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ABSTRACT

This study examined the effectiveness of self-regulated learning (SRL) training in facilitating students' learning with hyerpermedia as indicated by both performance and process data. Undergraduate students (n=131) were randomly assigned to either a training condition on how to regulate their learning (n=63) or a no training condition (n=68) and used a hypermedia environment to learn about the circulatory system. Students in the training group were given a 30-minute training period on the use of specific empirically based self-regulated learning variables designed to foster their conceptual understanding. Pretest, posttest, and verbal protocol data were collected. Findings reveal that the training condition facilitated the shift in learners' mental models significantly more than did the no training condition. Verbal protocol data indicated that this shift in trained students' conceptual understanding was based on the use of the SRL variables taught during training. Training participants regulated their learning by planning and activating their prior knowledge, engaging in several metacognitive monitoring activities, using several effective strategies, handling task difficulties and demands by planning their time and effort, and expressing interest in the topic. SRL training participants also differed in the amount of time spent on each representation of information. (Contains 1 table and 57 references.) (Author/SLD)

The Role of Self-Regulated Learning in Fostering Students Understanding of Complex Systems with Hypermedia

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Abstract

We examined the effectiveness of self-regulated learning (SRL) training in facilitating students' learning with hypermedia as indicated by both performance and process data. Undergraduate students (*N* = 131) were randomly assigned to either a training condition on how to regulate their learning (SRL_T, *n* = 63) or a no training condition (NO SRL_T, *n* = 68), and used a hypermedia environment to learn about the circulatory system. Students in the SRL_T group were given a 30-minute training period on the use of specific, empirically-based self-regulated learning (SRL) variables designed to foster their conceptual understanding. Pretest, posttest, and verbal protocol data were collected. Findings revealed that the SRL_T condition facilitated the shift in learners' mental models significantly more than did the NO SRL_T condition. Verbal protocol data indicated that this significant change in SRL_T students' conceptual understanding was based on the use of the SRL variables taught during training. SRL_T participants regulated their learning by planning and activating their prior knowledge, engaging in several metacognitive monitoring activities, using several effective strategies, handling task difficulties and demands by planning their time and effort, and expressing interest in the topic. SRL_T participants also differed in the amount of time spent on each representation of information.

The Role of Self-Regulated Learning in Fostering Students' Understanding of Complex Systems with Hypermedia

Hypermedia environments have the potential to enrich learners' understanding of complex topics by providing them with random, dynamic, non-linear access to a wide range of information represented as text, graphics, animation, audio, and video (Jacobson & Archodidou, 2000; Jonassen, 1996). However, the recent widespread use of hypermedia environments in schools has outpaced our understanding of *how* learners can learn effectively in such environments and *how* hypermedia can be designed to facilitate students' learning. A common assumption is that learners will not experience learning difficulties while using these complex, non-linear environments. However, one potential problem is that learners must regulate their own learning since hypermedia gives them a great deal of control over the amount and choice of instructional content. Self-regulated learning is therefore particularly important in understanding how they learn in such complex learning situations (Williams, 1996).

Researchers have recently begun to identify several problems associated with learners' inability to regulate their learning with hypermedia. These include failure to regulate their cognitive system, features of the hypermedia, and mediating learning processes. Given the importance of students' regulation of their learning with hypermedia, a next logical step in this area is to investigate the effectiveness of teaching learners self-regulatory strategies aimed at enhancing their learning with hypermedia. In the present study, we examined whether training on self-regulated learning is effective in facilitating students' ability to regulate their learning about the circulatory system using a hypermedia environment.

Indeed, the question of whether hypermedia environments can enhance students' learning remains unanswered. We now have a critical mass of studies on learning with hypermedia, however, results of these studies to date are inconclusive. Further, recent reviews (Tergan, 1997; Dillon & Gabbard, 1998; Williams, 1996) of this literature note that most studies lack theoretical foundations (e.g., focus on students' learning styles), lack methodological rigor (e.g., lack of adequate pretesting of learners) and/or lack analytical rigor (e.g., claim support for hypotheses when data fail to show statistically significant results), thus limiting our understanding of the potential benefits of hypermedia. Overall, these reviews on learning with hypermedia show inconclusive results as to the potential benefits of learning with hypermedia.

