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Scaffolding self-regulated learning and metacognition – Implications for the design of computer-based scaffolds

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Scaffolding students' self-regulated learning and metacognition during learning with computer-based learning environments (CBLEs) has become a critical issue that has recently received a tremendous amount attention by researchers from several communities. Traditional CBLEs such as intelligent tutoring systems (ITSs) have repeatedly demonstrated their ability to effectively scaffold student's learning of well-structured tasks such as algebra, based on their ability to dynamically and systematically monitor, adapt, and scaffold a learner's individual learning (Derry & Lajoie, 1993; Anderson et al., 1995; Shute & Psotka, 1996; Koedinger, 2001; Aleven & Koedinger, 2002).

Recent technological advances and widespread use of open-ended learning environments such as hypermedia, hypertext, collaborative learning environments, and web-based learning environments challenge traditional conceptions of scaffolding posing significant theoretical, conceptual, methodological, educational, and design challenges (see Hogan & Pressley, 1997; Hannafin et al., 1999; Azevedo, 2003, in press; Pea, 2004; Reiser, 2004; Puntambekar & Hubscher, 2005; Graesser et al., in press; Quintana et al., in press; White & Frekeriksen, in press). The purpose of this introductory article is three-fold: (1) to present an overview of these several challenges to the issue of scaffolding self-regulated learning and metacognition (2) derive implications for the design of computer-based scaffolds, and (3) illustrate how each of the five research studies addresses each of these issues. The papers presented in this special issue were part of a session at the annual meeting of the American Educational Research Association held in 2004.

Importance of scaffolding metacognitive and self-regulated learning

Scaffolding is a critical component in facilitating students' learning (see Chi et al., 1994, 2001). Scaffolding involves providing assistance to students on an as-needed basis, fading the assistance as learner competence increases (Wood et al., 1976). Scaffolds are tools, strategies, and guides used by human and computer tutors, teachers, and animated pedagogical agents during learning to enable them to develop understandings beyond their immediate grasp (Graesser et al., 2000; Reiser, 2002).

Several studies have recently provided evidence that when students learn about complex topics with computer-based learning environments (CBLEs) in the absence of scaffolding they show poor ability to regulate their learning, and failure to gain a conceptual understanding of the topic (Hill & Hannafin, 1997; Greene & Land, 2000; Land & Greene, 2000; Azevedo & Cromley, 2004). As a result, researchers have recently begun to emphasize the importance of embedded *conceptual*, *metacognitive*, *procedural*, and *strategic* scaffolds in CBLEs (e.g., Vye et al., 1998; Hannafin et al., 1999; Azevedo, 2000, in press; Lajoie et al., 2000; White et al., 2000; Brush & Saye, 2001; Hadwin & Winne, 2001; Azevedo, 2002; Baylor, 2002; Puntambekar, 2003).

Despite the potential learning benefits of using scaffolds to enhance students' learning with CBLEs, their effectiveness is difficult to determine, since most of these environments include multiple forms of (e.g., Oliver & Hannafin, 2000). Research about the effectiveness of scaffolds in CBLEs is challenging to conduct because these environments use a variety of different scaffolding techniques delivered by a variety of agents (human, peer, computer) (e.g., Luckin & DuBoulay, 1999; Conati & VanLehn, 2000; Aleven & Koedinger, 2002; Baylor, 2002; Azevedo et al., 2004). Therefore, we posit the effectiveness and nature of adaptive scaffolding warrants further empirical examination to guide ways that scaffolds might be embedded in CBLEs.

This special issue presents and summarizes data from laboratory and classroom research about scaffolding self-regulated learning and metacognition in either face-to-face tutoring sessions or CBLEs. Each group was asked to explicitly address three questions: (1) What does research tell us about guiding and scaffolding metacognition and SRL? (2) How might this research guide the development of metacognitive tools to foster and sustain students' metacognitive processes and SRL? (3) What are the challenges we must face in designing adaptive scaffolds that can guide learners to develop and revise self-regulatory skills and processes?

General issues related to scaffolding self-regulated learning and metacognition

Widespread use of CBLEs in laboratory and classroom settings, and other multi-user distributed social settings designed to support students learning of conceptually-challenging topics has led researchers from several disciplines to question the theoretical, conceptual, methodological, educational, and design issues related to scaffolding (e.g., see Palincsar, 1998; Stone, 1998).

