Figure 2. Planning Sheet Template for the WebQuest Assignment

Planning Sheet

Name:
Date:

1. **Target Learners**:
2. **Design Task:** What digital object do you want your target learners to design?
3. **Learning Issues**: What do you need to learn to develop a design-based lesson? Read Ch. 4 and the assignment instructions carefully to identify learning issues.
4. **Timeline**: Identify the steps or activities involved in developing a design-based lesson and determine how much time to spend on each activity. Use the following table format.

Steps or activities to be completed	Timeline

Figure 3. Planning Sheet Template for the Design-Based Lesson Assignment

As Figure 2 and Figure 3 show, the students in the experimental group were prompted to select their lesson topic and target learners, identify learning issues, and develop a timeline. The experimental group was required to complete and submit their planning sheet before they designed their technology-enhanced lessons.

The instructor provided feedback on the planning sheets (soft scaffolding), using the Assignments tool in Blackboard. In addition, during the design process, she provided question prompts (hard scaffolding) to facilitate monitoring and evaluation processes using the Announcements tool in Blackboard. For example, for the design-based lesson assignments, the experimental group was encouraged to ask themselves the following questions:

- Am I on the right track? Am I developing a lesson that is design-based?
- Is the design task appropriate for my target audience? Have I considered all options?
- Am I making good progress?
- What do I still need to learn to develop an effective design-based lesson?
- Am I making good use of my time?
- Am I using effective strategies for this assignment?
- Does my lesson plan include all the required elements?

Data Sources

Using mixed methods research (Creswell, 2009), the researchers collected both qualitative and quantitative data from multiple sources, including online surveys, planning sheets, technology-enhanced lessons, and reflection papers.

Surveys

Participants completed two online surveys (pre- and post-measures). The first survey was administered in the first week of the semester. The survey included two parts: (1) demographic questions and (2) a metacognitive skills questionnaire. The metacognitive skills questionnaire was created based on the Metacognitive Awareness Inventory (MAI) (Schraw, 2001; Schraw & Dennison, 1994). The MAI was selected because self-report measures were widely used in the self-regulated learning research.

Research (Cao, 2012; Pintrich, 2000; Winne & Hadwin, 1998) shows that a self-report instrument was able to measure general aptitudes or propensities in different self-regulatory processes. As Schraw and Dennison (1994) reported, scores on the subscales of the MAI have been related, in theoretically predictable ways, to components of students' motivation, metacognition, and academic performance, including self-efficacy, knowledge of cognition, regulation of cognition, monitoring accuracy, and test performance.

Our survey instrument was significantly different from the MAI. The MAI includes 52 items, which are classified into eight subcomponents, including declarative knowledge (DK), procedural knowledge (PK), conditional knowledge (CK), planning (P), information management strategies (IMS), monitoring (M), debugging strategies (DS), and evaluation (E). The metacognitive skills questionnaire used in this study, on the other hand, consisted of three subscales, including planning, monitoring, and evaluation (See Appendix A). Each subscale included six items. Although the MAI's planning, monitoring, and evaluation items were a starting point, those items irrelevant to design problem solving (e.g., "I ask myself questions about the material before I begin," "I ask myself questions about how well I am doing while I am learning something new," "I know how well I did once I finish a test," etc.) were not included. Instead, new items were added (e.g., "I figure out the steps or activities involved in completing a task," "I determine how much time to spend on each activity before I begin a task," and "I evaluate what went well and what could have been done better after I finish a task."). The second survey included the metacognitive skills questionnaire only. The post-measure was completed after submission of the two design assignments. Table 3 below shows Cronbach *α* coefficients for the subscales as well as the overall metacognitive skills for the pre-test and post-test. As can be seen from Table 3, our data produced acceptable reliabilities coefficients, ranging from the lowest .70 to the highest .90.

Table 3.