Recent cognitive research has shown that providing students with flexible access and a high degree of learner control in non-linear, random access hypermedia and hypertext environments rarely leads to deep conceptual understanding of complex topics (Jacobson & Archodidou, 2000; Jacobson, Maori, Mishra, & Kolar, 1996; Jacobson & Spiro, 1995; Puntambekar, 1995; Kozma, Chin Russell, & Marx, 2000; Shapiro, 1998, 1999, 2000). These studies indicate that students have difficulties in regulating aspects of their cognitive system (e.g., failure to activate relevant prior knowledge), difficulties regulating features of the hypermedia (e.g., coordinating and accessing multiple representations of information, determining an adequate instructional sequence), and difficulties regulating mediating learning processes (e.g., lack of planning, metacognitive monitoring, use of ineffective strategies). To understand the potential learning benefits of hypermedia systems, we need to understand the complex relation between learner characteristics and system features, and the mediating learning processes used to regulate learning with hypermedia. We argue that successful learning with these complex environments requires self-regulated learning of the type described by self-regulated learning (SRL) researchers.

Theoretical Framework: Self-Regulated Learning (SRL)

Several cognitive models of SRL posit that 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 (Winne, 2001; Winne & Hadwin, 1998; Zimmerman & Schunk, 2001). SRL is guided and constrained by both personal characteristics and the contextual features of the environment (Pintrich, 2000). Thus, these models offer a comprehensive framework with which to examine how students *learn* and how they *adapt* during learning with hypermedia. Several researchers (Azevedo, Guthrie, & Seibert, in press; Azevedo, Cromley, Seibert, & Tron, 2003; Azevedo, Cromley, Thomas, Seibert, & Tron, 2003; Azevedo, Verona, & Cromley, 2001; Hadwin & Winne, 2001; Winne & Stockley, 1998) have begun to examine the role of students' ability to regulate several aspects of their cognition, motivation, and behavior *during* learning of complex topics with hypermedia. Thus research has demonstrated that students have difficulties benefiting from hypermedia environments because they fail to engage in key mechanisms related to regulating their learning. In general, learners tend not to plan and activate their prior knowledge, rarely use metacognitive monitoring processes, use ineffective strategies, and exhibit difficulties in handling task difficulties and demands (Azevedo et al., *in press*, 2003a, 2003b).

Given these problems, we need to investigate whether students can be trained to regulate their learning in hypermedia learning situations. We argue that training students to self-regulate while using hypermedia to learn about complex topics is likely to foster students' learning in these environments. This approach is an extension of studies on the effectiveness of strategy instruction on students' learning in various content areas (for a recent review see National Reading Panel, 2000). Researchers have demonstrated the effectiveness of strategy instruction in several areas (e.g., Guthrie, Wigfield, & VonSecker, 2000; Magliano, Trabasso, & Graesser, 1999; Rosenshine & Meister, 1997). We extend the strategy instruction approach by training students to regulate their learning by using effective strategies but also to plan, monitor, and handle task difficulties and demands. Increased research efforts are critical to understanding whether students can be taught to regulate several aspects of their learning of complex topics with hypermedia. Only after we know about the strategies used by self-regulating learners can we design training interventions designed to foster student's understanding of complex topics.

SLR Training and Learning with Hypermedia

Several researchers have recently begun to test the role of students' self-regulatory behavior during learning with computerized environments. Several studies have suggested that self-regulatory skills may affect a learner's ability to benefit from hypermedia environments (Azevedo, *in press*; 2001; Hadwin & Winne, 2001; Winne & Stockley, 1998). The results indicate that not all learners are capable of effectively regulating their learning (e.g., selecting their own instructional sequencing, pacing, and amount of material to study). Several researchers (e.g., Williams, 1996) have indicated that there needs to be a greater understanding of the relationship between complex, non-linear hypermedia environments and self-regulatory skills. Some researchers have demonstrated that appropriate self-regulatory skills are required for successful learning in these environments (Armstrong, 1996; Azevedo et al., in press). Others have emphasized that self-regulatory skills are essential in order for learn successfully with hypermedia environments. For example, Hill & Hannafin (1997) have indicated that learners in a hypermedia environment should be able to regulate their own learning by planning, monitoring, controlling, and reflecting on their own learning. More specifically, they state that technology-based environments such as hypermedia should not be used unless the students already have appropriate prior knowledge, cognitive strategies, and metacognitive skills.

