

# Scaffold Ill-Structured Problem Solving Processes through Fostering Self-Regulation — A Web-Based Cognitive Support System

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## Abstract

This paper provides an overview of a web-based, database-driven cognitive support system for scaffolding ill-structured problem solving processes through fostering self-regulation. Self-regulation learning and ill-structured problem-solving theories guided the design framework of this cognitive tool. Of particular interest are the roles of question prompts, expert view, and peer review mechanisms in supporting self-monitoring, self-regulation, and self-reflection in the processes of ill-structured problem solving, which have been tested through empirical studies in various content domains and contexts. Based on findings, suggestions are made to improve the cognitive support system for future research, including mapping self-regulation learning processes more closely with ill-structured problem-solving processes, and focusing on the system's capability to automatically adapt scaffolding based on individual needs and prior knowledge.

## Purpose

Educational researchers have been emphasizing the needs to engage students in complex, ill-structured problem-solving tasks intended to help them see the meaningfulness and relevance of school knowledge to real world and to facilitate knowledge transfer by contextualizing knowledge in authentic situations (e. g., Bransford, Brown, and Cocking 2000; Jonassen 1997). Instructional strategies have been developed to help students apply knowledge to real world through solving ill-structured problems, such as anchored instruction (CTGV 1990), case-based reasoning (Kolodner and Guzdial 2000), and problem-based learning (Barrow and Tambly 1980; Hmelo-Silver 2004). Meanwhile, various instructional technologies and scaffolds have been developed to develop students' ill-structured problem solving skills. For example, Ge and Land (2003; 2004) proposed a framework to scaffold ill-structured problem solving using question prompts and peer interactions. Other researchers (e.g., Lajoie and

Azevedo 2000; 2006) also contended for creating technology-rich environments to promote active knowledge transfer and self-monitoring through expert prompting, modeling, and feedback.

Literature shows that problem solving skills are highly related to his/her self-regulatory abilities (Pressley & McCormick 1987; Wineburg 1998). Therefore, this research examines how problem solving processes can be supported through fostering students' metacognition and self-regulatory skills. The purpose of this article is to present the design research of a web-based cognitive support system, aiming at scaffolding student ill-structured problem solving processes through facilitating learners' self-monitoring and self-regulation skills. The underlying theoretical framework for the design of the system is discussed, followed by the implication for technology design and future research.

## Theoretical Frameworks

### Self-Regulation and Ill-Structured Problem Solving Processes

In order to understand how technology can best be designed to scaffold ill-structured problem solving, we need to first understand the cognitive and metacognitive requirements involved in problem solving processes (Land 2000) and how self-monitoring and self-regulation would facilitate ill-structured problem-solving processes.

Ill-structured problem solving involves four major processes (Voss and Post 1988; Voss et al. 1991; see review in Ge and Land 2003; 2004): (a) problem representation, (b) develop solutions, (c) make justifications and construct arguments, (d) monitor and evaluate problem-solving plans and solutions. The process of making justification and generating arguments and the process of monitoring and evaluation can happen

concurrently during the processes of problem representation and developing solutions, just as monitoring and control process can happen throughout the problem-solving processes (Pintrich 2000).

Ill-structured problem solving imposes both cognitive and metacognitive requirements on problem solvers (Jonassen 1997). The cognitive demands for solving ill-structured problems involves both domain-specific knowledge (Chi and Glaser 1985; Voss and Post 1988; Voss et al. 1991) and structural knowledge (Chi and Glaser 1985). When domain-specific knowledge and structural knowledge are absent or limited, metacognition, which involves both knowledge of cognition and regulation of cognition (Brown 1987; Pressley and McCormick 1987), is necessary for successfully solving ill-structured problems (Wineburg, 1998). Hence, self-regulation plays an important role in the problem solving processes of experts (Pressley and McCormick 1987; Zimmerman and Campillo 2003).

According to Pintrich (2000), regulation “is an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment.” (p. 453) Pintrich identified the four phases of self-regulation, including *forethought, planning and activation; monitoring; control; reaction and reflection*, each of which concerns with cognition, motivation/affect, behavior, and context, which are well aligned with ill-structured problem solving processes and consistent with some other similar self-regulation framework (e.g., Zimmerman and Campillo 2003). Understanding self-regulation processes underlying ill-structured problem solving processes helps researchers to identify or assess learners’ difficulties and better scaffold their self-monitoring, self-control and self-regulation processes needed to successfully complete problem solving tasks.