Cronbach Alpha Coefficients for the Pre- and Post-Test Measures

Scales	Pre-Test	Post-Test
Planning	.71	.70
Monitoring	.71	.76
Evaluation	.83	.70
Overall Metacognitive Skills	.90	.86

Technology-enhanced lessons

Participants were asked to design two different technology-enhanced lessons: (1) a WebQuest and (2) a technology-enhanced, design-based lesson. They were given approximately two weeks to complete each assignment. The first author graded their technology-enhanced lessons using rubrics, and the grades were used as the measure of the quality of design outcomes.

Planning sheets

The students in the experimental group were required to complete a planning sheet before designing each lesson. For the planning sheet, they were given a template, which was described above. The planning sheet forced the experimental group to select a topic and target audience, identify learning issues, and develop a timeline within the first four days.

Reflection papers

The students in both groups were asked to write a reflection paper after designing a WebQuest and another reflection paper after designing a technology-enhanced, design-based lesson. Open-ended questions were provided to facilitate reflection. The following are sample questions: Was it helpful to complete the planning sheet for the Design-Based Lesson assignment? Why or why not? Please explain (For the experimental group only). What strategies did you use to effectively complete the assignment? How did you monitor and evaluate your progress?

Data Analysis

Quantitative data from surveys and assignment grades were analyzed by using a repeated measures ANOVA. Rubrics were used to evaluate the quality of problem solving outcomes, that is, students' WebQuests and technology-enhanced, design-based lessons. Qualitative data from planning sheets and reflection papers were analyzed by using the constant comparative method (Glaser & Strauss, 1967; Strauss & Corbin, 1990). All qualitative data were carefully examined, coded, and constantly compared to other data for thematic analysis. Reflection papers from the experimental group and those from the comparison group were examined separately to compare two groups' metacognitive strategies.

Results

Research Question 1: What are the effects of metacognitive scaffolding on students' design problem solving processes and outcomes in an online environment?

Qualitative data analysis revealed that metacognitive scaffolding facilitated students' design problem solving processes by helping them set goals and deadlines, engage in research, organize their ideas and thoughts, correct misunderstandings, revise ineffective plans or strategies, avoid procrastination, use time effectively, and monitor and evaluate their progress.

Set goals and deadlines

Students in the experimental group reported that the planning sheet not only took away the overwhelming feeling and stress but also helped them focus and stay on task, by having them set goals and deadlines.

> "… The timeline was the most important tool. I was able to set goals and deadlines so that completing the WebQuest would not be cumbersome." (Katie, March 10, 2012)

> "The timeline component of the planning sheet was the most useful… This certainly would have been a frustrating task if I hadn't broken it into parts. I was able to set goals and deadlines. I started with what I wanted the end product to be and broke the assignment into chunks." (Linda, April 22, 2012)

Reflection data revealed that not all students in the comparison group engaged in planning activities. Some students started with an outline, but others just started designing a lesson without any planning.

> "I started with an outline of what I would like to accomplish with the lesson. This helped me keep on track of what I was trying to accomplish with the lesson." (Carol, April 22, 2012)

> "Next time, I think I will make a map/outline of what I was thinking of doing. This time, I just sat down and started typing. This led me to go back several steps and search for items that I needed to elaborate on. Writing out an outline of the project will be easier for future planning of a major project." (Becky, April 22, 2012)

Engage in research and organize ideas and thoughts

For each instructional design assignment, the students in the experimental group were required to identify what they needed to learn or learning issues before creating a lesson. Several students identified what their target learners would need to learn instead of what they needed to learn, but most students identified appropriate learning issues. Students reported in their reflection papers that identifying learning issues helped them engage in research before developing their lessons and organize their thoughts and ideas.

> "…Also, the learning issues were very important for me to figure out. The main issue I encountered was not being familiar with the iStopMotion software. I had to research and teach myself how to use it before I could implement it into a classroom setting. I needed to know all of the information so I could create a successful lesson…" (Abigail, April 22, 2012)

> "The planning sheet was very helpful. I am one of those types of people who have millions of ideas running through their heads simultaneously and I often end up with many unfinished

> products. The planning sheet helped me to focus and organize both my thoughts and ideas." (Linda, March 12, 2012)

Correct misunderstandings or develop a more complete understanding of the assignments

The planning sheet enabled the instructor to redirect the students on the wrong track and help them better understand the assignments. For example, five students in the experimental group chose an inappropriate topic for a WebQuest. Four of them changed their topic based on the instructor feedback and successfully designed a WebQuest.

