DOCUMENT RESUME

ED 477 465 TM 034 998

AUTHOR	Azevedo, Roger; Seibert, Diane; Guthrie, John T.; Cromley, Jennifer G.; Wang, Huei-yu; Tron, Myriam
TITLE	How Do Students Regulate their Learning of Complex Systems with Hypermedia?.
PUB DATE	2002-04-00
NOTE	36p.; Paper presented at the Annual Meeting of the American Educational Research Association (Chicago, IL, April 21-25, 2003).
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	EDRS Price MF01/PC02 Plus Postage.
DESCRIPTORS	*Hypermedia; Pretests Posttests; Protocol Analysis; *Training; *Undergraduate Students; Undergraduate Study
IDENTIFIERS	*Self Regulated Learning

ABSTRACT

This study examined the role of different goal-setting instructional interventions in facilitating students' shift to more sophisticated mental models of the circulatory system as indicated by both performance and process data. Researchers adopted the information processing model of self-regulated learning of P. Winne and colleagues (1998, 2001) and empirically tested the model by examining how students regulated their own learning when using a hypermedia environment to learn about the circulatory system. Undergraduate students (n=40) were randomly assigned to one of four goal-setting instructional conditions (co-regulation, strategy instruction, learner generated sub-goals, and bottom-up) and were trained to use a hypermedia environment. Pretest, posttest, transfer test, and verbal protocol data were collected using pretest-posttest comparison group design with a think-aloud methodology. Findings reveal that the co-regulation and strategy instruction conditions facilitated the shift in learners' mental models significantly more than the other conditions. Learners in the co-regulation condition benefitted by having the tutor co-regulate their learning by planning their goals, monitoring their emerging understanding, and providing scaffolding, using effective strategies, and providing motivational scaffolding. Learners in the strategy condition also made significant knowledge gains by regulated their learning differently since they did have the tutor to co-regulate their learning. Learners in the learner-generated subgoals and bottom-up conditions were less effective at regulating their learning and exhibited great variability in their ability to self-regulate their learning during the knowledge construction activity. Results provide a valuable initial characterization of self-regulated learning in a hypermdeia environment across several goal-setting instructional conditions. (Contains 4 tables and 40 references.) (Author/SLD)

How do students regulate their learning of complex systems with hypermedia?

Roger Azevedo, Diane Seibert, John T. Guthrie, Jennifer G. Cromley,

Huei-yu Wang, and Myriam Tron

University of Maryland, College Park

Please address all correspondence to:
Roger Azevedo, Ph.D.
University of Maryland
Department of Human Development
3304 Benjamin Building, 1117H
College Park, MD 20742
Tel: (301) 405-2799
Fax: (301) 405-2891
E-mail: ra109@umail.umd.edu

Paper presented at the annual conference of the

American Educational Research Association, New Orleans, LA (April 1-5, 2002).

Abstract

How do students regulate their learning of complex systems with hypermedia? This study examined the role of different goal-setting instructional interventions in facilitating students' shift to more sophisticated mental models of the circulatory system as indicated by both performance and process data. We adopted Winne and colleagues' (1998, 2001) information processing model of self-regulated learning and empirically tested their model by examining how students regulated their own learning when using a hypermedia environment to learn about the circulatory system. Undergraduate students ($N = 40$) were randomly assigned to one of four goal-setting instructional conditions (co-regulation, strategy instruction, learner-generated sub-goals, and bottom-up) and were trained to use a hypermedia environment to learn about the circulatory system. Pretest, posttest, transfer test, and verbal protocol data were collected using a pretest-posttest comparison group design with a think-aloud methodology. Findings revealed that the co-regulation and strategy instruction conditions facilitated the shift in learners' mental models significantly more than the other comparison conditions. Learners in the co-regulation condition benefited by having the tutor co-regulate their learning by planning their goals, monitoring their emerging understanding and providing scaffolding, using effective strategies, and providing motivational scaffolding. Learners in the strategy instruction condition also made significant knowledge gains but regulated their learning differently since they did not have the tutor to co-regulate their learning. Learners in the learner-generated sub-goals and bottom-up conditions were less effective at regulating their learning and exhibited great variability in their ability to self-regulate their learning during the knowledge construction activity. Our results provide a valuable initial characterization of self-regulated learning (SRL) in a hypermedia environment across several goal-setting instructional conditions.

Introduction

Understanding complex systems is a critical part of learning science and is necessary for solving real-world problems. However, complex systems have many characteristics that make them difficult to understand (Azevedo, Guthrie, Wang, & Mulhern, 2001; Azevedo, Verona, & Cromley, 2001; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001; Hmelo, Holton, & Kolodner, 2000). For example, in order to have a coherent understanding of the circulatory system, an intricate system of relations must be understood not only locally but system-wide as well (Chi, 2000; Chi, de Leeuw, Chiu, & Lavancher, 1994). Understanding system complexity is sometimes difficult because the properties of the system are not available for direct inspection and also because students must integrate multiple representations (e.g., text, diagrams, animations) to attain a fundamental conceptual understanding and use the representations to make inferences (Kozma, Chin, Russell, & Marx, 2000). Therefore, some researchers and educators have turned to hypermedia environments as a potential solution for enhancing students' understandings of complex systems.

This has led to an increased use of hypermedia environments for learning and teaching. There is, however, a continuing debate about the effectiveness of such technologies for learning. Several cognitive and educational researchers (Hartley, 2001; MacGregor, 1999; Mayer, Heiser, & Lonn, 2001; Narayanan & Hegarty, 1998; Shapiro, 1999, 2000) have recently begun to empirically test the effectiveness of hypermedia environments (e.g., animations of 140 sec duration) on students' learning. This research has begun to address several cognitive issues related to learning, including the role of basic cognitive structures (e.g., multi-modal STM stores), cognitive functions (e.g., mental animation), multiple representations (text, diagrams, video), navigation profiles, and system structure (e.g., linear vs. hierarchical) and features (e.g., advance organizers). These investigations employ a variety of methods and measures commonly used by educational and cognitive psychologists to measure learning, including reaction times, eye-tracking equipment, performance measures, and transfer tests.

There are several outstanding issues related to learning with hypermedia environments, which have not yet been addressed by psychologists and educational technologists, despite the plethora of research on learning with multimedia or hypermedia. Most importantly is the question of *how* (i.e., with what processes) does a learner regulate his/her learning with a hypermedia environment? Most of the research has used the *product(s)* of learning (i.e., learning gains based on pretest-posttest comparisons) to investigate the interplay between *learner characteristics* (e.g., low prior knowledge), *cognitive processes* (e.g., strategy use, metacognition), and *structure of the system* or the presence or absence of *system features*.

By contrast, little research has been conducted to understand the inter-relatedness and dynamics of SRL variables—cognitive, motivational/affective, behavioral, and contextual during the cyclical and iterative phases of planning, monitoring, control, and reflection during learning from hypermedia environments. The question of how students regulate their learning about complex systems during learning with hypermedia environments remains unanswered. Our study therefore examines how learners regulate their learning of the circulatory system by examining the shifts in mental models (from pretest to posttest) by examining the dynamics of SRL variables used during learning with hypermedia.

Theoretical Framework: Self-regulated Learning (SRL)

Self-regulated learning (SRL) is emerging as a significant paradigm in educational and psychological research (Boekaerts, Pintrich, & Zeidner, 2000; Paris & Paris, 2001; Zimmerman & Schunk, 2001). SRL 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 in the service of those goals. SRL is guided and constrained by both personal characteristics and the contextual features of the environment (Pintrich, 2000). The vast majority of SRL research has been in the area of academic learning and achievement. As such, very little research as been conducted by educational researchers on how students regulate their learning of complex systems (e.g., the circulatory system) when using a hypermedia environment.

Self-regulated learners are generally characterized as active learners who efficiently manage their own learning in many different ways (Winne, 1998; Winne & Perry, 2000; Schunk & Zimmerman, 1994). Self-regulated learning 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 (Pintrich, 2000). Models of self-regulation (e.g., Winne & Perry, 2000; Pintrich, 2000; Zimmerman, 2000) describe a recursive cycle of cognitive activities central to learning and knowledge construction activities (e.g., using a hypermedia environment to learn about the circulatory system). Most of these models propose four phases of self-regulated learning (Pintrich, 2000). The first phase includes planning and goal setting, activation of perceptions and knowledge of the task and context, and the self in relationship to the task. The second phase includes various monitoring processes that represent metacognitive awareness of different aspects of the self, task and context. Phase three involves efforts to control and regulate different aspects of the self, task, and context. Lastly, phase four represents various kinds of reactions and reflections on the self and the task and/or context. Our research on learners' SRL provides a critical but unexplored issue related using hypermedia environments for learning about complex scientific topics. Furthermore, there are several theoretical and methodological issues related to self-regulated learning that need to be addressed before we can effectively examine the how students regulate their learning during a knowledge construction activity of building sophisticated mental models of the circulatory system. Due to the complex nature of SRL, our research is aimed at experimentally manipulating the first phase of SRL—goal setting.

<u>The Role of Goals in Self-Regulated Learning</u>

Goal setting is an integral part of the forethought phase of self-regulation (Schunk, 2001;Winne, 1995, 1996, 2001; Zimmerman, 2000). Allowing students to set learning goals can enhance their commitment to attaining them, which is necessary in order for goals to affect performance. Goals play a major role in models of self-regulated learning (SRL) (see Boekaerts, Pintrich, & Zeidner, 2000; Paris & Paris, 2001; Zimmerman & Schunk, 2001; Zimmerman, 2002). Social cognitive theorists have found that self-set goals promote students' self-efficacy, proximal goals enhance achievement outcomes better than distant goals, and difficult goals enhance student motivation and achievement (see Schunk, 2001 for a review). Similarly, cognitive theorists (e.g., Winne, 2001) include goal setting and planning as critical stages during self-regulated learning. Goals allow a learner to dynamically and recursively engage in several other cognitive and motivational processes as he/she controls task resources (e.g., instructional cues, time allocation, social context), cognitive conditions (e.g., domain knowledge, knowledge of the task, and knowledge of learning strategies), and motivational conditions (e.g., self-efficacy, interest, task value).

Research on students' ability to use goal-setting to regulate their learning of science topics with hypermedia environments is still in its infancy. Azevedo, Guthrie, Seibert, and Wang (2001) recently examined the role of different goal-setting instructional interventions in facilitating students' shift to more sophisticated mental models of the circulatory system as indicated by both performance and process data. Azevedo et al. (2001) adopted Winne and colleagues' IPT model of self-regulated learning (Winne, 2001; Winne & Hadwin, 1998) and empirically tested the model by examining how students regulated their own learning when using a hypermedia environment to learn about the circulatory system. Twenty-four undergraduate students were randomly assigned to one of three goal-setting instructional conditions (learner-generated sub-goals, top-down, and bottom-up) and were trained to use a hypermedia environment to learn about the circulatory system. Pretest, posttest, transfer test, and verbal protocol data were collected using a pretest-posttest comparison group design with a think-aloud methodology. Findings revealed that the learner-generated sub-goals condition facilitated the shift in learners' mental models significantly more than did the other comparison conditions. Learners in the open-ended learner-generated sub-goals condition were also much better at regulating their learning during the knowledge construction activity. In general, they planned and monitored their learning more efficiently by creating sub-goals, activating prior knowledge, and engaging in self-questioning. They also used more effective learning strategies, were more effective in handling task difficulties and demands than comparison groups, and expressed interest in the topic. Their results provide a valuable initial characterization of SRL across several goal-setting instructional conditions during an individual knowledge construction activity.

