*Tech., Inst., Cognition and Learning*, Vol. 3, pp. 97-104
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# Using Computers as MetaCognitive Tools to Foster Students' Self-Regulated Learning

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This article provides an overview of our research on self-regulated learning (SRL) and students learning about complex and challenging science topics with hypermedia. We provide an overview of our research goals, present several theoretical and methodological issues addressed by our research, and provide a synthesis of the major findings from our laboratory and classroom research.

*Keywords: Self-regulated learning, metacognition, computers, scaffolding.*

## PROBLEM/ISSUE BEING ADDRESSED

Computer-based learning environments (CBLEs) are effective to the extent that they can adapt to the needs of individual learners by systematically and dynamically providing scaffolding of key learning processes during learning (Anderson et al., 1995; Derry & Lajoie, 1993; Lajoie, 2000; Shute & Psotka, 1996). The ability of these environments to provide adaptive, individualized instruction is derived from an understanding of how learner characteristics, system features, and the mediating learning processes interact within particular contexts (Azevedo, 2002, 2005; Lajoie & Azevedo, in press). A critical aspect of providing

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individualized instruction is scaffolding, or instructional support in the form of guides, strategies, and tools which are used during learning to support a level of understanding that would be impossible to attain if students learned on their own (see Collins, Brown, Newman, 1989; Hannafin, Land, & Oliver, 1999; Jonassen & Land, 2000; Pea, 2004; Puntambekar & Hubscher, 2005; Quintana et al., 2004). Despite our ability to provide scaffolding for well-structured tasks within traditional CBLEs such as intelligent tutoring systems (ITS), providing adaptive scaffolding of students' learning about conceptually challenging domains, such as the circulatory system and ecology, remains a challenge for hypermedia instruction. We argue that harnessing the full power of hypermedia learning environments will require empirical research aimed at understanding *what* kinds of scaffolds are effective in facilitating self-regulated learning, and *when* they are best deployed. Our research therefore focuses on examining the effectiveness of different human scaffolding conditions in facilitating undergraduate, high school, and middle school students' learning about the circulatory system and ecology with hypermedia learning environments. The empirical results of our research are then used to inform the design of adaptive hypermedia learning environments.

## GOALS OF OUR RESEARCH

Adaptive scaffolding has been used successfully in non-hypermedia based learning environments designed to teach students about well-structured tasks such as math, geometry, and physics (e.g., Aleven & Koedinger, 2002). However, research on scaffolding with hypermedia learning environments is scant (see Dillon & Gabbard, 1998). The recent widespread use of open-ended learning environments such as hypermedia has outpaced our understanding of *how* learners can effectively learn within such environments and *how* scaffolds can be implemented in hypermedia environments in order to adapt to students' individual learning needs (Shapiro & Neiderhauser, 2004). While there are a few studies on fixed, embedded scaffolds in hypermedia, very little empirical research has been conducted on the effectiveness of adaptive scaffolding and how it may facilitate students' learning within hypermedia. It is critical that researchers conduct more empirical research in this area to determine how different adaptive scaffolding methods foster self-regulatory processes that facilitate students' learning of challenging topics. In general, our research examines what kinds of scaffolding make a difference, why, and under what conditions. In our research, we examine the effectiveness of self-regulated learning (SRL) and externally-regulated learning (ERL) in facilitating qualitative shifts in students' mental models (from pretest to posttest) and the use of self-regulatory processes associated with these shifts in conceptual understanding.

More specifically, the goals of our research are to conduct laboratory and classroom research which addresses the following questions:

1) Do different scaffolding conditions influence students' ability to shift to more sophisticated mental models of complex and challenging science topics (i.e., the circulatory system and ecology)?
2) Do different scaffolding conditions lead students to gain significantly more declarative knowledge of complex and challenging science topics?
3) How do different scaffolding conditions influence students' ability to regulate their learning of complex and challenging science topics with hypermedia?
4) What is the role of external regulating agents (i.e., human tutors, classroom teachers, and peers) in students' self-regulated learning of complex and challenging topics with hypermedia?

## MAIN RESULTS (THEORETICAL, METHODOLOGICAL, AND EMPIRICAL)

### Theoretical Advances

We have chosen contemporary frameworks and models of self- regulated learning (SRL) (see Pintrich, 2000; Winne, 2001; Zimmerman, 2000) to guide our research and to build our emerging model of how students use self-regulated learning to learn about complex topics with hypermedia. Our model has allowed us to examine the complex interplay between learner characteristics (e.g., prior knowledge, developmental level), elements of the hypermedia environment (e.g., non-linear structure of hypermedia), and mediating self-regulatory processes (e.g., planning, strategy use, monitoring activities) used by students during learning with hypermedia. Based on our model, we hypothesize that students learning with hypermedia need to analyze the learning situation, set meaningful learning goals, determine which strategies to use, assess whether the strategies are effective in meeting the learning goal, and evaluate their emerging understanding of the topic. Students also need to monitor their understanding and modify their plans, goals, strategies, and effort in relation to contextual conditions (e.g., cognitive, motivational, and task conditions). Further, depending on the learning task, students may need to reflect on the learning episode and modify their existing understanding of the topic. Thus, learning with hypermedia requires the student to adaptively regulate these activities to meet task demands. If learners do not regulate their learning, hypermedia environments may appear to be ineffective. One way to foster student self-regulation is through the use of various kinds of contextual aids, which may include access to static educational resources or a human tutor who provides adaptive scaffolding to foster students' self-regulated learning. In studying these contextual aids, it is critical that researchers not only examine what students do but also determine *how* students regulate their learning and how external regulating agents, such as human tutors, can facilitate students' self-regulated learning.