Discussions related to scaffolding students' learning needs should also account for developmental level. Considering and adapting support to fundamental and often subtle developmental changes in students' cognitive, metacognitive, motivational factors, is essential for increasing potential for students to benefit from scaffolding (Pintrich & Zusho, 2002). In this special issue, we have purposely included studies across developmental levels: middle-school, high-school, college, and post-graduate levels of education. A consistent thread across studies is a focus on students with low prior knowledge of the topic or domain under investigation. The studies presented in this special issue also vary regarding the length of the learning session or instructional session from 40-min laboratory experiments, to year-long studies. Juxtaposing studies that vary in terms of length and developmental level provides opportunities to explore variations in the role, function, and types of scaffolding used over time. A careful analysis of the learning context, the nature of the learning activity or learning task, and the role of the CBLE (which is a component of the learning context) in supporting students' learning also needs to be considered. It should be noted that these general scaffolding issues interact with one another thus complicating our understanding of the role of scaffolding metacognitive and self-regulatory process in fostering students' learning.

Specific issues related to scaffolding self-regulated learning and metacognition

Papers presented in this volume contrast each other in the ways they tackle five fundamental issues for understanding scaffolding in the context of self-regulated learning and metacognition: (a) What attributes of scaffolding are emphasized? (b) What kind of learning is supported through scaffolding? (c) What or who is the source of scaffolded support? (d) What kinds of scaffolds are effective? (e) How are scaffolding needs diagnosed (see Table 1), and (f) What are the future directions and challenges to be faced? We use each theme to introduce the studies comprising this volume.

What attributes of scaffolding are emphasized?

Scaffolding involves calibrated support for diagnosed learning targets. Four attributes associated with scaffolding include: diagnosis, calibrated support, fading, and individualization. Support can be in the form of pre-stocked questions static questions, dynamic support that is tailored to the student and context, or computer-based tools that guide students in their thinking, etc. The attributes of the scaffolds emphasized in the studies range from adaptive scaffolding based on on-going diagnosis, calibrated to the individual learner which may include some degree of fading (Azevedo et al. 2005; Hadwin et al. 2005) to having the student engage in self-diagnosis with no other form of individualized support or fading (e.g., Choi et al., 2005; Dabbaugh & Kitsantas 2005; Puntambekar & Stylianou 2005).

What kind of learning is supported through scaffolding?

This question relates to a fundamental issue regarding the exact *purpose* of the scaffold. Scaffolding may support a range of instructional targets including: (a) learning domain knowledge (e.g., concepts, procedures, etc), (b) learning about one's own learning (e.g., metacognition, self-regulated learning), (c) learning about using the computer-based learning environment (e.g., procedures, embedded tools, functionality, etc), and (d) learning how to adapt to a particular instructional context (e.g., engaging in adaptive help-seeking behavior, modifying contextual features to facilitate learning, etc.).

Within each of these instructional targets, scaffolding may support the development of declarative, procedural, conceptual, or metacognitive knowledge. Scaffolding examined in each study in this volume targets different types of learning. Hadwin and colleagues focused on scaffolded support to help graduate students develop and appropriate self-regulatory strategies and behavior. Analyses focused exclusively on the evolution of self-regulatory control as it transitions from instructor to graduate student regulation during year-long instructional meetings. In contrast, Azevedo and colleagues supported ado-

Table 1. Description and explanation of issues related to scaffolding self-regulated learning and metacognition in the studies featured in this volume