We have also extended Winne and colleagues' IPT framework to examine the role of different goal-setting instructional interventions in facilitating high school students' regulation of their conceptual understanding of ecological systems with a Web-based water quality simulation environment (Azevedo, Ragan, Cromley, & Pritchett, 2002). Building on Winne and colleagues' information processing theory of SRL, we used their theory to examine 1) students' self-regulation, 2) co-regulation, and 3) the role of the teacher as an external regulator during a knowledge construction activity. Sixteen 11th and 12th grade high school students were randomly assigned to one of two goal-setting instructional conditions (teacher-set goals, TSG and learner-generated sub-goals, LGSG) and used RiverWeb[SM] collaboratively, during a three-week curriculum on water quality in an environmental science class. Students' emerging understanding was assessed using their pretest and posttest scores, and also assessed through an analysis of their discourse during several collaborative problem-solving episodes. The LGSG condition facilitated a shift in students' mental models significantly more than did the TSG condition. Students in the LGSG condition were also much better at regulating and co-regulating their learning during the knowledge construction activity than were TSG students. In general, they planned and monitored their learning more efficiently by creating sub-goals, activating prior knowledge, and engaging in adaptive help-seeking. They also used more effective learning strategies and were more effective in handling task difficulties and demands than was the TSG group. Our results provide a valuable initial characterization of the complexity of self- and co-regulated learning in a complex, dynamic technology-enhanced student-centered classroom. Our findings are critical in terms of expanding existing conceptualizations of SRL, co-regulation, and the role of teachers and peers as external regulating agents; and, how the results will be used to inform the design of new system features to *study* and *support* SRL and co-regulated learning.

Winne and colleagues' information processing model of self-regulation accounts for students' cyclical and recursive cycles of control and monitoring during the four phases of self-regulated learning—perceiving tasks, setting goals and plans, adopting tactics, and enacting tactics. SRL updates self-knowledge and perceptions of the task's changing states, thereby creating information that self-regulated learners can (if they so choose) use to select, adapt, or generate tactics and strategies over the course of the learning episode.

According to Winne and Hadwin (1998, 2001), self-regulating learners go through four cyclical and iterative phases. During the first phase the learner processes information about the conditions that characterize the task; that is, the learner constructs a perception that defines what the task is (Butler & Winne, 1995; Winne, 1997). Two main sources of information contribute to definitions of a task: the first is *task conditions* (information about the task that the learner interprets based on the task environment, such as a list of general teacher-set learning goals). The second source of information is *cognitive conditions,* information that the learner retrieves from LTM and the learner's estimation of prior knowledge, memory of anxiety about similar tasks, and attributions related to ability. Once information about these task and cognitive conditions is active in working memory, the student integrates it to construct an idiosyncratic definition of the task.

In phase two, the learner frames a goal and assembles a plan to approach it. According to Winne and colleagues (1998; 2001), goals have profiles of standards and each standard in a goal's profile is a value against which products can be monitored throughout the task. By cycling through phase two, goals can be updated as work on the task itself proceeds (in phase three). According to the model, once goals are active, learners then proceed to learn by using the COPES (conditions, operations, products, evaluations, and standards) script for the task.

In phase three, the learner applies the tactics and strategies identified in phase two. Search tactics copy information into WM from LTM that relate to the student's definition of the task. Each product created by carrying out a tactic or strategy has facets (similar to goals) that can be modeled in the same shape as the goal profile from phase 2. Monitoring compares the shape of the goal profiles and generates internal feedback. Phase four is optional; according to the model, the learner may decide to make major adaptations to the schemas that structure how self-regulated learning is carried out.

This model also postulates that metacognitive monitoring, metacognitive control, and feedback are key features of self-regulated learning which take place in all four phases (Butler & Winne, 1995; Winne 1996, 1997, 2001; Winne & Hadwin, 1998). Without cognitive evaluations about the differences between a) the current profile of work on a task and b) goals that specify standards for a satisfactory product, there is no guidance about how to regulate learning. Monitoring produces information—as a list of both matches and mismatches between the standards for a task, and mismatches between the standards for a task and a representation in WM of the product(s) of (a phase of) a task. Within the limits of cognitive resources and given particular external task conditions, the updates from each phase afford potential for the learner to exercise metacognitive control that adapts engagement in mid-task (Winne, 2001).

Overall, there is a limited amount of psychological research that addresses a) whether students regulate their use and generation of sub-goals across domains and b) the complexity of SRL between the learner and tutor in students' learning of complex science topics (e.g., circulatory system) using hypermedia environments. There is a need for more clarity with respect to the role of goals and goal-setting during knowledge construction activity from CBLEs which contain multiple representations (e.g., text, diagrams, animations). There is also a need for more detail with respect to how other sub-components of self-regulated learning (e.g., planning, monitoring, strategy use, handling of task difficulty and demands, and interest) are related to self-set goals and experimenter-set goals, and sub-goals during learning of complex science topic with a hypermedia environment.

Based on Winne and colleagues' (1998, 2001) model of SRL, we hypothesized that the questions we posed to participants would serve as a series of experimenter-set sub-goals that would scaffold and therefore facilitate students' understanding (from pretest to posttest). The questions would allow them to cognitively monitor their search of the environment and the answers to each question (i.e., products of information processing) and compare these to their standard (i.e., overall learning goal). This would allow them to generate feedback regarding any discrepancy between current understanding and the overall learning, and permit them to exercise cognitive control to reduce any discrepancies in learning.

In the *bottom-up condition (BU)*, the student answered questions that began with simple system components and then ended with system-wide relations. This condition was designed to examine whether starting with more specific domain-related questions would be more beneficial in facilitating students understanding of the domain. In the *learner-generated sub-goals* (LGSG) condition students were given the general learning goal and were allowed to set their own learning sub-goals while using the hypermedia environment to learn about the circulatory system. In the *strategy instruction (SI)* condition students were given a 30-minute training session on how to regulate their learning during the knowledge construction activity (on the use of planning, monitoring, strategy use, handling task difficulty and demands, and generating interest). In the *co-regulation (CO-REG)* condition students had access to a tutor who monitored their learning and co-regulated their learning of the circulatory system.

Research Questions

In this study, we investigated how four different goal-setting instructional interventions facilitate students' shift from less- to more sophisticated mental models of a complex system (i.e., the circulatory system). Three specific research questions are addressed in this paper. First, do different goal-setting conditions, embedded in four instructional interventions, influence students' shift to more sophisticated mental models of a scientific topic represented in a hypermedia environment? Second, which self-regulated learning variables influence students' ability to regulate and co-regulate their learning from hypermedia and lead them to shift to more sophisticated mental models of a scientific topic represented in a hypermedia environment? Third, what are the qualitative differences in students' self- and co-regulated learning in the four goal-setting conditions? We briefly discuss how the results of our study can be applied to inform the design of adaptive hypermedia environments aimed at detecting, tracing, modeling, and fostering learners' self-regulated learning of complex scientific topics (Azevedo, 2001).

Method

Participants

Participants consisted of 40 undergraduate students (29 women and 11 men) who received extra credit in their Educational Psychology course for their participation. Ages ranged from 20 to 30 years (M = 22 years). Sixty percent (n = 24) were seniors, 30% (n = 12) were juniors, and 10% (n = 4) were sophomores. The students were non-biology majors and had an average GPA of 3.2 (SD = 0.5). Most participants reported average or little knowledge of biology and the circulatory system.

Research Design

This study combined a pretest-posttest comparison group design (40 students randomly assigned to one of four goal-setting instructional conditions—co-regulation, strategy instruction, learner-generated sub-goals, and bottom-up) with a think-aloud protocol methodology (Afflerbach, 2000; Ericsson & Simon, 1993; Pressley & Afflerbach, 1995). Participants were asked to verbalize their thinking processes as they learned about the circulatory system using a hypermedia environment.

Measures

The paper-and-pencil materials consisted of a consent form, a participant questionnaire, a pretest, a posttest, and a transfer test. All of the paper-and-pencil materials, except for the consent form and questionnaire, were constructed in consultation with the second author, a nurse practitioner who is also a faculty member at a school of nursing in a large mid-Atlantic university. Prior to taking part, all participants signed a letter that stated the purpose of the study and gave their informed consent. The participant questionnaire solicited information concerning age, sex, current GPA, number and title of undergraduate biology courses completed, and experience with biology and the circulatory system. There were four parts to the pretest: (1) a sheet on which students were asked to match 16 words with their corresponding definitions related to the circulatory system, (2) a color picture of the heart on which students were asked to label 20 components, (3) an outline of the human body on which students were asked to draw the path of blood throughout the body (making sure that the path included the heart, lungs, brain, feet, and hands), and (4) another sheet which contained the instruction, *"Please write down everything you can about the circulatory system."* The posttest was identical to the pretest. The transfer test contained the following four questions, one at the top of each of three separate sheets of paper: (1) Mr. Jones had a heart attack which destroyed 50% of his left ventricular function; his left ventricle could only work at half capacity. Although his heart continued to beat normally, it was too weak to keep up with the large volume of blood it needed to pump. Describe what would happen to Mr. Jones over time. (2) Some snake bites can be dangerous because their venom causes muscle paralysis (muscles become immobile – can't move). How is it that a person can die in a short amount of time from such a snake bite, even when the bite is on the ankle? (3) It's well known that high blood pressure is dangerous. Is it dangerous to have low blood pressure too? Why? (4) Alcohol initially expands (dilates) the peripheral blood vessels (blood vessels in the arms and legs). As a result, the heart beats faster right after alcohol is consumed. How could the expansion of blood vessels lead to a faster heart rate?

Hypermedia Environment

During the experimental phase the participants used a hypermedia environment, installed on a 486 MHz laptop computer with an 11-inch color monitor and a sound card, to learn about the circulatory system and answer questions related to the circulatory system. We used Microsoft's Encarta Reference Suite ™ (2000) hypermedia environment, which includes Encarta's Encyclopedia Deluxe, Interactive Atlas, World English Dictionary, and Research Organizer. For this study, participants were limited to using the encyclopedia portion of the package. This contains five main sections: 1) introduction to the circulatory system, 2) components of the circulatory system, 3) operations and function (systemic circulation, pulmonary circulation, additional functions, and blood pressure), 4) disorders of the circulatory system, and 5) the circulatory system in non-humans. It also included multiple representations of information—text, static diagrams, photographs, and a digitized animation depicting the functioning of the circulatory system.

Tutor and Learner Scripts for the Co-Regulation and Strategy Instruction Conditions.