> "… I needed some redirection and feedback from the instructor prior to developing my layout. Because we developed the planning sheet first, I was able to reroute my thought processes in developing a WebQuest." (Emily, March 12, 2012)

Revise ineffective plans or strategies

The last component of the planning sheet was a timeline. For each design assignment, the students in the experimental group were asked to identify the steps or activities involved in the lesson design and to determine how much time to spend on each activity. They were required to use a given table format for the timeline. Some students' timelines revealed their ineffective strategies. For example, some allocated insufficient time on activities, and others sequenced activities ineffectively. The instructor helped them revise their plans through individual feedback.

Use time effectively and avoid procrastination

The planning sheet helped the students in the experimental group use time effectively, avoid procrastination, and complete the assignments in a timely manner by having them make critical design decisions early in the design process.

> "Not only did the planning sheet help me with the timeline, it also showed me that if I spent too much time on one part of the assignment I would have to spend less time on the next part." (Jason, April 22, 2012)

> "The planning sheet was helpful to complete before creating the WebQuest. Although you did not have to really complete anything on the planning sheet, it still required me to begin brainstorming what I wanted my WebQuest to focus on and how I was going to complete each element of the WebQuest in a timely manner. The planning sheet kept me from procrastinating on this assignment." (Morgan, March 10, 2012)

Some students in the comparison group apparently completed the design assignments at the last minute or did not use the given time effectively. Several students in the comparison group commented in their reflection papers that they would spend more time on the design assignments.

> "Next time, I would work more on my assignment a little at a time and not mostly just on the weekend. I also feel like I could have spent more time on detailing the steps of the procedure part of the assignment..." (Logan, April 22, 2012)

> "In the future, when working on a larger assignment of this nature I would spend more time at the beginning stages of creation making sure that my overall concept matched with the objectives of the lesson..." (Alison, April 22, 2012)

Monitor and evaluate progress

Qualitative data analysis revealed that both experimental and comparison groups used similar monitoring and evaluation strategies. Specifically, the major strategies commonly used by students included rereading the assignment instructions and evaluation criteria, working on the lesson little by little over time, and using the sample lesson as a roadmap. The following two quotes are from the reflection papers written by the students in the experimental group.

> "To monitor and evaluate my progress while completing assignments like this one, I first refer to the instructions and grading criteria provided by the professor, then I look at the example provided. I use these as a guide and continually refer back to them as I work toward completing my project to ensure that I am completing all of the requirements of the assignment… At the end,

> I review the entire project and compare it with the grading criteria to make sure that I haven't forgotten any important aspects of the assignment." (Grace, April 22, 2012)
>
> "I monitored and evaluated my progress by working on the lesson in bits and pieces over a few days. I am the type of person who needs to think of an idea and tweak it in my mind or on paper a few times before I want to create the final result. The planning sheet is a good way to monitor progress though." (Amy, April 22, 2012)

The following quotes show that the students in the comparison group used similar strategies to monitor and evaluate their progress.

> "I used the rubric to monitor and evaluate my progress while completing the design-based lesson plan. I referred to the rubric before, during, and after completing each section of the lesson plan. Once I completed the project, I used the rubric to perform a self-evaluation and ensure all of the required elements were in place." (Daniel, April 22, 2012)
>
> "I worked on building my lesson over about a week's time. Each day I would add something new so I wasn't trying to get the entire assignment completed at one time. This also gave me time to sit down between times working on the assignment and question my actions…" (Elizabeth, April 22, 2012)

The main difference between the two groups was that the experimental group used their planning sheet, especially the timeline section, to monitor and evaluate their progress. Data analysis revealed that the planning sheet served as a roadmap during the students' design problem solving. A number of students in the experimental group reported that the planning sheet and question prompts helped them monitor and evaluate their progress. Several students commented that they would continue to use the planning sheet when developing new lessons. One student mentioned that she would definitely utilize it in her own classroom with her students. Although most students found the planning sheet to be very helpful, three students reported that it was not helpful to complete the planning sheet because plans change at every turn. One believed that it would be useful for procrastinators only.