Scaffolding Issue	Azevedo at al study	Hadwin et al study	Puntambekar & Stylianou study	Choi et al study	Dabbagh & Kitsantas study
Attributes of scaffolding	Adaptive scaffolding (AS)	• diagnosis	• self-diagnosis	• self-individualized	• limit complexity of environment
	• ongoing diagnosis	• calibrated support	• no calibrated support	• self diagnosis	• graduallyremovelimits
	• calibrated to individual	• individualized support	• no individualized support	• on-line guidance for generating effective peer questions	• control from other to student
	• temporary fading	• fading	• no fading support		• provided protocols, models, rubrics, questions, etc.
	Fixed scaffolding (FS) guided questions calibrated to study session	Transition form teacher to student SRL			
Learning that is supported	Shift to sophisticated mental models of the circulatory system	Transition of self-regulatory control from instructor to graduate student during year-long project	Extraction of relevant science-related material to support design task	Generation and conditional knowledge of three different types of peer questioning strategies	Acquisition of metacognitive skills, strategic learning, and other SRL processes such as planning, monitoring, goal setting
	SRL behaviors (planning, monitoring, learning strategies...)				
What/who *scaffolds*?	Support by human tutor: versus fixed scaffolds	Support student-instructor dialogue (prompting, questioning, etc.)	Support by paper based metanavigational scaffold	Support by metacognitive scaffolds, peer feedback, instructor prompting	Support through web-based pedagogical tools (WBPT) and distance instructor

Table 1. Continued

Scaffolding Issue	Azevedo at al study	Hadwin et al study	Puntambekar & Stylianou study	Choi et al study	Dabbagh & Kitsantas study
Diagnosing when to scaffold?	Tutor diagnosed and individualized support	Instructor diagnosed and individualized scaffolding support	Self-diagnosis	Self-diagnosis	Scaffolds designed for the task
		Student self-diagnosed & requested support			Feedback on proposal diagnosed individual difficulties
Findings	Adaptive scaffolding more effective for moving students toward more sophisticated mental models, increasing declarative knowledge, & increasing frequency of some SRL strategies	Teachers withdraw and students increase their participation in instructional discourse over time	Students who received: metanavigation provided better explanations of the concepts they included in their maps and richer explanations of the connections they made among them	On-line guidance seems to affect the frequency of questions generated over time	Different WBPT support different self-regulatory strategies
		Over time there was a significant decrease in dialogue targeting task definition; increase in dialogue targeting strategy enactment, and goal-setting		Students generally generated significantly more clarification & elaboration questions	
				No significant differences between groups on the quality of their questions	

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Scaffolding Issue	Azevedo at al study	Hadwin et al study	Puntambekar & Stylianou study	Choi et al study	Dabbagh & Kitsantas study
Future directions & challenges	Technological challenges: (1) Dynamic adaptive hypermedia environments should tailor scaffolding to knowledge & SRL; (2) Adaptive hypermedia environments should diagnose, guide and evaluate planning, monitoring, strategy use	Technological challenges: (1) Pedagogical agents need to scaffold diagnosis, calibration, and fading; (2) Diagnosis & calibration should target the appropriate phase of SRL	Technological challenges:(1) Adaptive support within hypertext system should incorporate hierarchical priority of rules to inform decisions about the appropriate type of metanavigational support, (2) Rules should consider: when to encourage monitoring, how much explanation before prompts are given the readers, their prior knowledge and reading comprehension	Technological challenges: (1) Scaffolds in open-ended learning environments should be based on the role of the questioning process and prior knowledge, metacognition, and task complexity	Technological challenges: (1) Different computer based scaffolds support different aspects of SRL (fit the tool to the type of SRL support that is needed)

lescents' shift to more sophisticated mental models of the circulatory system by having a human tutor (external regulating agent) deploy several cognitive, metacognitive, and self-regulatory processes for the learner. Here the focus was on both domain knowledge and metacognitive processes. The other three studies examined some variation of supporting the acquisition of metacognitive skills, strategic learning, and other self-regulatory processes such as planning, monitoring, goal setting (Dabbagh & Kitsantas, 2005), supporting students' ability to generate different types of complex questions (i.e., clarification/elaboration, counter argument, and context-specific; Choi et al., 2005), and supporting students' metanavigational behavior to (Puntambekar & Stylianou, 2005).

What or who is the source of scaffolded support?

Learning support and scaffolding can be provided by the learner (e.g., through questioning), by the static prompts or templates in a CBLE, or by an external human or artificial agent in the learning and/or social context where the learning is taking place? This special issue tackles problems in designing pedagogical agents for scaffolding SRL and metacognition. However, we each tackle that question from different positions along a continuum from scaffolding learning through the use of static prompts and CBLE's to dynamically and adaptively scaffolding through a human agent.