Despite the importance of self-regulation for learning with hypermedia, there has been relatively little empirical research on students' use of self-regulatory strategies during learning with such complex technology-based learning environments. Recent studies have either attempted to identify the strategies learners use during learning with these environments (e.g., Greene & Land, 2000; Hill & Hannafin, 1997) or identify the effectiveness of embedded strategies in these environments (e.g., McManus, 2000). The latter set of studies has attempted to identify the effectiveness of embedded SRL learning strategies such as advance organizers, navigation maps, note-taking, and search tools (e.g., Eom & Reiser, 2000; Hartley, 2001; McManus, 2000; Shapiro, 2000; Young, 1996). Overall, these studies indicate that high self-regulating learners (defined by pretest measures of SRL) tend to outperform (but not significantly) low-self-regulating learners in complex technology-based environments. In sum, studies examining the role of learner characteristics and embedded strategies have led to mixed results.

While these studies have attempted to study individual strategies or a few embedded strategies, they have not provided evidence of the complex, dynamic nature of SRL during learning with hypermedia. Existing studies are not sufficient for establishing clear, empirically-based guidelines for the design of strategy instruction interventions designed to train students to regulate their learning with hypermedia. While some researchers have emphasized the need to understand how SRL changes when a learner studies with the hypermedia environment (Weller, Repman, Lan, & Rooze, 1995), others have recommended selecting one or a few SRL processes for study while holding others constant.

Several researchers have recently examined how students self-regulate their learning with hypermedia. These studies offer theoretical and methodological advantages by adopting models of SRL (e.g., Winne, 2001; Winne & Hadwin, 1998) and examining the dynamics of SRL to explore how students regulate their learning of complex topics with hypermedia. A study by Azevedo, Guthrie, & Seibert (in press) on college students' ability to learn about complex science topics examined whether students could regulate their own learning when using a hypermedia environment to learn about the circulatory system. Their results indicated that students differ in their ability to regulate their learning. Students who showed significant learning gains from pretest to posttest regulated their learning by using effective strategies, planning their learning by creating sub-goals and activating prior knowledge, monitoring their emerging understanding, and planning their time and effort. In contrast, those who did not show large learning gains used equal amounts of effective and ineffective strategies, planned their learning by using sub-goals and recycling goals in working memory, handled task difficulties and demands by engaging mainly in help-seeking behavior, and did not engage in much monitoring of their learning. This study established that some students can learn with hypermedia environments and that the ability to learn about complex systems is associated with the deployment of certain SRL mechanisms during learning.

A subsequent study by Azevedo, Cromley, Seibert, & Tron (2003a) examined the effect of different conceptual scaffolding instructional interventions on facilitating students' understanding of a complex topic. They randomly assigned 51 students to one of three conceptual scaffolding instructional conditions (no scaffolding, fixed scaffolding, and adaptive scaffolding). Learners in the adaptive scaffolding condition, where students had access to a tutor to regulate their learning, learned significantly more than those in the other conditions. The tutor in the adaptive instructional condition assisted students in establishing goals, monitoring emerging understanding, using effective strategies, and providing motivational scaffolding. Learners in the no scaffolding and fixed scaffolding (who were given a list of expert-set sub-goals to guide their learning) conditions were less effective at regulating their learning and exhibited great variability in self-regulating their learning during the knowledge construction activity.

These results provide a valuable initial characterization of the role of SRL in accounting for differences in conceptual knowledge gains when students use hypermedia environments to learn about complex science topics. The results have led us to the present study, in which we examine whether students can be trained to regulate their learning about complex systems with hypermedia.

In this study, we extend their research to empirically test whether their results could be used to train students to use self-regulating variables to learn about complex science topics with hypermedia.