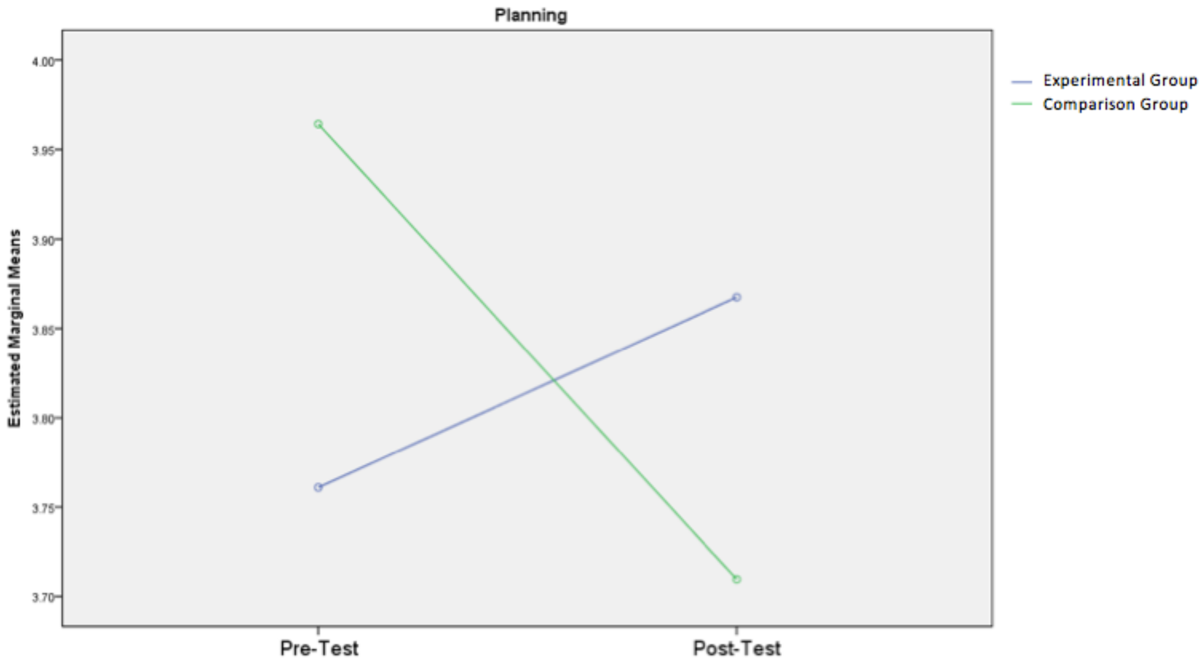
Table 4.
The Effects of Metacognitive Scaffolding on Design Outcomes

	Experimental Group		Comparison Group		F	Sig.
	Mean	SD	Mean	SD		
WebQuest (40)	35.48	8.00	34.38	10.51	.14	.71
Design-Based Lesson (50)	41.87	13.55	40.56	15.56	.10	.76

Despite the benefits of metacognitive scaffolding mentioned above, quantitative data analysis revealed that metacognitive scaffolding did not have significant effects on the problem solving outcomes, which were technology-enhanced lessons. The results of the Analysis of Variance (ANOVA) showed no significant difference between experimental and comparison groups with regard to their grades (See Table 4).

Research Question 2: How does metacognitive scaffolding affect students' metacognitive skills?

Four separate one-way repeated measures ANOVAs were conducted to examine the potential differences between the experimental and comparison groups in planning, monitoring, evaluation, and overall metacognitive skills. No significant differences were found between the experimental and comparison groups on the three subscales (i.e., planning, monitoring, and evaluation) and the overall metacognitive skills.



Note: Age (= 33.20) was used as a covariate.