### **The Role of Question Prompts**

Literature reveals that question prompting is an effective instructional strategy for directing students to the most important aspects of a problem, as well as encouraging self-explanation, elaboration, planning, monitoring and self-reflection, and evaluation (Bransford and Stein 1993; Chi et al. 1989; King 1991, 1992; Lin and Lehman 1999; Palincsar and Brown 1984; Scardamalia and Bereiter 1989). Chi et al. (1989) found that successful learners tend to generate more working explanations, particularly in response to an awareness of limited understanding. It seems questions prompts cause learners to be metacognitive aware of the problem situations and their limited understandings, and that in an effort to respond to the questions, students exert mental efforts to work with the problem through various cognitive activities, such as providing explanations, elaborating thoughts, and making

adjustments to their strategies. It is assumed that these cognitive activities help students to self-regulate their problem solving processes and strategies.

The positive effects of question prompts on scaffolding ill-structured problem solving have been confirmed by some recent studies (e.g., Ge and Land 2003; Ge, Chen, and Davis 2005; Ge, Planas, and Er 2010), particularly in problem representation, making justifications, developing solutions, and monitoring and evaluating problem solving. In addition, question prompts proved to be beneficial in developing learners’ metacognitive awareness and self-regulatory abilities. Students who were provided with question prompts used them as a checklist to monitor their problem solving processes, to confirm if they were on the right track, and to check their courses of action (Ge and Land 2003; Ge, Chen, and Davis 2005).

### **The Role of Social Support**

In this study, social support specifically refers to peer support and expert support. The literature supports the benefits of peer support in the form of peer interactions. The peer interaction process, including providing explanations to and receiving explanations from peers, engage students in deeper cognitive processing, such as clarifying thinking, reorganizing information, correcting misconceptions, and developing new understandings (see Webb and Palincsar 1996, for review). In addition, it makes an individual’s thinking visible and allows students to learn from multiple perspectives and solutions (Ge and Land 2003; Linn, Bell, and Hsi 1998). As noted by Zimmerman and Campillo (2003), peer interactions support self-regulation during problem solving.

The other social role is provided by a domain expert. Research on expert-novice comparison indicates that experts and novices demonstrate different patterns in problem solving (e.g., Anderson 2000; Bereiter and Scardamalia 1993; Bransford, Brown, and Cocking 2000; Dreyfus and Dreyfus 1986), hence the explicit modeling and mentoring by an expert is assumed to have positive effects in supporting self-regulation (Zimmerman and Campillo 2003). In a cognitive apprenticeship, the mentor makes his thinking visible to a novice through social dialogues when the two engage in the same problem-solving experience (Brown et al. 1989; Collins, Brown, and Newman 1989). Scaffolding is provided when the mentor provides modeling, coaching, and scaffolding (Jonassen, 1999) to a novice during ill-structured problem solving processes.

### **A Web-Based Cognitive Support System**

Based on the theoretical frameworks and assumptions discussed above, a database-driven, web-based cognitive support system was developed to scaffold complex, ill-structured problem solving processes through facilitating the development of metacognitive awareness and self-

regulatory skills (Ge and Er 2005; Ge, Planas, and Er 2010). The system is characterized by the question prompt mechanism (e.g., *procedural, elaborative, and reflective prompts*), supported with two additional mechanisms: peer review and expert view. In addition, the system consists of a digital library containing various cases indexed according to topic, domain, and level of difficulty, as well as a database used to save and store learners' responses which can be retrieved and displayed on the screen upon needs (see Ge, Chen, and Davis 2005; Ge et al. 2005; Kauffman, et al. 2008).

### **Case Library**

The database-driven case library is an important component of the system as those real-world cases serve as anchors (CTGV 1990), or enabling contexts (Hannafin, Land, and Oliver 1999), to engage students in an ill-structured problem-solving environment. The cases are indexed, grouped, and searchable with keywords, topics, and levels of difficulty. Each of the cases sets up a context for problem solving and challenges students to seek or generate a solution through manipulating problem space, articulating their reasoning to the problem solutions, and developing a cogent and valid argument to support their proposed solution(s). Therefore, the cases motivate students to set a learning goal and keep them focused. Perceiving the value and relevance of a task, students will attempt to regulate and control their value beliefs, which is an important self-regulation process (Pintrich, 2000).

### **Question Prompts**

Question prompts are generated based on an expert's mental model and processes in problem solving. They are designed to model and guide learners through complex, ill-structured problem solving processes by engaging learners in reflective thinking, monitoring and evaluation processes. These prompts can be categorized into a) procedural prompts, b) elaboration prompts, and c) reflective prompts, each of which serves different cognitive and metacognitive purposes.

Procedural prompts are a set of question prompts, which are designed to guide learners step by step through the entire processes of a specific problem-solving task (e.g., problem representation, developing solutions, constructing arguments, and monitoring and evaluation) while engaging learners in self-monitoring and self-regulation process. Procedural prompts serve as a problem-solving blueprint, directing students' attention to important aspects of problem solving and help them to monitor their problem solving processes.