Overview of Current Study and Hypotheses

In this study, we investigated the effectiveness of training students to regulate their learning with hypermedia. Would providing students with training on how to regulate their learning lead to significant changes in their understanding of the circulatory system during learning with hypermedia? In this paper we focus on three research questions—(1) *Does training students to regulate their learning influence their ability to shift to a more sophisticated mental model of the circulatory system?* (2) *How does SRL training influence students' ability to regulate their learning from hypermedia?* (3) *Do students in different training conditions spend equal amounts of time on different representations of information to learn about the circulatory system?* We used a hypermedia environment and two experimental conditions to attempt to answer these questions. In the *SRL training condition* (SRL_T) students received a 30-minute training session on how to regulate their learning of the circulatory system when using a hypermedia environment. Prior to the experiment, we designed a 4-page script for the SRL_T condition. It contained a table showing phases and areas of SRL, a diagram illustrating the experimental session, and a table with a list of SRL variables, which Azevedo et al. (in press) have found that self-regulated learners enact when using a hypermedia environment to learn about the circulatory system. Learners were specifically instructed to use the SRL variables explained in the script to learn with the hypermedia environment. Subsequently, students were given a general learning goal and were allowed to generate their own learning goals during learning.

The SRL_T condition was designed to test whether training student on how to regulate their learning was effective in shifting students' conceptual understanding (from pretest to posttest), and whether the students used the SRL variables they learned during the training phase to regulate their learning in the hypermedia environment. Based on Winne and colleagues' (1998; 2001) SRL model and our previous research, we hypothesized that there would be a significant increase in students' conceptual understanding and that this shift would be associated with a significant use of SRL variables taught during the training session.

The *no SRL training condition (NO SRL_T)* was identical to the SRL_T condition, except that students did not receive any training on how to regulate their learning of the circulatory system. This NO SRL_T condition was designed to determine how students would regulate their learning without the benefit of training on how to regulate their learning. We hypothesized that these students would not learn significantly more than the SRL_T students and that there would be significantly fewer participants who would use key SRL variables (taught to the SRL_T students) at high levels.

Method

Participants

Participants were 131 undergraduate students (96 women and 35 men) who received extra credit in their Educational Psychology course for their participation. Their mean age was 22.1 years and mean GPA was 3.15. Forty-one percent ($n = 21$) were seniors, 35% ($n = 18$) were juniors, 14% ($n = 7$) were sophomores, and 10% ($n = 5$) were freshmen. The students were non-biology majors and the pretest confirmed that all participants had average or little knowledge of the circulatory system.

Research Design

This study combined a pretest-posttest design (131 students randomly assigned to one of two experimental conditions—SRL Training [SRL_T] and No SRL Training [NO SRL_T]) with a think-aloud protocol methodology (Ericsson & Simon, 1993). There were 63 participants in the SRL_T condition and 68 in the NO SRL_T condition.

Measures

Paper-and-pencil materials consisted of a consent form, a participant questionnaire, a pretest, and a posttest. All of the paper-and-pencil materials, except for the consent form and questionnaire, were constructed in consultation with 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 (matching), (2) a color picture of the heart on which students were asked to label 20 components (labeling), (3) an outline of the human body on which students were asked to draw the path of blood throughout the body (ensuring that the path included the heart, lungs, brain, feet, and hands) (flow), and (4) another sheet which contained the instruction, *"Please write down everything you can about the circulatory system"*(essay). The pretest and posttest were identical.

Hypermedia Environment

During the experimental phase the participants used Microsoft's Encarta Reference Suite™ (2000) 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. For this study, participants were limited to using the encyclopedia portion of the package. During the training phase learners were shown the three most relevant articles in the environment (blood, heart, and circulatory system), which included multiple representations of information—text, static diagrams, photographs, and a digitized animation depicting the functioning of the circulatory system. During learning, participants were allowed to use all of the features incorporated in Encarta such as the search button, hyperlinks, and multiple representations of information, and were allowed to navigate freely within the environment.

Script for the SRL Training (SRL_T) Condition.

Prior to the experiment, the experimenters designed a script for the learners assigned to the SRL training condition. The 4-page script 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) based on Azevedo et al., (in press). 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.

Procedure

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 following instructions were read and presented to the participants in writing.