Two conditions involved developing scripts for the tutor (CO-REG and SI). Prior to the experiment, the experimenters and the nurse practitioner designed a tutor script for the co-regulation condition. Using the script, the tutor assisted the student with co-regulating his or her learning via the tutor's monitoring and facilitating the student's emerging understanding, thereby by assisting the student with the different phases (planning, monitoring, controlling, and reflection) and areas (cognition, motivation, self, and context) of SRL. The tutor received extensive training on the Winne and Hadwin (1998, 2001) model of SRL, and was familiar with our previous research findings (Azevedo et al., 2001). In addition, we designed a 4-page script for the learners assigned to this condition which contained 1) a copy of Pintrich's (2000, p. 454) table of the phases and areas of SRL, 2) a 1-page diagram illustrating the experimental session, and 3) a 2-page table with a list of SRL variables (with corresponding descriptions and examples) which we have found that self-regulated learners enact when using a hypermedia environment to learn about the circulatory system (based on Azevedo et al., 2001). The SRL variables included planning (planning, sub-goals, prior knowledge activation), monitoring (feeling of knowing, judgment of learning, self-questioning, content evaluation, identifying the adequacy of information), strategies (selecting new informational source, summarization, re-reading, and knowledge elaboration), task difficulty and demands (time and effort planning, task difficulty, and control of context), and interest. The same 4-page script was used for students assigned to the strategy instruction condition.

<u>Procedure</u>

The participants were randomly assigned to one of four groups: co-regulation (n =10), strategy instruction (n = 10), learner-generated sub-goals (n = 10), and bottom-up (n = 10). The first author tested participants individually. First, the participant questionnaire was handed out, and participants were given as much time as they wanted to complete it. Second, the pretest was handed out, and participants were given 30 minutes to complete it. Participants wrote the answers on the pretest and did not have access to any instructional materials. Third, the experimenter provided instructions for the learning task. The instructions were slightly different for each of the experimental conditions. The following instructions were read and presented to the participants in writing.

<u>Bottom-Up (BU) Condition</u>. For the BU condition the instructions were: "*You are being presented with a hypermedia encyclopedia, which contains textual information, static diagrams, and digitized video clips of the circulatory system. We are trying to learn more about how students read, search, and learn from hypermedia environments, as well as what role do multiple representations play in learning about the circulatory system. Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body. Your task is to answer 10 questions about the circulatory system, which you will answer by searching the hypermedia environment. In order for us to assess what representations are informative for you to learn about the circulatory system, we ask you to 'think aloud' continuously while you read and search the encyclopedia. Say everything you are thinking. Tell me what you're doing and why you're doing it. I'll be here in case anything goes wrong with the computer and the equipment. Please remember that it is very important to say everything that you are thinking while you are working on this task*".

<u>Learner-Generated Sub-Goals (LGSG) Condition</u>. The instructions for the LGSG condition were identical except that participants were told that, instead of answering 10 questions about the circulatory system, "*Your task is to learn all you can about the circulatory system in 45 minutes*"

<u>Strategy Instruction (SI) Condition</u>. Learners in the SI condition went over their script (previously described) with the experimenter for approximately 30 minutes. For the strategy instruction condition, the instructions were identical to those for the LGSG condition except that the experimenter would stop them every ten minutes and ask them about their regulation of the different phases and areas of learning, and whether they were going to make any modifications to

their goal(s) (e.g., monitor their progress towards the overall learning goal, decide whether to set new sub-goals to attain the overall learning goal).

Co-Regulation (CO-REG) Condition. In the CO-REG condition, learners and the nurse practitioner went over the script (previously described) with the experimenter. For the co-regulation condition the instructions, were identical to the strategy instruction, except that instead of the experimenter interrupting them regularly, the tutor would assist them in regulating their learning by using various strategies, scaffolding their learning, and intervening when they asked for assistance, throughout the 45 minute session (e.g., help them plan sub-goals, monitor their cognitive processes, provide feedback, make them draw external representations) (see Table 3 for a complete list).

Following the instructions, a practice task was administered to encourage all participants to give extensive self-reports on what they were inspecting and reading in the hypermedia environment and what they were thinking about as they worked. The experimenter reminded participants to keep verbalizing when they were silent for more then three seconds (e.g., "say what you are thinking"). All participants were reminded of the global learning goal (*"Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body"*) as part of their instructions for learning about the circulatory system. Participants in all conditions were given 45 minutes to use the hypermedia environments to learn about the circulatory system.

Participants in the BU condition were asked 10 questions. These questions were designed to serve as 10 domain-related, experimenter-set goals that, cumulatively, would allow the students to reach the most sophisticated mental model of the circulatory system (i.e., model 12—double loop advanced). A list of these questions is presented in Table 1. For example, the first question was, "Describe the function of each type of cell found in blood?" and the last one was "Why does the body require a cardiovascular system?" When participants had completed their search of the hypermedia environment for each question the experimenter asked, "What is your answer?" Their verbal answers were recorded on video- and audio tape for subsequent analysis.

Insert Table 1 about here

All participants were given the posttest followed by the transfer test either after the 45 minutes (for the CO-REG, SI, and LGSG conditions) or after answering all of the questions about the circulatory system (for the BU condition). All participants completed the posttest and transfer test individually by writing their answers on the sheets provided by the experimenter; they did not have access to any instructional materials, including their notes and drawings, or the hypermedia environment. They were given 30 minutes to complete the posttest and 10 minutes to complete the transfer test.

Data Analysis

In this section we describe the coding of the students' mental models, the quality rating of the students' answers to the circulatory system questions, the students' answers for the matching task and labeling of the heart diagram, the segmentation of the students' verbalizations captured while they were either learning or answering questions about the circulatory system, the coding scheme we developed and used to analyze the students' self-regulatory behavior and co-regulated learning between the student and the tutor, and inter-rater reliability measures.

Coding the Students' Mental Models. Our analyses focused on the participants' shifts in mental models based on the different goal-setting instructional interventions. A mental model is an internal mental representation of some domain or situation that supports understanding, problem solving, reasoning, and prediction in knowledge-rich domains (Gentner & Stevens, 1983; Markman & Gentner, 2001). The mental models approach has been used extensively to explain reasoning about a number of domains including circulatory system (Azevedo et al., 2001, 2002; Chi, 2000; Chi et al., 1994, 2001), physical systems and mechanisms (Hegarty & Just, 1993; Narayanan & Hegarty, 1998), electrical circuits (White, Shimoda, & Frederiksen, 2000), human-computer interaction (Norman, 1988), development of astronomical knowledge (Vosniadou & Brewer, 1992), and the nature of matter (Hogan, 1999).

In order to have a coherent understanding of the circulatory system, an intricate system of relations must be understood not only locally, but also system-wide as well. The relations include within-a-component, between-component, and hierarchical relations, as well as processes such as oxygenation and the interaction between the systemic and pulmonary systems which involve relationships among several components. Our initial approach (Azevedo et al., 2001, 2002) was based on Chi and colleagues' research (Chi, 2000; Chi et al., 1994) which we subsequently extended, with the assistance of a nurse practitioner to include the knowledge presented in the hypermedia environment and the students' performance on the pre- and posttests.

One goal of our research was to capture the initial and final mental model that each participant had of the circulatory system. This analysis depicted the status of each student's mental model prior to and after learning, as an indication of representational change that occurred with deep understanding. In our case, the status of the mental model refers to the correctness and completeness in regard to the local features of each component, the relationships between among the local features of each component, and the relationships among the local features of different components.

We followed Chi and colleagues' (1994) method in order to analyze the participants' mental models. In brief, a student's initial mental model of how the circulatory system works was derived from their statements from the section on the pretest which asked them to "*Please write down everything you can about the circulatory system*" as well as the student's drawing of the path of blood throughout the body. Similarly, a student's final mental model of how the circulatory system works was derived from their statements from the section on the posttest which asked them to "*Please write down everything you can about the circulatory system*" and their drawing of the path of blood throughout the body. In addition, we expanded Chi's original (1994; 2000) six general types of mental models and strategically embedded six more, resulting in 12 models which represent the progression from no model to the most accurate: (1) no understanding, (2) basic global concepts, (3) basic global concepts with purpose, (4) basic single loop model, (5) single loop with purpose, (6) advanced single loop model, (7) single loop model with lungs, (8) advanced single loop model with lungs, (9) double loop concept, (10) basic double loop model, (11) detailed double loop model, and (12) advanced double loop model. A complete description of the necessary features for each mental model is provided in Table 2.

Insert Table 2 about here

Scoring the Students' Answers on the Matching Task and Labeling of the Heart Diagram. We scored the matching task by giving each student either a 1 (for a correct match between a concept and its corresponding definition) or a 0 (for an incorrect match between a concept and definition) on his/her pretest and posttest. Similarly, we scored the heart diagram by giving each student either a 1 (for each correctly labeled component of the heart) or a 0 (for each incorrect label). The scores for each student's pretest and posttest on the matching task and heart diagram were tabulated separately and used in subsequent analyses.

Quality Rating of Students' Answers to the Questions. For the BU condition, we recorded and rated the *answer* for each of the 10 questions; answers consisted of the subjects attempting to verbally answer the question when the experimenter asked, "What is your answer to this question?" We also rated each participant's answer to the four transfer questions. The answers to the questions were initially coded by the nurse practitioner on a scale of 0 (none), 1 (very basic), 2 (basic), 3 (adequate), 4 (comprehensive), and 5 (very comprehensive). The answers that received a rating of 5 were thorough, complete, well formulated, accurate, and coherent without extraneous information. The answers that received a rating of 4 were thorough, complete, well formulated, accurate, and coherent but had extraneous information. The answers that received a rating of 3 were correct but less complete, poorly elaborated, or vague. The answers that received a rating of 2 were basic and oversimplified. Answers that received a rating of 1 were inaccurate, and oversimplified; blank answers were given a score of zero.

Segmenting and Coding Students' Verbalizations. The raw data collected from this study consisted of 1610 minutes (27 hr) of audio and video tape recordings from the 40 participants, who gave extensive verbalizations while they learned about the circulatory system. During the first phase of data analysis, a graduate student transcribed the audio tapes and created a text file for each participant. This phase of the data analysis yielded a corpus of 693 single-spaced pages ($M = 17$ pages per participant) with a total of 196,959 words ($M = 4924$ words per participant).

During the second phase of data analysis, a second graduate student verified the accuracy of the transcriptions by comparing each text file with the video tape recording of the participant. The original text file was updated. This process is critical in order for the experimenter to later coordinate verbalizations with the types of information the participant used to answer each question.

In the third phase of data analysis, the second graduate student segmented the transcripts and recorded when each participant did the following: (1) switched topics or sections in the hypermedia environment (e.g., switched from Introduction to the Circulatory System to Systemic Circulation); (2) scrolled up or down the same screen, topic or section, and whether or not there were multiple representations of information sources (e.g., from a section with text and diagrams to the same section without diagrams); and, (3) switched from one information source to another or attempted to coordinate multiple representations of information sources. We noted from the video tape recording the time elapsed during each of these three activities as well as the total time per experimental condition and, time required to answer each question in the BU condition. This phase of the data analysis yielded 5102 segments ($M = 127.5$ per participant), based on the original 693 pages. This segmentation was subsequently used to code the students' self-regulatory behavior.