Figure 4. Planning: Estimated Marginal Means of Pre-test and Post-test

However, a significant interaction effect was found between time (pre/post-test) and condition (experimental/comparison), $F(1, 46) = 4.11$, $p = .048$, $\eta^2 = .08$, when age was used as a covariate. The planning subscale had a different effect depending on the condition when age was controlled. As Figure 4 shows, the experimental group showed an increase in pre- to post-test scores in the planning subscale (Pre-test Mean = 3.76, Post-test Mean = 3.87), while the comparison group showed a decrease in pre- to post-test scores in the planning subscale (Pre-test Mean = 3.96, Post-test Mean = 3.71).

Discussion

This study was limited by a relatively small sample size and a short intervention period. However, the findings of the study contribute to the understanding of metacognitive scaffolding in complex problem solving, provide practical insights into supporting metacognitive processes in online environments, and suggest specific directions for future research.

The results revealed that metacognitive scaffolding facilitated students' design problem solving processes by engaging them in metacognitive activities as well as in research. This finding is consistent with previous research (An, 2010; Bulu & Pedersen, 2010; Chen & Chan, 2011; Ge & Land, 2003). Interestingly, many students in the comparison group did not engage in planning activities, such as setting goals, identifying learning issues, identifying steps or activities involved in the lesson design, and allocating time to each step or activity. Although some students in the comparison group made an outline before designing their lesson, others just started designing a lesson without a plan. This is in line with previous findings from Azevedo and his colleagues' studies (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004). It is important to keep in mind that students do not always engage in planning activities without appropriate scaffolding. In terms of monitoring and evaluation, both experimental and comparison groups used similar strategies. As mentioned earlier, the main difference between the groups was that the experimental group used the timeline section of their planning sheet to monitor and evaluate their progress.

The metacognitive scaffolds provided to facilitate the students' planning process, including planning sheet templates and feedback on planning sheets, turned out to be effective. The major components of the planning sheet templates were learning issues and timeline sections. For the learning issues section, the students in the experimental group were prompted to identify what they needed to learn to complete the design tasks. For the timeline section, they were prompted to identify the steps or activities involved in the design tasks and determine how much time to spend on each activity. Identifying learning issues is critical for complex, ill-structured problem solving, but students do not always engage in the activity. Five students initially listed what their target audience would need to learn, and the instructor helped them identify appropriate learning issues by providing feedback on their planning sheets. The results indicate that the planning sheet templates (hard scaffolding) can effectively facilitate students' planning process in an online environment, but soft scaffolding (instructor feedback) is necessary for some students. The students in the experimental group reported that the timeline section was the most useful tool. Qualitative data analysis showed that the timeline section helped the students use time effectively by having them set goals and deadlines, took away the overwhelming feeling and stress, and served as a roadmap during the design problem solving process. The planning sheet templates used in this study appear to have potential to improve students' planning skills in online problem solving environments. Future research should explore how the planning sheet components can be used to develop computer-based scaffolds in order to provide students with more adaptive and flexible scaffolding. Also, future research could explore ways to design and develop computer-based scaffolds or virtual agents that provide guidance and suggestions as students set goals, identify learning issues, and develop a problem-solving plan.

The results of repeated measures ANOVAs showed that the experimental group made significant improvement in planning skills. A significant interaction effect was found when age was used as a covariate. The experimental group showed an increase in pre- to post-test scores in the planning subscale, while the comparison group showed a decrease in pre- to post-test scores in the planning subscale. It was interesting that age emerged as a significant covariate. There was no significant difference in age between the experimental and comparison groups. The interaction effect disappeared when other variables, such as gender and GPA, were used as a covariate. Future research should examine the interaction effect more closely using the multivariate experimental design. Stratified sampling of the participants by age will help in determining the contribution of each factor (i.e., time and condition) to the changes of metacognitive skill scores.