No SRL training (NO SRL_T) condition. For the no SRL training condition the instructions were: "*You are being presented with a hypermedia encyclopedia, which contains textual information, static diagrams, and a digitized video clip of the circulatory system. We are trying to learn more about how students learn from hypermedia environments, as well as what role multiple representations play in learning about the circulatory system. Your task is to learn all you can about the circulatory system in 45 minutes. 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. We ask you to 'think aloud' continuously while you use the hypermedia environment to learn about the circulatory system. I'll be here in case anything goes wrong with the computer or the equipment. Please remember that it is very important to say everything that you are thinking while you are working on this task.*"

SRL training (SRL_T) condition. In the SRL training condition, learners went over the script (previously described) with the experimenter for approximately 30 minutes before using the hypermedia environment to learn about the circulatory system. The instructions for the SRL training instruction condition were identical to those for the NO SRL_T condition, except that learners were specifically instructed to use the SRL variables explained in the script to learn from the hypermedia environment.

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 learned. 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 had access to the instructions (which included the learning goal) during the learning session. Participants in both conditions were given 45 minutes to use the hypermedia environment to learn about the circulatory system. They spent an equal amount of time using the hypermedia environment to learn about the circulatory system (F [1, 129] = 1.75, $p > .05$; SRL_T *Mean* = 44.0 min, *SD* = 1.7; NO SRL_T *Mean* = 44.4, *SD* = 1.4). They were allowed to takes notes and draw during the learning session, although not all chose to do so.

All participants were given the posttest after using the hypermedia environment to learn about the circulatory system. They were given 30 minutes to complete the posttest. All participants independently completed the posttest in 30 minutes without their notes or any other instructional materials by writing their answers on the sheets provided by the experimenter.

Data Analysis

In this section we describe the coding of the students' mental models, the students' answers for the matching task and labeling of the heart diagram, the segmentation of the students' verbalizations while they were learning about the circulatory system, the coding scheme used to analyze the students' self-regulatory behavior, and inter-rater reliability measures.

Coding and scoring the students' mental models. Our analyses focused on the participants' shifts in mental models based on the different training 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 including the circulatory system (e.g., Azevedo et al., in press, 2002; Chi et al., 1994, 2001; Hegarty & Just, 1993; Vosniadou & Brewer, 1992).

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 and among the local features of each component, and the relationships among the local features of different components.

We followed Chi and colleagues' (1994) method for analyzing 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 essay section on the pretest as well as the student's flow diagram. Similarly, a student's final mental model of how the circulatory system works was derived from their statements from the essay section on the posttest and their flow diagram. In addition, we expanded Chi and colleagues' (1994; 2000) original six general types of mental models and strategically embedded six more, resulting in 12 models which represent the progression from no understanding to the most accurate and understanding: (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. The mental models accurately reflect biomedical knowledge provided by the nurse practitioner. A complete description of the necessary features for each mental model is provided in Table 1.

Insert Table 1 about here

We scored students' pretest and posttest mental models by assigning the numerical value associated with the mental models described in Table 1. For example, a student who stated that blood circulates would be given mental model of 1. These values for each student's pretest and posttest mental model were recorded and used in a subsequent analysis to determine the shift in their conceptual understanding (see inter-rater reliability below).

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 (range 0-16). 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) on his/her pretest and posttest (range 0-20). The scores for each student's pretest and posttest on the matching task and heart diagram were tabulated separately and used in subsequent analyses.

Time spent in multiple representations of information. A graduate student watched the video recording of each participant and recorded the time each learner spent on each representation (text, text and diagram, video, and external construction) present in the hypermedia environment. We recorded when each participant did the one of the following: (1) switched from one information source to another or (2) shifted from viewing the content in the environment to constructing their own representations (e.g., notes, drawings) on the paper provided by the experimenter. The total time spent on each representational type was tallied and used in subsequent analyses.

Segmenting and coding students' verbalizations. The raw data collected from this study consisted of 5,571 minutes (93 hr) of audio and video tape recordings from the 131 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. Transcripts were prepared for 129 of the 131 participants; 2 tapes could not be transcribed due to poor audio quality. This phase of the data analysis yielded 3,113 single-spaced pages (M = 24.1 pages per participant) with a total of 670,113 words (M = 5,195 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.