Coding Learners' Self-Regulatory Behavior and Co-Regulatory Behavior Between Learner and Tutor. We extended our existing coding scheme (Azevedo et al., 2001, under review) for analyzing participants' self-regulatory behavior based on several recent models of self-regulation (Hadwin et al., 2001; Pintrich, 2000; Winne, 1995; 1997; 2001; Winne & Hadwin, 1998; Winne & Perry, 2000; Zimmerman, 1989; 2000; 2001). More specifically, we adopted the key elements of these models (i.e., Winne's [2001] and Pintrich's [2000] formulation of self-regulation as a four-phase process) and extended these key elements to capture the major phases of self-regulation. These are: (1) planning and goal setting, activation of perceptions and knowledge of the task and context, and the self in relationship to the task; (2) monitoring processes that represent metacognitive awareness of different aspects of the self, task, and context; (3) efforts to control and regulate different aspects of the self, task, and context; and, (4) various kinds of reactions and reflections on the self and the task and/or context. Subsequently, we elaborated on these four major phases by both including variables presented in several models (e.g., goals, plans, judgement of learning; Hadwin et al., 2001; Pintrich, 2000; Winne, 2001; Winne & Hadwin, 1998; Winne & Perry, 2000; Zimmerman, 2000) and constructing new variables (e.g., selecting a new informational source). The latter were derived from both students' self-regulatory behavior and co-regulated behavior between the learner and tutor (e.g., tutor-initiated instructional methods and varying levels of scaffolding designed to enhance students understanding) while learning with a hypermedia environment.

The classes, descriptions and examples of the planning, monitoring, strategy use, task difficulty and demands, and interest variables used for coding the learners' and tutors' self-regulatory behavior are presented in Table 3. Each code can be applied to the learner, to tutor direct instruction, or to tutor scaffolding of that variable. The following is a brief description with examples from the protocols of the coding scheme, which is grouped into five categories: planning, monitoring, strategy use, handling task difficulty and demands, and interest.

The first category is classified as *Planning* and is comprised of four variables. *Planning* involves coordinating the selection of operators. Its execution involves making behavior conditional on the state of the problem and a hierarchy of goals and sub-goals. For example, "First I'll look around to see the structure of environment and then I'll go to specific sections of the circulatory system." *Goals* consist either of operations that are possible, postponed, or intended, or of states that are expected to be obtained. Goals can be identified because they have no reference to already-existing states. For example, "I'm looking for something that's going to discuss how things move through the system." *Prior Knowledge Activation* was coded when searching memory for relevant prior knowledge either before performing a task or during task performance. For example, "It's hard for me to understand, but I vaguely remember learning about the role of blood in high school." *Recycle Goal in Working Memory* was coded when the learner restates the goal (e.g., question or parts of a question) in working memory (WM). For example, "...describe the location and function of the major valves in the heart."

Insert Table 3 about here

The second category is classified as *Monitoring* and is comprised of six variables. *Judgement of Learning* (JOL) was coded when becoming aware that the learner does not know or understand everything that was read. For example, "I don't know this stuff, it's difficult for me." *Feeling of Knowing* (FOK) was coded when there is awareness of the learner having read something in the past and having some understanding of it, but not being able to recall it on demand. For example, "... let me read this again since I'm starting to get it..." *Self-Questioning* was coded when a learner asks him/herself a question and then re-reads to improve his/her understanding of the content. For example, when the learner spends time reading text and then states "what do I know from this?" and reviews the same content. *Content Evaluation* was coded for monitoring content relative to goals. For example, "I'm reading through the info but it's not specific enough for what I'm looking for." *Identify Adequacy of Information* was coded for assessing the usefulness and/or adequacy of the content being read, watched, etc. For example, "...structures of the heart...here we go..." *Monitoring Progress Towards Goals* was coded for periodic assessments of whether the student had learned enough to meet a learning goal. For example, "Are we getting to some of these questions that they asked?"

The third category is classified as *Strategy Use* and is comprised of seventeen variables based on the participant's selection and use of various cognitive strategies for memory, learning, reasoning, problem solving, and thinking. *Selecting a New Informational Source* may include selecting a new representation, coordinating multiple representations, etc. For example, a learner reads about the location of valves in the heart and then switches to watching the video to see their location. *Coordinating Informational Sources* included coordinating multiple representations. For example, "I'm going to put that [text] with the diagram." *Read New Paragraph* involves selecting a different section of text in order to understand. For example, "Read . . .the first couple of sentences in each one of the paragraphs." *Free Search* was coded when the learner searches hypermedia environment without specifying a specific plan or goal. For example, "I'm going to the top of the page to see what is there." *Goal-Directed Search* was coded when the learner searches hypermedia environment with reference to a specific plan or goal. For example, "Try writing electrical." *Summarization* was coded for summarizing what was just read, inspected, or heard in the hypermedia environment. For example, "this says that white blood cells are involved in destroying foreign bodies." *Taking Notes* was coded when copying text from the hypermedia environment. For example, "I'm going to write that under heart." *Reviewing Notes* was coded when the learner reviewed notes he or she had taken. For example, "Carry blood away. Arteries—away." *Memorization* was coded when learners stated that they were going to memorize something in the hypermedia environment. For example, "I'm going to try to memorize this picture." *Mnemonic* included verbal mnemonics for remembering information from the environment. For example, "Superior because it's up on top." *Drawing* included any kind of diagram made by learners. For example, "...I'm trying to imitate the diagram as best as possible" *Re-reading* was coded when the learner re-reads or revisits a section of the hypermedia environment. For example, "let me read this again." An *inference* was coded when the learner makes inferences based what he/she read, saw or heard in the hypermedia environment. For example, the learner inspects a diagram of the heart and states "so the blood....through the ...and then goes from the atrium to the ventricle...and then...." *Hypothesizing* was coded when the learner asks questions that go beyond what they have read, seen or heard. For example, "I wonder why just having smooth walls in the vessels prevent blood clots from forming...I wish they explained that...." *Knowledge Elaboration* was coded when a learner elaborates what he/she has just read, seen, or heard with prior knowledge. For example, after inspecting a picture of the major valves of the heart the learner states "so that's how the systemic and pulmonary systems work together." *Evaluate Content as Answer to Question* was coded when the learner suggests that what he/she has just read or seen is the answer to a question. For example, the learner reads text and then states... "So, I think that's the answer to this question." *Find Location in Environment* was coded when the learner returns to the environment after a discussion and has to find where he/she had been reading. For example, "We were down here somewhere"

The fourth category is classified as *Task Difficulty and Demands* and is comprised of five variables. *Time and Effort Planning* was coded when attempting to intentionally control behavior. For example, "I'm skipping over that section since 45 minutes is too short to get into all the details." *Help-Seeking Behavior* was coded when a learner seeks assistance from the tutor or experimenter regarding either the adequacy of their answer or their instructional behavior. For example, "... do you want me to give you a more detailed answer?" *Task Difficulty* was coded for statements related to any of the following: (1) the task is either easy or difficult, (2) the questions are either simple or difficult, and/or (3) using the hypermedia environment is more difficult than using a book. For example, "this is harder than reading a book." *Control of Context* was coded when using the features of the hypermedia environment to enhance the reading and viewing of information. For example, a learner double-clicks on the heart diagram to get a close-up of the structures. *Expectation of Adequacy of Information* was coded when there is the expectation that a certain type of representation will prove adequate given the current goal. For example, "...the video will probably give me the info I need to answer this question."

The fifth category is classified as *Motivation* and is comprised of six variables. *Interest Statement* was coded when the learner indicated a certain level of interest in the task or in the content domain of the task. For example, "interesting", "this stuff is interesting", and "I used to have high cholesterol." *Positive Feedback* was coded when the tutor told the learner his or her statement was correct, or repeated the learner's correct statement. For example, "Uh huh." *Negative Feedback* was coded when the tutor told the learner his or her statement was incorrect. For example, "No." *OK* was coded for ambiguous feedback after a correct or incorrect statement from the learner. *Encouragement* was coded when the tutor made an encouraging statement to learner. For example, "That will become clearer as we go on." *Choice* was coded when the tutor offered the learner a choice of next steps. For example, "What do you want to do first?"

We used our SRL model to re-segment the 5,102 segments (from the previous data analysis phase). This phase of the data analysis yielded 5,102 segments (M = 127.6 per participant) with corresponding SRL variables, based on our model.

Inter-Rater Reliability Measures. Inter-rater reliability was established by recruiting and training a graduate student to use the description of the mental models (see Table 2). She was instructed to independently code all 80 selected protocols (pre- and posttest descriptions of the circulatory system from each participant) using the 12 mental models of the circulatory system previously described and presented in Table 2. There was agreement on 72 out of a total of 80 student descriptions yielding a reliability coefficient of .90. Similarly, the inter-rater reliability was established for the coding of the learners' self-regulated behavior by comparing the individual coding of the same graduate student, who was trained to use the coding scheme (see Table 3). She was instructed to independently code 1,530 randomly selected protocol segments (30% of the 5,102 coded segments with corresponding SRL variables), with that of one of the experimenters. There was agreement on 1,347 out of 1,530 segments yielding a reliability coefficient of .88. Inconsistencies were resolved through discussion between the experimenters and the student.

Results

The data analyzed in this study consisted of outcome measures from pretests and posttests, together with the verbal protocols collected during learning with the hypermedia environment from each of 40 participants. It also included the quality of ratings for the answers to the transfer questions. We used the outcome measures to analyze a) the shift in the sophistication of learners' mental models, b) the number of correctly matched concepts and definition related to the circulatory system, and c) the number of components of the heart that participants labeled. We report on the quality ratings of learners' answers to the transfer questions. We also calculated the time learners spent on each type of representation (text, text and diagram, video, and externally constructed representation). We calculated the proportion of SRL variables used by learners in each instructional condition (and tutor in the CO-REG condition) from the verbal protocols. We also provide a qualitative description of how a "typical" learner in each of the four conditions would regulate (and co-regulate) their learning of the circulatory system, based on the verbal protocols. Analyses are reported that address the guiding questions.

Question 1: Do different goal-setting conditions influence students' ability to shift to a more sophisticated mental model of the circulatory system? Across groups, 88% of all learners formed more sophisticated mental models of the circulatory system as a result of the four goal-setting conditions. All the students in the CO-REG and SI conditions developed (from pretest to posttest) more sophisticated mental models than those in the LGSG and BU (100% and 100% versus 70% and 80%, respectively).

We used a 4 (condition: CO-REG, SI, LGSG, BU) X 2 (time: pretest, posttest) mixed design to analyze the shift in learners' mental models between pretest and posttest. The first factor, Goal-Setting Instructional Condition, was a between-groups; the second factor, Time, was a within-subjects measure. The number of participants in each cell is 10 for all analyses. A 4 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, $F(1, 36) = 67.78$, $MSE = 308.1$, $p < .05$, and a significant interaction between condition and time, $F(3, 36) = 4.16$, $MSE = 56.7$, $p < .05$. The simple main effect analysis showed no significant differences between the conditions at pretest, but there were significant differences at posttest ($F[1,36] = 3.10$, $p < .05$). The BU and LGSG learners' mental models did not improve (from pretest to posttest), but there was significant shift for the CO-REG ($F(1, 36) = 12.55$, $p < .05$) and SI ($F(1, 36) = 11.98$, $p < .05$) goal-setting instructional conditions.