Elaborative prompts (e.g., *What is the example of ...? Why is it important? How does it affect...?*) are designed to prompt students to articulate their thoughts and elicit their explanations (King 1991). This kind of prompts "force" them to elaborate their thinking and formulate

explanations. Elaboration prompts have been proved to direct students' attention to understanding *when, why* with college students in a science related content domain (Lin and Lehman 1999), thus enhancing learners' metacognitive awareness and fostering their self-monitoring and self-regulation processes.

Reflection prompts (e.g., *What is our plan? Have our goals changed? To do a good job on this project, we need to . . .*) are designed to encourage reflection on a meta-level that students do not generally consider (Davis and Linn, 2000). King (1991) found that reflective prompts encouraged student to engage in self-monitoring process during problem solving, such as planning, monitoring, and evaluation. Davis and Linn (2000) found that reflection prompts helped students to integrate knowledge in science.

### **Database**

Database allow students to retrieve their responses they have saved to be displayed on the web page for reviewing and examination, which assumingly help them generate solutions, construct arguments, and evaluate their solutions and strategies. Thus, database not only serves to store and retrieve data, but also makes students' thinking visible for self-reflection (Davis and Linn 2000) and help them to evaluate and revise their responses. Consequently, the database plays a role in facilitating students' self-monitoring and self-regulation. Additionally, the data can also be made available for peer evaluation in a collaborative problem-solving context or for comparing with an expert's problem solving approach.

### **Peer Review**

Upon submitting their own problem solving reports, the system allows a student to view his/her group members' solutions. The peer review mechanism was designed to enable students to see multiple perspectives from peers' solution reports and help them consider things they have not thought about previously. By reviewing their peers' thinking, students are compelled not only to attend more closely to their peers' but also their own ideas, rationales, plans and solutions for self-reflection. As a result, a student will want to revise their problem solving strategies or solutions or make proper adjustments. In addition, it also increases students' confidence when they get confirmation from peers' responses.

### **Expert View**

Expert modeling is provided by presenting students with an expert's solution to a complex problem. This support mechanism offers students an opportunity to observe an expert's reasoning and compare it with their own reasoning. It is assumed that the comparison will result in disequilibrium (Piaget 1985), which leads to self-regulation, mediated by reflection prompts that enable students to contemplate and articulate any gaps at a deeper

level. In addition, the visual display of an expert's problem-solving report appearing side by side with a student's solution report on the same screen further facilitates students' self-monitoring and self-reflection through identifying gaps between their thinking and an expert's thinking.

## Empirical Findings

### Advantages

The effect of the cognitive support system, particularly question prompts, have been studied in various content domains and on different target audience in the past years, including undergraduate students in information science and technology, education, and pharmacy as well as graduate students in instructional design (see Ge and Land 2003; Ge, Chen, and Davis 2005; Ge et al. 2005; Ge, Planas, and Er 2010; Kauffman et al. 2008). Both quantitative and qualitative studies have been used to investigate the effects of the cognitive support system on students' ill-structured problem solving performance. In all the research contexts, the participants were provided with real-world cases representing complex, ill-structured problems related to the domain of the target audience.

In the experimental studies (Ge and Land 2003; Ge et al. 2005; Ge, Planas, and Er 2010; Kauffman et al. 2008), the participants were assigned to either experimental or control group and were asked to complete a problem solving task in a web-based learning environment by generating solutions to the problem presented by the case, with or without scaffolds. In the qualitative studies or mixed studies, all the participants used the cognitive support system, and think-aloud protocols, observations and or follow-up interviews were conducted to study the effect of the system (Ge and Land 2003; Ge, Chen, and Davis 2005; Ge, Planas, and Er 2010). Specific requirements were provided, asking students to analyze the problem, develop solutions, making justifications, and evaluate their solution plan.

Overall, the results from a series of studies (quantitative, qualitative, and mixed) confirmed the positive effects of the cognitive support system, particularly the effect of various types of embedded question prompts on scaffolding problem solving processes in each of the problem solving processes (dependent variables): *problem representation*, *generating solutions*, *constructing argument*, and *monitoring and evaluating* (e.g., Ge and Land 2003; Ge et al. 2005; Ge, Planas, and Er 2010; Kauffman et al. 2008). Although some of the experimental studies did not directly measure self-monitoring and self-regulation skills during problem-solving processes, the qualitative data obtained from think-aloud protocols and observations revealed that learners' problem-solving performance was influenced by their execution of self-awareness, self-monitoring, and regulation skills mediated

by the scaffolds of question prompts (Ge and Land 2003; Ge, Chen and Davis 2005; Ge, Planas, and Er 2010).