Coding learners' self-regulatory behavior. We used Azevedo and colleagues' (in press) model of SRL for analyzing the participant's self-regulatory behavior. Their model is based on several recent models of SRL (Pintrich, 2000; Winne, 1995; 1997; 2001; Winne & Hadwin, 1998; Winne & Perry, 2000; Zimmerman, 1989; 2000; 2001). It includes 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. Their model also includes SRL variables derived from students' self-regulatory behavior that are specific to learning with a hypermedia environment (e.g., coordinating informational sources).

The classes, descriptions and examples (from the protocols) of the planning, monitoring, strategy use, task difficulty and demands, and interest variables used for coding the learners' self-regulatory behavior are presented in Appendix A.

We used Azevedo and colleagues' (in press) SRL model to re-segment the data from the previous data analysis phase. This phase of the data analysis yielded 11,529 segments (M = 89 per transcript) with corresponding SRL variables. A graduate student coded the transcriptions by assigning each coded segment one of the SRL variables presented in Appendix A (see inter-rater reliability below).

Inter-rater reliability measures. Inter-rater reliability was established by recruiting and training a graduate student to use the description of the mental models developed by Azevedo et al. (in press). The graduate student was instructed to independently code all 262 selected protocols (pre- and posttest descriptions of the circulatory system from each participant) using the 12 mental models of the circulatory system. There was agreement on 249 out of a total of 262 student descriptions yielding a reliability coefficient of .95. Similarly, 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 with that of one of the experimenters. She was instructed to independently code 5,783 randomly selected protocol segments (50% of the 11,529 coded segments with corresponding SRL variables). There was agreement on 5,705 out of 5,783 segments yielding a reliability coefficient of .98. Inconsistencies were resolved through discussion between the experimenters and the student.

Results

Question 1: Does training students to regulate their learning influence their ability to shift to a more sophisticated mental model of the circulatory system? We used a 2 (condition: SRL training [SRL_T], no SRL training [NO SRL_T]) X 2 (time: pretest, posttest) mixed design to analyze the shift in learners' mental models and scores on the matching and labeling tasks. For all three analyses the first factor, Training Condition, was a between-subjects factor; the second factor, Time, was a within-subjects measure. The number of participants in each cell is 63 for the SRL_T condition and 68 for the NO SRL_T condition for all analyses pertaining to this question.

Shift in mental models. A 2 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, F (1, 129) = 191.78, MSE = 4.189, p < .05, ES = 0.60, and a significant interaction between condition and time, F (2, 128) = 10.714, MSE = 4.189, p < .05, ES = 0.08. Independent sample t-tests found no significant differences between the conditions at pretest, t (130) = .022, p > .05, but there were differences at posttest, t (130) = -3.861, p < .05. The results indicate that the SRL_T condition led to the highest mean "jump," or improvement, in students' mental models. On average, students in the SRL_T condition "jumped" 4.4 (SD = 2.9) mental models from pretest to posttest. In contrast, students in the NO SRL_T condition jumped considerably less (M = 2.7, SD = 2.6). The means and standard deviations are presented in Table 2.

Insert Table 2 about here

Matching task. A 2 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, F (1, 129) = 107.56, MSE = 235.20, p < .05, ES = 0.46, but no significant interaction between condition and time, F (2, 128) = .678, MSE = 235.20, p > .05, ES = 0.01. The results indicate that the learners in both experimental conditions improved their scores on the matching task from pretest to posttest (see Table 2).

Labeling task. A 2 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, F (1, 129) = 319.06, MSE = 138.39, p <.05, ES = 0.71, and a significant interaction between condition and time, F (2, 128) = 20.817, MSE = 138.39, p <.05, ES = 0.14. Participants in all conditions significantly improved their scores on the labeling task from pretest to posttest. Independent sample t-tests found no significant differences between the conditions at pretest t (129) = - 0.76, p > .05, but there were differences at posttest t (129) = - 4.42, p < .05. The results indicate that the SRL_T condition led to a higher mean improvement on the labeling task. On average, students in the SRL_T condition increased their scores by 32.6% (SD = 17.0) from pretest to posttest. In contrast, students in the NO SRL_T condition increased considerably less (M = 19.3%, SD = 16.7; see Table 2).

A second purpose of our research was to examine how learners in different training conditions regulate their learning of the circulatory system. Therefore, we now report on the processing involved in the learners' shifts in mental models from pretest to posttest.