The results indicate that the CO-REG condition led to the highest mean "jump," or improvement, in students' mental models (e.g., participant S14 "jumped" from a model 2 on the pretest to a model 12 on the posttest). On average, students in the CO-REG condition "jumped" 6.1 mental models ($SD = 2.9$) from pretest to posttest, followed by learners in the SI condition, who jumped an average of 5 mental models ($SD = 2.7$). In contrast, students in the LGSG and BU conditions jumped considerably less ($M = 2.6$, $SD = 4.2$ and $M = 2.0$, $SD = 3.6$, respectively). The LGSG condition led to a higher percentage of students with no change in mental models (20%) when compared to the BU, CO-REG, and SI conditions (10%, 0%, and 0%, respectively). In contrast, 10% of the students in both the LGSG and BU conditions shifted their mental models in a negative direction, whereas none of students assigned to the CO-REG or SI condition decreased their mental model from pretest to posttest. This shift in a "negative" direction was observed in two students; one shifted from a somewhat rudimentary initial mental model to a less-than-rudimentary mental model (i.e., 8—6), and one shifted from a sophisticated mental model to a less sophisticated mental model (i.e., 11—7).

Quantitative statistical analyses on the matching task, labeling task, transfer questions, and use of informational sources during the knowledge construction activity will be presented at the conference.

We conclude that both the CO-REG and SI conditions facilitated the shift in learners' mental models significantly more than did the comparison conditions. Another purpose of our research was to examine how learners in different goal-setting conditions regulate their learning of a complex biological system during a knowledge construction task. Therefore, we now report the processing involved in the learners' shifts in mental models from pretest to posttest.

Question 2: How Do Goal-Setting Conditions Influence Students' Ability to Regulate Their Learning from Hypermedia? In this section we present the results of five chi-square analyses that were performed to determine whether there were significant differences in the distribution of students' use of SRL variables, across the four goal-setting conditions. The proportions of the SRL variables used by learners across the goal-setting conditions are presented in Table 4.

Insert Table 4 about here

Overall Regulation of Learning During a Knowledge Construction Activity. We examined how learners regulated their learning of the circulatory system by calculating how often they used each of the variables related to the five main SRL categories related to *planning, monitoring, strategy use, handling task difficult and demands, and interest.* A 4 x 5 chi-square analysis revealed a significant difference in the distribution of SRL categories used by learners during the knowledge construction activity across the four goal-setting conditions (χ^2 [12, N = 3,026] = 326.28, $p < .001$) (see Table 4). Learners in the CO-REG condition spent 87% of their time regulating their learning by using strategies, monitoring their learning, and dealing with task difficulties and demands (32%, 30%, and 25%, respectively). Learners in the other conditions also spent the majority of their time regulating their learning by using learning strategies, and planning and monitoring their learning, but did not devote much time to dealing with task difficulties or interest (range 2%-15%). Due to the overall significant differences across conditions in how learners regulated their learning, we subsequently performed individual chi-square analyses to investigate the proportion of how much each individual SRL variable was used during the knowledge construction activity, and was therefore responsible for the significant shifts in conceptual understanding.

Planning. We examined how learners planned their learning of the circulatory system by calculating how often they used each of the four variables related to *planning* during the knowledge construction activity. These variables included planning, sub-goaling, prior knowledge activation, and recycling a goal in working memory. A 4 x 4 chi-square analysis revealed a significant difference in the distribution of SRL variables used by learners in *planning* their learning of the circulatory system across the four goal-setting conditions (χ^2 [9, N = 477] = 405.92, $p < .001$) (see Table 4). Overall, the predominant planning method for the students in the CO-REG condition was to activate their prior knowledge, whereas the learners in the SI and LGSG conditions planned their learning by creating sub-goals. Also, learners in these Co-REG, SI, and LGSG conditions never planned by recycling goals in working memory. By contrast, the predominant planning activity for learners in the BU condition was to recycle goals in working memory.

Monitoring. We examined how learners monitored their learning of the circulatory system by calculating how often they used each of the six variables related to *monitoring* during the knowledge construction activity. These variables included judgment of learning, feeling of knowing, self-questioning, content evaluation, identifying the adequacy of information available in the hypermedia environment, and monitoring progress toward goals. A 4 x 6 chi-square analysis revealed a significant difference in the distribution of SRL variables related to students' *monitoring* activities used by learners across the four goal-setting conditions (χ^2 [15, N = 772] = 334.93, $p < .001$) (see Table 4). Overall, the students in the CO-REG condition monitored their learning by using feeling of knowing (FOK) and judging their learning (JOL) (55% and 34%, respectively), and rarely monitored their progress towards goals, almost never evaluated the content in the hypermedia environment, identified the adequacy of information or engaged in self-questioning (6%, 3%, 3%, and 0%, respectively). Learners in both the SI and LGSG conditions used an almost equal balance of the six monitoring activities during the knowledge construction activity. In contrast, students in the BU condition monitored their learning mainly by evaluating the content of the hypermedia environment (45%), seldom judging their learning (JOL), identifying the adequacy of information, monitoring their progress toward goals, or self-questioning (15%, 14%, 13%, 11%, and 3%, respectively).

Strategies. We also examined the types and frequency of *strategies* used by learners during the knowledge construction activity of learning about the circulatory system. We categorized the 16 strategies into either effective strategies (including selecting a new information source, coordinating informational sources, goal-directed search, summarization, taking notes, reading notes, drawing, re-reading, making inferences, hypothesizing, knowledge elaboration, and using mnemonics) or ineffective strategies (reading a new paragraph, free search, memorization, and evaluating content as answer to goal). A 4 x 2 chi-square analysis revealed a significant difference in the distribution of SRL variables related to students' *strategy* use by learners across the four goal-setting conditions (χ^2 [3, N = 1302] = 235.01, $p < .001$) (see Table 4). Overall, the students in the CO-REG, SI, and LGSG conditions controlled their learning by using effective strategies (e.g., re-reading, summarizing, and knowledge elaboration) (97%, 91%, and 87%, respectively). In contrast, students in BU condition controlled their learning by using a equal amount of both effective and ineffective strategies (e.g., free search, memorizing, evaluating content as the answer to a goal (53% and 47%, respectively).

Task Difficulty and Demands. The manner and frequency with which learners dealt with *task difficulty and demands* during the knowledge construction activity was also examined. These variables included time and effort planning, help-seeking behavior, task difficulty, control of context, and expectation of adequacy of information. A 4 x 5 chi-square analysis revealed a significant difference in the distribution of SRL variables related to task difficulty and demands experiences by learners across the four goal-setting conditions (χ^2 [12, N = 449] = 264.04, p < .001) (see Table 4). Learners in the CO-REG and BU conditions handled task difficulties by seeking help either from the tutor or the experimenter (90 and 65%, respectively), and almost never used any of the other four SRL variables (2%, 8%, 1%, 0%, and 1%, 9%, 8%, and 18%, respectively). In contrast, the students in the SI and LGSG conditions dealt with task difficulty and demands by using a combination of the five variables in this category (38%, 23%, 23%, 8%, 8%, and 51%, 17%, 11%, 17%, and 23%, respectively).

Interest. A small proportion of the coded segments in the LGSG, SI, and CO-REG conditions were related to the learners' level of interest regarding the task and/or domain (6%, 2%, and 2%, respectively) (see Table 4). In contrast, none of the coded segments in the BU condition revealed any indication of learners' interest during the knowledge construction activity. A chi-square analysis was not performed on this variable, since the observed frequencies were either too small or zero and would therefore violate certain statistical assumptions (e.g., minimum cell sizes for observed frequencies).

Co-Regulation During a Knowledge Construction Activity. A second question for our research was to determine (in the CO-REG condition) how the tutor and learner co-regulated their learning with the hypermedia environment. We first divided the CO-REG segments into student-initiated (S-I), tutor-initiated (T-I), and tutor-scaffolded (T-S) segments. We see the CO-REG condition as an interactive session as defined by Chi et al. (2001), since there were equal amounts of student-initiated and tutor-initiated coded segments (37% and 43%, respectively), and the other 19% of the coded segments consisted of tutor scaffolding. We performed a chi-square analysis to determine if there was a significant difference in the distribution of the student's or tutor's use of SRL variables related to planning, monitoring, strategy use, task difficulty and demand (T-S, T-I, and T-S). A 3 x 5 chi-square analysis revealed a significant difference in the distribution of SRL categories used by both learners and tutors during the knowledge construction activity across the student-initiated, tutor-initiated, and scaffolding episodes (χ^2 [8, N = 3300] = 2,039.12, $p < .001$). Learners (during S-I) most often used strategies, monitoring, and handling task difficulty and demands (32%, 28%, and 25%, respectively), seldom planned their learning, and showed little interest in the topic (13% and 2%, respectively). Tutor initiated (T-I) moves involved mainly strategies and monitoring (44% and 38%, respectively), assisting the learners in planning their learning (15%), rarely included handling task demands and difficulty (3%), and never included any interest in the topic (0%). By contrast, the tutor's scaffolding (T-S) moves were mainly related to generating interest and fostering motivation (59%) during learning by providing positive feedback, negative feedback, offering encouragement, and providing the student with choices over instructional content. Tutor scaffolding also included indicating which strategy learners should use to learn, monitoring activities, and planning episodes (15%, 14%, and 12%, respectively).

Question 3: What are the Qualitative Differences in Students' Self-Regulatory Learning in the Three Goal-Setting Conditions? In this section, we present a description of how a "typical" learner in each of the four goal-setting instructional conditions regulated his/her learning of the circulatory system. The descriptions provided below are meant to give the reader a sense of how the different goal-setting conditions affected learners' ability to regulate their learning with a hypermedia environment.

Co-Regulation (CO-REG). In general, learners began by reviewing the overall goals from the instruction sheet and usually began with the first sub-goal. The tutor usually suggested beginning reading with the overview of the circulatory system, and they often proceeded through the environment in a linear fashion, exploring sub-topics in depth as the learner and tutor co-constructed knowledge of the circulatory system. As other tutoring researchers have seen, the tutor appeared to have a "miniscript," a flexible framework which helped her conduct the tutoring session (Graesser & Person, 1994).

During reading, the tutor often supplied the pronunciation of anatomical terms (e.g., alveoli). After each sub-section, the tutor typically assessed the student's understanding of what was read by asking the student a question or requesting that the student summarize. As the student explained what he or she had read, the tutor typically clarified concepts, and often supplied information the student was missing, either information from the environment or from the tutor's prior knowledge. The tutor often used analogies (e.g., a blood vessel is lke a hose under pressure), mnemonics (e.g., A for *arteries*, which carry blood *away* from the heart). Students often asked questions about the learning content or process, which the tutor answered. We hypothesize that the tutor recognized certain aspects of the learning situation which might pose difficulty for students (e.g., pronouncing unfamiliar words, sections of text that required many inferences). The tutor therefore monitored the student's level of understanding by asking for summaries, and also facilitated understanding by providing information that was not in the text from her background knowledge, using analogies and providing mnemonics.