In addition, some studies also measured some additional dependent variables or investigate the effect of additional independent variables. For example, in Ge and Land's (2003) study question prompts were compared with peer interactions (another independent variable). Kauffman et al. (2008) also investigated the quality of writing a problem solving report as a dependent variable, in addition to problem solving performance. The study found that the pre-service teachers who received procedural problem-solving prompts not only showed better problem solving performance, but also wrote with more clarity than the students who did not receive problem solving prompts. Furthermore, the study conducted by Ge, Planas, and Er (2010) indicated that simply engaging pharmacy students in revising their problem solving solution reports improved their performance over time. It suggested that providing learners an opportunity to evaluate and revise their solutions seemed to have offered them time and space to engage in self-reflection and self-regulation activities, which in turn benefited their problem solving experience.

The qualitative findings indicated that the expert view mechanism served as expert modeling and a standard for the pharmacy students to compare with their own problem-solving approaches and confirm whether they were on the right track or not (Ge, Planas, and Er 2010). This kind of comparison allowed the students to see where the discrepancies were, and thus helped them to reflect on what must be improved in the future. Most importantly, seeing how an expert solved an ill-structured problem increased the students' confidence in solving similar problems themselves. These findings showed how providing expert modeling may help students engage in self-regulation activities.

### Limitations

Despite the numerous advantages of the cognitive system as discussed above, the research also revealed the limitations of the system. For instance, Ge, Chen and Davis's (2005) study showed that question prompts could also be limited or impeding. In the absence of specific-domain knowledge question prompts were futile in activating a learner's prior knowledge or relevant schema. On the other hand, for students who perceived themselves as more competent and confident, question prompts not only seemed as redundant but also interfering with their thought flow during their problem solving processes (Ge, Chen, and Davis 2005).

In Ge et al.'s (2010) study, peer review mechanism did not show any advantage for the treatment group over the control group. This could be due to the fact that this experiment did not offer peers the opportunity to make comments or suggestions to each other, but only viewing each others' solutions. The feedback from this finding has

been incorporated to improve the system, and the current version of which allows peers to type notes, comments and suggestions.

Nevertheless, the content analysis in Ge et al's (2010) study showed that viewing peer responses did influence the quality of the students' revisions in the treatment group. In addition, the students in the treatment condition indicated that the peer review process allowed them to see multiple perspectives, different ideas, and different approaches. This finding indicated that peer review was useful, but it was insufficient. Peers must also be allowed by the system to provide feedback and make suggestions to each other in their social interactions.

## Implications

The empirical findings have led us to the effort of improving or enhancing the support mechanisms of the system in a number of ways. For example, a question-prompt generator has been generated to allow a user, such as an instructor or a subject matter expert, to create a protocol for modeling each of the problem-solving processes. This feature enables a user (e.g., a teacher or an expert) to input prompts for various problem scenarios and content domains. In addition, the findings also suggested several areas this system can be improved in the future, including (a) adaptively adjusting scaffolding level according to learners' prior knowledge and metacognition skills, as well as their progress over time based on the results of assessments, (b) enhancing the system with various feedback mechanisms, ranging from programmed feedback to dynamic feedback from teachers, experts, community members.

A comprehensive review of the works done in the past years has helped us to identify some gaps and challenges in the research of creating an adaptive cognitive support system to facilitate self-regulated processes and problem solving processes. One of the research goals that have not been fulfilled is to assess the transfer effects of self-regulatory and problem-solving skills at different points of an extended period of time as scaffolding is gradually withdrawn.

For future research, one of the challenges is the direct measurement of self-regulation skills. Although the empirical findings have confirmed that question prompts embedded in the cognitive support system scaffold problem solving processes, there have not been quantitative indicators to demonstrate the extent or level of self-regulation facilitated by question prompts, the influence of self-regulation on ill-structured problem solving outcomes, and the influence of problem solving skills on the development of self-regulation skills.

The second challenge is to examine ways to map self-regulatory processes with ill-structured problem-solving processes and generate an integrated conceptual

framework, which would illustrate (a) the interrelationships between self-regulated processes and ill-structured problem-solving processes, and (b) the intricate interactions among different areas for self-regulation (i.e., cognition, motivation, behavior, and context) (Pintrich, 2000) in supporting each of the ill-structured problem solving processes. This kind of conceptual framework will guide our instructional design in developing students' self-regulation and problem solving skills in ill-structured tasks.

The third challenge is the measurement of optimal amount/level of scaffolding needed for each individual learner based on his/her prior knowledge and metacognitive skills so that proper scaffolding can be provided accordingly within his/her zone of proximal development. It is expected that the findings of this research will inform instructional design regarding creating an adapted scaffolding system that would provide timely and proper amount of scaffolding when needed and withdraw scaffolding when it is not needed.

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