Interestingly, the metacognitive scaffolding did not have a significant influence on students' monitoring and evaluation skills. Qualitative data analysis also showed that both groups used similar monitoring and evaluation strategies during design problem solving. It is possible that students in the experimental group did not take advantage of the question prompts provided to facilitate their monitoring and evaluation processes. Research studies report that students sometimes ignore the question prompts provided (Ge & Land, 2003) or answer them superficially (Greene & Land, 2000). Another explanation might be that the period of treatment was not long enough. The improvement of monitoring and evaluation skills might require a longer period of time. Also, as noted, the study was limited by a relatively small sample size. A larger sample size might lead to different results. Future research should use a larger sample size and a longer time frame and ensure that participants pay close attention to question prompts provided. It is also suggested that future research use a retrospective survey and interviews rather than typical pre- and post-surveys to examine the effect of metacognitive scaffolding on metacognitive skills. The participants in this study tended rate themselves higher on the pretest than on the post-test. It is possible that people overestimate their knowledge and skills at the beginning and realize that they did not know as much as they thought they did after interventions. Having participants reflect on the changes of their knowledge and skills after interventions would be more effective.

Although metacognitive scaffolding had positive effects on design problem solving processes, it did not have significant effects on design outcomes. The experimental group's mean scores were slightly higher than the comparison group's mean scores, but the differences were not statistically significant. It is possible that the content-specific scaffolding provided in this study, including sample lessons, enabled the students in the comparison group to design quality lessons without receiving metacognitive scaffolding. The literature suggests that metacognition is necessary for ill-structured problem solving especially when domain-specific knowledge and structured knowledge are absent or limited (Wineburg, 1998, 2001). Metacognitive scaffolding could have more influence on problem solving outcomes when students are not given content scaffolding. It might be interesting to compare the design outcomes of students in the following four conditions: content-specific scaffolding, metacognitive scaffolding, both content-specific and metacognitive scaffolding, and no scaffolding. Although Roll and his colleagues (2012) found that metacognitive scaffolding increased the quality of solutions, there is a lack of research on the effects of metacognitive scaffolding on problem solving outcomes. Further studies should examine the effects of metacognitive scaffolding on problem solving outcomes as well as on problem solving processes with different types of complex, ill-structured problems in different settings.

Conclusion

Using mixed-methods research, this study investigated the effects of metacognitive scaffolding on students' design problem solving processes and outcomes as well as on their metacognitive skills in an online environment. Qualitative data analysis revealed that metacognitive scaffolding facilitated students' design problem solving processes by helping them set goals and deadlines, engage in research, organize their ideas and thoughts, correct misunderstandings, revise ineffective plans or strategies, avoid procrastination, use time effectively, and monitor and evaluate their progress. However, metacognitive scaffolding did not have significant effects on the problem solving outcomes. Perhaps, metacognitive scaffolding could have more influence on problem solving outcomes when students are not given content scaffolding.

With regard to metacognitive skills, the experimental group showed significant improvement in planning skills when age was used as a covariate. The result suggests that the planning sheet templates used in this study could serve as a useful tool in online problem solving environments. They can effectively engage students in planning activities and have potential to improve students' planning skills. Metacognitive scaffolding did not have significant effects on monitoring and evaluation skills. More research is needed in this area.

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Appendix A:

The Metacognitive Skills Questionnaire

Subscale	Items
Planning	1. I read instructions carefully before I begin a task. 2. I set specific goals for myself before I begin a task. 3. I think about what I really need to learn before I begin a task. 4. I consider several alternative ways to complete a task and choose the best one. 5. I figure out the steps or activities involved in completing a task. 6. I determine how much time to spend on each activity before I begin a task.
Monitoring	1. I ask myself periodically if I am on the right track. 2. I ask myself periodically if I am making progress toward my goals. 3. I ask myself if I have considered all options while working on a task. 4. I find myself pausing regularly to check my comprehension. 5. I ask myself periodically if I am making good use of my time to best accomplish my goals. 6. I regularly check the effectiveness of strategies while working on a task.
Evaluation	1. I ask myself how well I accomplish my goals once I'm finished. 2. I ask myself if there were more effective ways to do things after I finish a task. 3. I summarize what I've learned after I finish a task. 4. I evaluate what went well and what could have been done better after I finish a task. 5. I ask myself if I have considered all options after I finish a task. 6. I ask myself if I learned as much as I could have once I finish a task.

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