Students typically began by reading the overview of the circulatory system, then read about chambers of the heart, blood components, and systemic and pulmonary circulation. The tutor then usually asked the student to draw a diagram of the heart and the major blood vessels that carry blood to and from the chambers. We hypothesize that the tutor saw the act of drawing the diagram as an important part of the learning process, but wanted to wait until students had read or heard about the various parts of the heart first, before asking students to construct a drawing.

The tutor also often summarized what was read, restated information that had been read previously, and restated information when students were confused. The tutor noted the importance of certain passages or information, and advised the student to skip others, recommended particular representations, and suggested search strategies. About every 15 minutes, the tutor typically asked the student to assess progress towards the overall goal. Tutors therefore both modeled for, and scaffolded students' own enactment of, self-regulated learning actions in planning, monitoring, and strategy use.

The tutor also provided feedback (both positive and negative), encouragement, and expressed interest in the learning domain. Tutors therefore used a combination of instruction, cognitive scaffolding, and motivational scaffolding that other tutoring researchers have observed (Lepper, Woolverton, Mumme, & Gurtner, 1993), in the course of supporting students' self-regulated learning.

Strategy Instruction (SI). In general, learners used a goal-directed approach to learning, based on an initial inspection of the section headings and diagram captions found in hypermedia environment. They planned their learning of the circulatory system by setting multiple sub-goals and activating prior knowledge. The first five to ten minutes of the learning session were typically devoted to searching the hypermedia environment for headings, sub-headings, and inspecting the diagrams available in various sections (e.g., circulatory system, blood, and heart). We hypothesized that they were getting an overview of the content and multiple representations embedded in the hypermedia environment and relating it to what they already knew about the content. Furthermore, we also hypothesize that this planning would allow them to process the content in a manner that would enhance deep understanding of the content.

Once learners got an overview of the content, they then pursued their sub-goals, which were initially constructed based on what they already knew about the topic (i.e., prior knowledge activation). These sub-goals allowed them to focus on specific content included in the various sub-sections of the hypermedia environment. For example, they might read the sub-section about the systemic circulation and inspect the related diagrams. They used various effective monitoring strategies while learning and while relating the micro-context (e.g., reading a sub-section) to the macro-context (the various topics related to the circulatory system), and related the current content to their prior knowledge. They also engaged in self-questioning during learning; they monitored the content relative to the current learning sub-goal; and continuously assessed the usefulness and/or adequacy of the content they were reading, inspecting, and/or watching. We hypothesize that these monitoring activities were extremely effective in allowing the learner to make the conceptual links between the macro-context and micro-context.

Learners also used highly effective strategies to learn about the circulatory system. For example, they would read small chunks of text and go back and re-read them until they felt comfortable with the content. They were very adept at selecting and using multiple representational formats (i.e., text, diagrams, and video) to enhance their understanding of the content. They would also summarize what they read and continuously elaborate their evolving conceptual understanding. We hypothesize that these strategies enabled them to construct continuously evolving conceptual links between the macro-context and the micro-context. We also hypothesize that these strategies did not overloaded their working memory capacity and ability to monitor their learning. They revisited the same content several times and integrated, synthesized, and elaborated the material. They were also very thorough in searching the hypermedia environment, and their thoroughness seemed to be related to an interest in the topic.

They would rarely mention that the material they were reading was difficult for them to understand. In addition, they managed task difficulties and demands extremely well and rarely relied on external help (i.e., the experimenter) for assistance in helping them define terms, or in structuring their learning.

Learner-Generated Sub-Goals (LGSG). In general, learners exhibited great variability in the way they regulated their learning. For the most part, they approached the knowledge construction activity by setting up sub-goals and activating prior knowledge, they also used a combination of all six monitoring methods to regulate their learning, and also tended to use effective strategies to learn about the circulatory system. However, other did not set-up sub-goals, or monitored their learning, and did not handle task difficulty and demands accordingly. The variability found in this condition poses several interesting issues on learners' SRL. For example, in an open-ended task learners define the task differently, may decide to plan their learning and activate prior knowledge, or monitor their learning, use effective strategies, and generate a great amount interest to sustain the learning activity. In contrast, a few of the learners regulated their learning in a similar manner to the learners in the SI condition.

Bottom-Up Condition (BU). In general, learners did not use a goal directed approach to learning; they exhaustively searched the hypermedia module for answers to the questions posed by the experimenter. They recycled the goal (i.e., question posed by the experimenter) in working memory when they had to segment a complex question into several parts ("list all the structures, electrical, mechanical, and support, that comprise the heart", "describe the location and function of the major valves in the heart"). We hypothesize this led them to allocate the majority of their cognitive resources to recycling the sub-goals (i.e., parts of the questions) in working memory. They did not engage in planning (i.e., coordination of multiple goals), failed to integrate and elaborate the instructional content available in the hypermedia module, and did not engage in processes that would allow them to process the content in a manner that would enhance deep understanding of the content. Furthermore, they rarely engaged in prior knowledge activation.

Typically, learners would search for text, diagrams, and animation and read out loud what they thought was the answer to a particular question. In most cases, they would read large segments of text and then ask the experimenter if they were on the right track. They engaged in ineffective monitoring activities during learning and relied almost exclusively on external sources of monitoring (i.e., the experimenter). They also used ineffective strategies to learn the materials. For example, they would rarely summarize what they read, and when they did the summary was very superficial. Their undirected search through the hypermedia environment was dominated by a data-driven approach, where they would sometimes set-up multiple sub-goals and exhaustively search Encarta looking for text, static diagrams, and animation. Once they found a particular section (of text) or diagram they would: (1) continue reading it exhaustively and give the experimenter the read-aloud text as the answer, (2) quickly judge that the text or diagram was not useful in answering the question and continue searching Encarta for another piece of text or image, (3) answer a drawing question by searching for an appropriate diagram and copying it down, and/or (4) answer a drawing question by searching for the animation and stopping it regularly while they copied it down.

We hypothesize this approach overloaded learners' working memory capacity and hindered their ability to monitor their learning from one question to the next. They attempted to coordinate multiple representations of information but failed to integrate these representations into a deeper understanding of the content. They rarely revisited the same content and when they did, they did so superficially and did not attempt to integrate or synthesize the material. The revisiting was done solely to extract the material need to answer a given question. They relied heavily on the content for the answers ("the guy in the video will give me the answer," "well that's my answer right there!", "I have a diagram here that's going to help me draw the flow of blood through the chambers"). They were not persistent in finding the answers to the questions, and their lack of persistence seemed to be related to a lack of interest in the topic.

Learners also failed to understand the content, since their primary goal was to find information needed to answer a question, and because they read large chunks of text which exceeded their working memory capacity. Furthermore, this problem was compounded by the fact that they did not use effective strategies, nor did they make any effort to elaborate based the revisiting instructional materials or attempting to integrate those materials. Some students were aware that they did not understand the material yet still failed to engage in processes that would facilitate their understanding. For example, there were a few episodes when students would summarize what they had just read. However, even though their summary statements were very short and shallow (e.g., "ok, so it's the system that transports things through the body") they were marked by remarks of certitude (e.g., "I don't really understand this and I think that's it"). Another strategy included searching for content that used terminology identical to that in the questions (e.g., "I'm looking for something that's going to use the exact same terminology," "I'm still trying to come up with anything that's electric").

Learners would sometimes mention that the material they were reading was difficult for them to understand. However, they dealt with task difficulties and demands by relying a great deal on external help (i.e., the experimenter) for assistance in defining terms or in assessing the quality of their answers (help which was not provided).

Conclusion

This study examined the role of different goal-setting instructional interventions in facilitating students' shift to more sophisticated mental models of the circulatory system as indicated by both performance and process data. We adopted Winne and colleagues' (1998, 2001) information processing model of self-regulated learning and empirically tested their model by examining how students regulated their own learning when using a hypermedia environment to learn about the circulatory system. Undergraduate students ($N = 40$) were randomly assigned to one of four goal-setting instructional conditions (co-regulation, strategy instruction, learner-generated sub-goals, and bottom-up) and were trained to use a hypermedia environment to learn about the circulatory system. Pretest, posttest, transfer test, and verbal protocol data were collected using a pretest-posttest comparison group design with a think-aloud methodology. Findings revealed that the co-regulation and strategy instruction conditions facilitated the shift in learners' mental models significantly more than the other comparison conditions. Learners in the co-regulation condition benefited by having the tutor co-regulate their learning by planning their goals, monitoring their emerging understanding and providing scaffolding, using effective strategies, and providing motivational scaffolding. Learners in the strategy instruction condition also made significant knowledge gains but regulated their learning differently since they did not have the tutor to co-regulated their learning. Learners in the learner-generated sub-goals and bottom-up conditions were less effective at regulating their learning and exhibited great variability in their ability to self-regulate their learning during the knowledge construction activity. Our results provide a valuable initial characterization of self-regulated learning (SRL) in a hypermedia environment across several goal-setting instructional conditions. In addition, we discuss during the presentation how they can be used to inform the design of adaptive hypermedia environments to teach students about complex systems.

References

Afflerbach, P. (2000). Verbal reports and protocol analysis. In M. Kamil, P. Mosenthal, P. Pearson, & R. Barr (Eds.) *Handbook of reading research: Vol III* (pp. 163-179). Mahwah: NJ: Erlbaum.

Azevedo, R. (2001, May). *Using hypermedia to learn about complex systems: A self-regulation model*. Paper presented at a workshop on help provision and help seeking in interactive learning environments at the 10th International Conference on Artificial Intelligence in Education.

Azevedo, R. (2002). Beyond intelligent tutoring systems: Computers as MetaCognitive tools to enhance learning? *Instructional Science, 30*(1), 31-45.

Azevedo, R., Guthrie, J.T., Wang, H., & Mulhern, J. (2001, April). *Do different instructional interventions facilitate students' ability to shift to more sophisticated mental models of complex systems?* Paper presented at the Annual Conference of the American Educational Research Association, Seattle, WA.

Azevedo, R., Ragan, S., Cromley, J.G., & Pritchett, S. (2002, April). *Do different goal-setting conditions facilitate students' ability to regulate their learning of complex science topics with RiverWeb?* Paper presented at the Annual Conference of the American Educational Research Association, New Orleans, LA

Azevedo, R., Verona, M.E., & Cromley, J.G. (2001). Fostering students' collaborative problem solving with RiverWeb. In J.D. Moore, C.L. Redfield, & W.L. Johnson (Eds.), *Artificial intelligence in education: AI-ED in the wired and wireless future* (pp. 166-175). Amsterdam: IOS press.

Boekaerts, M., Pintrich, P., & Zeidner, M. (20000), *Handbook of self-regulation*. San Diego, CA: Academic Press.