Puntambekar & Stylianou presented students with written-based prompts designed to assist student navigational behavior during a design task. Similarly, Choi and colleagues' embedded static scaffolds designed to facilitate students' ability to refine their questions and responses to challenging questions Dabbagh and Kitsantas focused primarily on the effectiveness of support provided through web-based pedagogical tools (WBPT) with human instructor supports provided primarily in the form of individualized feedback on a project. In contrast, Azevedo and colleagues compared fixed scaffolds that were embedded in the CBLE to dynamic adaptive tutoring provided by a human regulating agent. Continuing along the same line Hadwin and colleagues examined changes in SRL during less formal human scaffolding throughout an extended year-long course project.

Diagnosing when to scaffold during learning

A central feature of scaffolding is that there is some form of diagnosis that aids in decisions about how to individualize scaffolding support for the learner, task, or context. Diagnosis highlights an important difference between original conception of scaffolding with more recent notions of the term. The studies in this volume can be contrasted with respect to: (a) who did the diagnosing, and (b) whether the diagnosis is focused on the individual learner, the task, or the studying context/tools. For example, Dabbagh & Kitsantas, Choi et al., and Puntambekar & Stylianou did not focus on calibrating instructional support to the individual, and did not use human agents to diagnose problem areas that might require remediation.

What is the mark of successful scaffolding and what kinds of scaffolds are effective?

The studies in this volume measured the effectiveness of scaffolding in multiple ways. For example, self-report measures of goal setting, task strategies, self-monitoring, self-evaluation, time planning and management, help seeking, usefulness for each web-based tool (Dabbagh & Kitsantas, 2005), shifts in students' conceptual understanding and declarative knowledge and the frequency of self-regulatory processes used during learning (Azevedo et al., 2005), transitioning of control from instructor to students over time during discourse about a complex task (Hadwin et al., 2005), frequency and quality of questions generated during learning and (Choi et al., 2005), and students explanations of the concepts included in their concept maps (Puntambekar and Stylianou, 2005). It is important to highlight that multiple data sources were used and converged in order to explain the effectiveness of scaffolding.

As a result of the varied approaches to researching scaffolding, papers in this volume also presented diverse findings. Azevedo et al. found that adaptive scaffolding was effective for moving students toward more sophisticated mental models, increasing declarative knowledge, & increasing frequency of some SRL strategies. Choi et al. found that on-line guidance seems to affect the frequency of questions students generate over time. Specifically, students generally generated significantly more clarification & elaboration questions although no significant differences were found between groups on the quality of their questions. Dabbaugh et al. found that different WBPTs support different self-regulatory strategies. And Hadwin et al. found that teachers withdraw and students increase their participation in self-regulatory discourse over time. Specifically, there was a significant decrease in dialogue targeting task definition; increase in dialogue targeting strategy enactment, and goal-setting. In Puntambekar and Stylianou's study, students who received metanavigation provided better explanations of the concepts they included in their maps and richer explanations of the connections they made among them.

What are the future directions and challenges to be faced in designing computer-based supports for scaffolding self-regulated learning and metacognition?

Individually and collectively these papers provide several directions for the design of computer-based scaffolds. Several technical challenges exist in developing dynamic adaptive computer-based scaffolds that dynamically modify scaffolding methods to knowledge and SRL sophistication. In this paragraph, we list some suggestions drawn from papers in this volume: (1) design specific computer based scaffolds to support different aspects of self-regulated learning (i.e., fit the tool to the type of SRL support that is needed); (2) target scaffolds in hypermedia environments to diagnose, support, evaluation planning, monitoring, and strategy use; (3) develop pedagogical agents to diagnose specific problems, calibrate support to the appropriate phase of SRL and the specific problem, and fade or adapt support as students self-regulate their own content learning; and, (4) build adaptive support based on some hierarchical priority of rules that inform the decisions of what type of metanavigational support should be given to students. The rules should take the following into consideration: when to encourage monitoring, how much explanation before prompts is given the readers, their prior knowledge and reading comprehension.

Design guidelines emerging from research presented in this volume pose important challenges for the future of pedagogical agents, and provide direction for both design and empirical examination of those agents.

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