To address students' documented difficulties in regulating their own learning, we have extended our current model by examining the role of a human tutor as an external regulating agent. As such, any scaffold (human/non-human, static/dynamic) that is designed to guide or support students' learning with hypermedia is considered a part of the task conditions. The role of scaffolds that are part of the task conditions (and therefore external to the learner's cognitive system) need to be experimentally examined to determine their effectiveness in fostering self-regulated learning. In our studies, we hypothesize that human tutors can assist students in building their understanding of the topic by providing dynamic scaffolding during learning and assisting them in deploying specific self-regulatory skills (e.g., activating students' prior knowledge). In so doing, a human tutor can be seen as an external regulatory agent that monitors, evaluates, and provides feedback regarding a student's self-regulatory skills. This feedback may involve scaffolding students' learning by assisting them in planning their learning episode (e.g., creating sub-goals, activating prior knowledge), monitoring several activities during their learning (e.g., monitoring progress towards goals, facilitating recall of previously learned material), prompting effective strategies (e.g., hypothesizing, drawing, constructing their own representations of the topic), and facilitating the handling of task demands and difficulty. Empirically testing the effectiveness of self-regulated learning and externally-regulated learning can elucidate how these different scaffolding methods facilitate students' self-regulated learning and provide evidence that can be used to inform the design of hypermedia learning environments (see, for example, Azevedo & Cromley, 2004; Azevedo, Cromley, & Seibert, 2004; Azevedo, Cromley, Winters, Moos, & Greene, 2005; Azevedo, Guthrie, & Seibert, 2004; Azevedo, Moos, Winters, Greene, Cromley, Olson, & Godbole-Chaudhuri, 2005; Azevedo, Winters, & Moos, 2004; Cromley, Azevedo, & Olson, 2005; Greene & Azevedo, 2005).

**Methodological**

In our lab and classroom research, we use a mixed-methodology approach to combine *product* and *process* learning measures to examine students' self-regulated learning with hypermedia. For *product* data, we use mixed factorial designs, with students randomly assigned to one of several scaffolding conditions to examine qualitative shifts in students' conceptual understanding (i.e., mental models of the topic) and their gains on several measures of declarative knowledge from pretest to posttest. We also collect *process* data in our lab and classroom research by using think-aloud protocol methodology and classroom discourse analysis to examine the complex, dynamic nature of students' self-regulated learning and the influence of other external regulatory agents (i.e., human tutors, teachers, and peers) on students' learning with hypermedia.

**Empirical Results**

In general, our results show that students' learning about a challenging science topic with hypermedia can be facilitated if a human provides them with adaptive content and process scaffolding designed to regulate their learning. This type of sophisticated scaffolding is effective in facilitating students' learning as indicated by a) shifts in their mental models b) gains in declarative knowledge from pretest to posttest; and c) process data regarding students' self-regulatory behavior. In contrast, providing students with either fixed scaffolds (i.e., list of domain-specific sub-goals) or no scaffolding tends to lead to smaller shifts in students' mental models and smaller gains in declarative knowledge. Verbal protocols provide evidence that students in different scaffolding conditions differentially deploy key self-regulated learning processes, suggesting an association between these scaffolding conditions, mental model shifts and declarative knowledge gains. To date, we have researched 35 different regulatory processes whose use is related to such process and product data. These processes include those related to planning (including sub-goals, activating prior knowledge), monitoring activities (related to one's cognitive system and emerging understanding, hypermedia system and its content, and dynamics of the learning task), effective and ineffective learning strategies, and methods of handling task difficulties and demands.

## CONCLUSIONS

First, this line of research provides a valuable characterization of the complexity of self- and externally-regulated learning processes and the corresponding hierarchy of feedback loops during learning in laboratory studies and in learner-centered science classrooms.

Second, our findings provide the empirical basis for the design of technology-based learning environments as metacognitive tools to foster students' learning of conceptually challenging science topics (see Azevedo, 2005; Brusilovsky, 2001, 2004). However, these design decisions must also be based on the limitations and successes of current adaptive computer-based learning environments for well-structured tasks, current technological limitations in assessing learning of challenging and conceptually-rich, ill-structured topics in hypermedia learning environments, and instructional decisions regarding "*what, when,* and *how*" to model certain key self-regulated learning processes in hypermedia environments.

*Acknowledgments*

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The research described above is supported by funding from the National Science Foundation (Early Career Grant, REC#0133346), the University of Maryland's College of Education and School of Graduate Studies, the US Department of Education, and subcontracts from Vanderbilt University (based on a grant from the US Dept. of Education awarded to Dr. John Bransford) and Simon Fraser University (based on a grant from the Social Sciences and Humanities Research Council of Canada awarded to Dr. Philip Winne), awarded to the first author.

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