Butler, D. & Winne, P.H. (1995). Feedback as self-regulated learning: A theoretical synthesis. *Review of Educational Review, 65*, 245-281.

Chi, M. T.H. (2000). Self-explaining: The dual processes of generating inference and repairing mental models. In R. Glaser, R. (Ed.), *Advances in instructional psychology: Educational design and cognitive science* (vol.5) (pp. 161-238). Mawah, NJ: Erlbaum.

Chi, M. T.H., de Leeuw, N., Chiu, M.-H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*, 439-477.

Chi, M. T.H., Siler, S., Jeong, H., Yamauchi, T., & Hausmann, R. (2001). Learning from human tutoring. *Cognitive Science, 25*, 471-534.

Ericsson, K.A., & Simon, H.A. (1993). *Protocol analysis: Verbal reports as data (2nd ed.)*. Cambridge, MA: MIT Press.

Gentner, D., & Stevens, A. (1983). *Mental models*. Hillsdale, NJ: Erlbaum.

Hadwin, A.F., Winne, P.H., Stockley, D.B., Nesbit, J.C., & Woszczyna, C. (2001). Context moderates students' self-reports about how they study. *Journal of Educational Psychology, 93*(3), 477-487.

Hartley, K. (2001). Learning strategies and hypermedia instruction. *Journal of Educational Multimedia and Hypermedia, 10*(3), 285-305.

Hegarty, M., & Just, M. (1993). Constructing mental models of machines from text and diagrams. *Journal of Memory & Language, 32*(6), 717-742.

Hogan, K. (1999). Thinking aloud together: a test of an intervention to foster students' collaborative scientific reasoning. *Journal of Research in Science Teaching, 36*(10), 1085-1109.

Kozma, R., Chin, E., Russell, J., & Marx, N. (2000). The roles of representations and tools in the chemistry laboratory and their implications for chemistry learning. *Journal of the Learning Sciences, 9*(2), 105-144.

MacGregor, S.K. (1999). Hypermedia navigation profiles: cognitive characteristics and information processing strategies. *Journal of Educational Computing Research, 20*(2), 189-206.

Markman, A., & Gentner, D. (2001). Thinking. *Annual Review of Psychology, 52*, 223-247.

Mayer, R.E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: when presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187-198.

Narayanan, N.H., & Hegarty, M. (1998). On designing comprehensible interactive hypermedia manuals. *International Journal of Human-Computer Studies, 48*, 267-301.

Paris, S.G., & Paris, A.H. (2001). Classroom applications of research on self-regulated learning. *Educational Psychologist, 36*(2), 89-101.

Pintrich, P.R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451-502). San Diego, CA: Academic Press.

Pressley, M., & Afflerbach, P. (1995). *Verbal reports of reading: The nature of constructively responsive reading*. Hillsdale, NJ: Erlbaum.

Schunk, D. (2001). Social cognitive theory of self-regulated learning. In & B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 125-152). Mawah, NJ: Erlbaum.

Shapiro, A. (1999). The relationship between prior knowledge and interactive overviews during hypermedia-aided learning. *Journal of Educational Computing Research, 20*(2), 143-167.

Shapiro, A. (2000). The effect of interactive overviews on the development of conceptual structure in novices learning from hypermedia. *Journal of Interactive Multimedia and Hypermedia, 9*(1), 57-78.

Vosniadou, S., & Brewer, W. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*(4), 535-586.

White, B.Y., Shimoda, T.A., & Frederiksen, J.R. (2000). Facilitating students' inquiry learning and metacognitive development through modifiable software advisers. In S.P. Lajoie (Ed.), *Computers as cognitive tools II: No more walls: Theory change, paradigm shifts and their influence on the use of computers for instructional purposes* (pp. 97-132). Mawah, NJ: Erlbaum.

Winne, P.H. (1995). Inherent details in self-regulated learning. *Educational Psychologist, 30*, 173-187.

Winne, P.H. (1996). A metacognitive view of individual differences in self-regulated learning. *Learning and Individual Differences, 8*(4), 327-353.

Winne, P.H. (1997). Experimenting to bootstrap self-regulated learning. *Journal of Educational Psychology*, 397-410.

Winne, P.H. (2001). Self-regulated learning viewed from models of information processing. In & B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 153-189). Mawah, NJ: Erlbaum.

Winne, P.H., & Hadwin, A.F. (1998). Studying as self-regulated learning. In D.J. Hacker, J. Dunlosky, & A. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 277-304). Hillsdale, NJ: Erlbaum.

Winne, P.H., & Perry, N.E. (2000). Measuring self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 531-566). San Diego, CA: Academic Press.

Zimmerman, B. (1989). Models of self-regulated learning and academic achievement. In B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theory, research, and practice* (pp. 1-25). NY: Springer-Verlag.

Zimmerman, B. (2000). Attaining self-regualtion: A social cognitive perspective. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-39). San Diego, CA: Academic Press.

Zimmerman, B. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In & B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 1-37). Mawah, NJ: Erlbaum.

Zimmerman, B., & Schunk, D. (2001). *Self-regulated learning and academic achievement* (2nd ed.). Mawah, NJ: Erlbaum.

Table 1

Questions Used in the Bottom-Up (BU) Goal-Setting Instructional Condition.

Bottom-Up Questions:

1. Describe the function of each type of cell found in blood.
2. Name all the components of blood.
3. Name some major functions of blood (yes, there is more than one!)
4. Describe the location and function of the major valves in the heart.
5. Draw and verbally describe blood flow through the heart chambers.
6. Describe the electrical conduction system in the heart. What purpose does it serve and what structures are involved?
7. List all the structures (electrical, mechanical and support) that comprise the heart
8. Draw a line diagram connecting all the major components of the cardiovascular system and describe the movement of blood through the system.
9. Name the major elements of the cardiovascular system
10. Why does the body require a cardiovascular system? What purpose does it serve?

Table 2

Necessary Features for Each Type of Mental Model.

1. No understanding

2. Basic Global Concepts
- blood circulates

3. Global Concepts with Purpose
- blood circulates
- describes "purpose" - oxygen/nutrient transport

4. Single Loop – Basic
- blood circulates
- heart as pump
- vessels (arteries/veins) transport

5. Single Loop with Purpose
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe "purpose" - oxygen/nutrient transport

6. Single Loop - Advanced
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe "purpose" – oxygen/nutrient transport
- mentions one of the following: electrical system, transport functions of blood, details of blood cells

7. Single Loop with Lungs
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- mentions lungs as a "stop" along the way
- describe "purpose" – oxygen/nutrient transport

8. Single Loop with Lungs - Advanced
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- mentions Lungs as a "stop" along the way
- describe "purpose" – oxygen/nutrient transport
- mentions one of the following: electrical system, transport functions of blood, details of blood cells

9. Double Loop Concept
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describes "purpose" - oxygen/nutrient transport
- mentions separate pulmonary and systemic systems
- mentions importance of lungs

10. Double Loop – Basic
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe "purpose" - oxygen/nutrient transport
- describes loop: heart - body - heart - lungs - heart

11. Double Loop – Detailed
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe "purpose" - oxygen/nutrient transport
- describes loop: heart - body - heart - lungs – heart
- structural details described: names vessels, describes flow through valves

12. Double Loop - Advanced
- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe "purpose" - oxygen/nutrient transport
- describes loop: heart - body - heart - lungs - heart
- structural details described: names vessels, describes flow through valves
- mentions one of the following: electrical system, transport functions of blood, details of blood cell

Table 3

Classes, Descriptions and Examples of the Variables Used to Code Learners' Self-Regulatory Behavior and Co-Regulated Behavior Between Learner and Tutor.

Variable	Description[1]	Example
Planning		
Planning	A plan involves coordinating the selection of operators. Its execution involves making behavior conditional on the state of the problem and a hierarchy of goals and sub-goals	**Student:** "First I'll look around to see the structure of environment and then I'll go to specific sections of the circulatory system" **Tutor Scaffolding:** "What are you going to do?" **Tutor Instruction:** "Read this and then we'll go into the next section"
Goals	Consist either of operations that are possible, postponed, or intended, or of states that are expected to be obtained. Goals can be identified because they have no reference to already-existing states	**Student:** "I'm looking for something that's going to discuss how things move through the system" **Tutor Scaffolding:** "So what part are you going to start with, do you think?" **Tutor Instruction:** "We have to go find the answer to that"
Prior Knowledge Activation	Searching memory for relevant prior knowledge either before beginning performance of a task or during task performance	**Student:** "It's hard for me to understand, but I vaguely remember learning about the role of blood in high school" **Tutor Scaffolding:** "And then what happens in the lungs?" **Tutor Instruction:** "Remember, it's inside the blood vessel"
Recycle Goal in Working Memory	Restating the goal (e.g., question or parts of a question) in working memory (WM)	**Student:** "...describe the location and function of the major valves in the heart"

[1] All codes refer to what was read, seen, or heard in the environment and/or during discussions.

Monitoring		
Judgment of Learning (JOL)	Learner becomes aware that they don't know or understand everything they read	**Student (JOL):** "I don't know this stuff, it's difficult for me" **Tutor Instruction:** "We already read that"
Feeling of Knowing (FOK)	Learner is aware of having read something in the past and having some understanding of it, but not being able to recall it on demand	**Student:** "... let me read this again since I'm starting to get it..." **Tutor Scaffolding:** "Which side of the heart would be doing that work?" **Tutor Instruction):** "You're pretty comfortable with that part."
Self-Questioning	Posing a question and re-reading to improve understanding of the content	**Student:** [Learner spends time reading text] and then states "what do I know from this?" and reviews the same content
Content Evaluation	Monitoring content relative to goals	**Student:** "I'm reading through the info but it's not specific enough for what I'm looking for" **Tutor Scaffolding:** "Did it say there were platelets, too?" **Tutor Instruction:** "This is mostly history. I don't know if we're really interested that much"
Identify Adequacy of Information	Assessing the usefulness and/or adequacy of the content (reading, watching, etc.)	**Student:** "...structures of the heart...here we go..." **Tutor Instruction:** "So it's pretty important."
Monitor Progress Toward Goals	Assessing whether previously-set goal has been met.	**Student:** "Those were our goals, we accomplished them" **Tutor Scaffolding:** "Are we getting to some of these questions that they asked?" **Tutor Instruction:** "That's pretty much what you needed to know"

Strategy Use		
Selecting a New Informational Source	The selection and use of various cognitive strategies for memory, learning, reasoning, problem solving, and thinking. May include selecting a new representation, coordinating multiple representations, etc.	**Student:** [Learner reads about location valves] then switches to watching the video to see their location **Tutor Scaffolding:** "Well, you want to look at the heart again?" **Tutor Instruction:** "Go back [to the diagram and] look at that guy"
Coordinating Informational Sources	Coordinating multiple representations, e.g., drawing and notes.	**Student:** "I'm going to put that [text] with the diagram"
Read New Paragraph	The selection and use of a paragraph different from the one the student was reading.	**Student:** "OK, now on to pulmonary" **Tutor Instruction:** "Read . . .the first couple of sentences in each one of the paragraphs."
Review Notes	Reviewing learner's notes.	**Student:** "Carry blood away. Arteries—away."
Memorization	Learner tries to memorize text, diagram, etc.	**Student:** "I'm going to try to memorize this picture"
Free Search	Searching the hypermedia environment without specifying a specific plan or goal	**Student:** "I'm going to the top of the page to see what is there"
Goal-Directed Search	Searching the hypermedia environment after specifying a specific plan or goal	**Student:** Learner types in blood circulation in the search feature **Tutor Scaffolding:** "Try writing electrical" [in the search feature] **Tutor Instruction:** "Heartbeat—that would probably be it"
Summarization	Summarizing what was just read, inspected, or heard in the hypermedia environment	**Student:** "This says that white blood cells are involved in destroying foreign bodies" **Tutor Scaffolding:** "If you were to . . . re-describe that . . . ?" **Tutor Instruction:** "It's for oxygen and nutrient exchange."
Taking Notes	Copying text from the hypermedia environment	**Student:** "I'm going to write that under heart" **Tutor Scaffolding:** "I use shortcuts . . . RA for right atrium" **Tutor Instruction:** "Don't write down everything"

Draw	Making a drawing or diagram to assist in learning	**Student:** "...I'm trying to imitate the diagram as best as possible" **Tutor Scaffolding:** "Why don't you just . . . start with a circle?" **Tutor Instruction:** "It will be easier to understand if you make a drawing."
Re-reading	Re-reading or revisiting a section of the hypermedia environment	**Student:** I'm reading this again. **Tutor Instruction:** "Do this vein thing again."
Inferences	Making inferences based on what was read, seen, or heard in the hypermedia environment	**Student:** ...[Learner sees the diagram of the heart] and states "so the blood....through the ...then goes from the atrium to the ventricle... and then..." **Tutor Scaffolding:** "Do you suppose it has to go through capillaries again in the lungs?" **Tutor Instruction:** "So that's its own separate system."
Hypothesizing	Asking questions that go beyond what was read, seen or heard	**Student:** "I wonder why just having smooth walls in the vessels prevent blood clots from forming...I wish they explained that..."
Knowledge Elaboration	Elaborating on what was just read, seen, or heard with prior knowledge	**Student:** [after inspecting a picture of the major valves of the heart] the learner states "so that's how the systemic and pulmonary systems work together" **Tutor Instruction:** "The walls of capillaries are one cell layer thick"
Mnemonic	Using a verbal or visual memory technique to remember content	**Student:** Arteries—A for away **Tutor Scaffolding:** "Artery, because it's going away" **Tutor Instruction:** "Superior because it's up on top."
Evaluate Content as Answer to Goal	Statement that what was just read and/or seen meets a goal or sub-goal	**Student:** [Learner reads text]..." So, I think that's the answer to this question"
Find Location in Environment	Statement about where in environment learner had been reading.	**Student:** "That's where we were." **Tutor Instruction:** "We were down here somewhere"

Task Difficulty and Demands

Time and Effort Planning	Attempts to intentionally control behavior	**Student:** "I'm skipping over that section since 45 minutes is too short to get into all the details" **Tutor Instruction (TITEP):** "We've got 5 minutes left"
Help Seeking Behavior	Learner seeks assistance regarding either the adequateness of their answer or their instructional behavior	**Student (HS):** "Do you want me to give you a more detailed answer?"
Task Difficulty	Learner indicates one of the following: (1) the task is either easy or difficult, (2) the questions are either simple or difficult, (3) using the hypermedia environment is more difficult than using a book	**Student:** "This is harder than reading a book" **Tutor Instruction:** "You won't remember endocrine probably"
Control of Context	Using features of the hypermedia environment to enhance the reading and viewing of information	**Student:** [Learner double-clicks on the heart diagram to get a close-up of the structures] **Tutor Scaffolding:** "That's good, now type heart" **Tutor Instruction:** "Click on the little triangle there for heart"
Expectation of Adequacy of Information	Expecting that a certain type of representation will prove adequate given the current goal	**Student (EA):** "...the video will probably give me the info I need to answer this question" **Tutor Instruction (TIEA):** "Click on the heart because I think it helps sometimes to see those structures"

Motivation

Interest Statement	Learner has a certain level of interest in the task or in the content domain of the task	**Student:** "Interesting", "This stuff is interesting" **Tutor Instruction:** "Yeah, it's amazing!"
Positive feedback	Tutor tells learner his or her statement was correct, or repeating learner's correct statement.	**Tutor:** "Uh huh."
Negative feedback	Tutor tells learner his or her statement was incorrect.	**Tutor:** "No."
OK	Ambiguous feedback from tutor; could be a response to a correct or incorrect statement.	**Tutor:** "OK"
Encouragement	Tutor makes encouraging statement to learner.	**Tutor:** "That will become clearer as we go on."
Choice	Tutor offers learner a choice of next steps.	**Tutor:** "What do you want to do first?"

Table 4

Proportion of Self-Regulated Learning Variables Used by Learners By Instructional Condition.

Variable	Co-Regulated Learning	Strategy Instruction	Learner-Generated Sub-Goals	Bottom-Up
Planning ***				
Planning	.03	*.08*	*.09*	0
Sub-Goals	.13	***.61***	***.56***	.25
Prior Knowledge Activation	***.70***	.13	.19	.13
Recycle Goal in Working Memory	0	0	0	***.50***
Monitoring Progress Toward Goals	.13	*.18*	*.16*	.11
Monitoring ***				
Judgment of Learning (JOL)	*.37*	.14	**.29**	.10
Feeling of Knowing (FOK)	***.58***	.23	.20	.15
Self-Questioning	0	*.22*	.13	.03
Content Evaluation	.02	**.31**	.20	***.50***
Identify Adequacy of Information	.02	.10	*.16*	*.16*
Strategy Use ***				
Effective Strategies (Selecting a New Informational Source, Coordinating Informational Sources, Goal-Directed Search, Summarization, Taking Notes, Read new Paragraph, Read New Paragraph, Draw, Re-Reading, Inferences, Hypothesizing, Knowledge Elaboration, Mnemonics)	***.97***	**.91**	**.87**	**.53**
Ineffective Strategies (Free Search, Memorization, Find Location in Environment, Evaluate Content as Answer to Goal)	.03	.09	.13	.47
Task Difficulty and Demands ***				
Time and Effort Planning	.02	.38	.51	.013
Help Seeking Behavior	.9	.23	.17	.65
Task Difficulty	.08	.23	.11	.09
Control of Context	.006	.08	.17	.08
Expectation of Adequacy of Information	0	.08	.023	.18
Interest				
Interest Statement	.26	.23	**.51**	0

*** $p < .001$

Note. The **bold** type indicates the highest proportion across SRL variables within goal-setting conditions.
Note. The *italicized* type indicates the highest proportion across conditions within each SRL variable.

U.S. Department of Education
Office of Educational Research and Improvement (OERI)
National Library of Education (NLE)
Educational Resources Information Center (ERIC)

ERIC
Educational Resources Information Center

REPRODUCTION RELEASE

(Specific Document)

TM034998

I. DOCUMENT IDENTIFICATION:

Title: How do students regulate their learning of complex systems with hypermedia?	
Author(s): ROGER AZEVEDO, DIANE SEIBERT, JOHN T. GUTHRIE, JENNIFER G. CROMLEY, HUEI WANG, + MYRIAM TRON	
Corporate Source: —	Publication Date: APRIL 2002

II. REPRODUCTION RELEASE:

In order to disseminate as widely as possible timely and significant materials of interest to the educational community, documents announced in the monthly abstract journal of the ERIC system, *Resources in Education* (RIE), are usually made available to users in microfiche, reproduced paper copy, and electronic media, and sold through the ERIC Document Reproduction Service (EDRS). Credit is given to the source of each document, and, if reproduction release is granted, one of the following notices is affixed to the document.

If permission is granted to reproduce and disseminate the identified document, please CHECK ONE of the following three options and sign at the bottom of the page.

The sample sticker shown below will be affixed to all Level 1 documents	The sample sticker shown below will be affixed to all Level 2A documents	The sample sticker shown below will be affixed to all Level 2B documents
PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY ____ Sample ____ TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)	PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE, AND IN ELECTRONIC MEDIA FOR ERIC COLLECTION SUBSCRIBERS ONLY, HAS BEEN GRANTED BY ____ Sample ____ TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)	PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY ____ Sample ____ TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
1	2A	2B
Level 1	Level 2A	Level 2B
☑	☐	☐
Check here for Level 1 release, permitting reproduction and dissemination in microfiche or other ERIC archival media (e.g., electronic) *and* paper copy.	Check here for Level 2A release, permitting reproduction and dissemination in microfiche and in electronic media for ERIC archival collection subscribers only	Check here for Level 2B release, permitting reproduction and dissemination in microfiche only

Documents will be processed as indicated provided reproduction quality permits.
If permission to reproduce is granted, but no box is checked, documents will be processed at Level 1.

I hereby grant to the Educational Resources Information Center (ERIC) nonexclusive permission to reproduce and disseminate this document as indicated above. Reproduction from the ERIC microfiche or electronic media by persons other than ERIC employees and its system contractors requires permission from the copyright holder. Exception is made for non-profit reproduction by libraries and other service agencies to satisfy information needs of educators in response to discrete inquiries.

Sign here, → please

Signature: [signature]	Printed Name/Position/Title: ROGER AZEVEDO ASSISTANT PROF	
Organization/Address: UMD	Telephone: 301-405-2799	FAX: 301-405-2891
	E-Mail Address: RA109@umail.umd.edu	Date: 5/28/03

(Over)

III. DOCUMENT AVAILABILITY INFORMATION (FROM NON-ERIC SOURCE):

If permission to reproduce is not granted to ERIC, *or*, if you wish ERIC to cite the availability of the document from another source, please provide the following information regarding the availability of the document. (ERIC will not announce a document unless it is publicly available, and a dependable source can be specified. Contributors should also be aware that ERIC selection criteria are significantly more stringent for documents that cannot be made available through EDRS.)

Publisher/Distributor:
Address:
Price:

IV. REFERRAL OF ERIC TO COPYRIGHT/REPRODUCTION RIGHTS HOLDER:

If the right to grant this reproduction release is held by someone other than the addressee, please provide the appropriate name and address:

Name:
Address:

V. WHERE TO SEND THIS FORM:

Send this form to the following ERIC Clearinghouse:

ERIC CLEARINGHOUSE ON ASSESSMENT AND EVALUATION
UNIVERSITY OF MARYLAND
1129 SHRIVER LAB
COLLEGE PARK, MD 20742-5701
ATTN: ACQUISITIONS

However, if solicited by the ERIC Facility, or if making an unsolicited contribution to ERIC, return this form (and the document being contributed) to:

ERIC Processing and Reference Facility
4483-A Forbes Boulevard
Lanham, Maryland 20706

Telephone: 301-552-4200
Toll Free: 800-799-3742
FAX: 301-552-4700
e-mail: ericfac@inet.ed.gov
WWW: http://ericfacility.org