Question 2: How does SRL training influence students' ability to regulate their learning from hypermedia? In this section we present the results of a series of chi-square analyses that were performed to determine whether there were significant differences in the distribution of students' use of SRL variables, across the two experimental conditions. We conducted a series of chi-square tests to examine how learners' use of self-regulatory variables differed across conditions. We first converted the raw counts to percentages for each person's use of each strategy. We then conducted a median split across all conditions for the proportion of use for each variable. We were then able to identify, for each variable, which participants used that variable at a proportion above or below the median. For example, participant S16 used Content Evaluation 16 times out of 47 utterances, or 12.77% of her moves. Across all participants, the median proportion for CE was 2.99%, placing S16 above the median proportion for CE. By contrast, participant S53 used CE once out of 100 moves, or 1.00% of her moves, placing her below the median proportion for CE. We then conducted a 2 x 2 chi-square analysis for each self-regulatory variable to determine whether the distribution of participants above and below the median across the treatments was significantly different from the null. 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.* The number of learners using each SRL variable above the median proportion across conditions and the results of the chi-squares tests are presented in Table 3.

Insert Table 3 about here

Planning. Chi-square analyses revealed significant differences in the number of participants who used three of the four planning variables above the median proportion across the training conditions (see Table 3 for all chi-square results). Overall, a significantly larger number of students in the SRL_T condition planned their learning by activating their prior knowledge and planning. By contrast, the learners in the NO SRL_T condition planned their learning by recycling goals in their working memory. A chi-square analysis did not reveal significant difference in the number of participants who created subgoals above the median proportion across the conditions.

Monitoring. Chi-square analyses revealed significant differences in the number of participants who used four of the six variables related to monitoring above the median proportion across the training conditions (see Table 3). Students in the SRL_T condition monitored their learning by using feeling of knowing (FOK), judging their learning (JOL), and monitored their progress toward goals. In contrast, learners in the NO SRL_T condition monitored their learning by identifying the adequacy of information. A chi-square analysis did not reveal significant difference in the number of participants who engaged in self-questioning or content evaluation above the median proportion across the conditions.

Strategies. Chi-square analyses revealed significant differences in the number of participants who used 11 of the 17 planning strategies above the median proportion across the training conditions (see Table 3). A significantly larger number of learners in the SRL_T condition used drawing, summarizing, taking notes, reading notes, knowledge elaboration, coordinating informational sources, and find location in the environment to learn about the circulatory system. In contrast, a large proportion of learners in the NO SRL_T condition learned by selecting new informational sources, engaging in free search and goal-directed search of the hypermedia environment, and evaluating the content as the answer to the goal. Six chi-square analyses did not reveal significant differences in the number of participants who, across conditions, used mnemonics, inferences, rereading, hypothesizing, reading a new paragraph, and memorization of instructional material above the median proportion (see Table 3).

Task Difficulty and Demands. Chi-square analyses revealed significant differences in the number of participants who used two of the five variables related to handling task difficulties and demands above the median proportion across the training conditions (see Table 3). A large proportion of learners in the SRL_T condition handled task difficulties by planning their time and effort. In contrast, the students in the NO SRL_T condition dealt with task difficulty and demands by controlling the hypermedia environment to enhance the reading and viewing of information. Three chi-square analyses did not reveal significant differences in the number of participants who, across conditions, used help-seeking behavior, expected the adequacy of information, or task difficulty above the median proportion (see Table 3).

Interest. A significant large proportion of learners in the SRL_T condition expressed interest in the topic (above the median frequency) during learning compared to the NO SRL_T condition (see Table 3).

We next present a qualitative description of how a "typical" learner in each training condition regulated their learning of the circulatory system, based on the verbal protocols.

SRL Training (SRL_T) Condition. In general, learners began by reviewing the overall learning goal from the instruction sheet and setting one or more learning sub-goals. 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. Students then often drew a diagram of the heart and the major blood vessels that carry blood to and from the chambers. Students frequently took notes on the flow of blood through the heart, technical terms (e.g., alveoli), and other new information.

Students would often summarize what they had read, restate information that had been read previously, and activate relevant prior knowledge. They frequently commented on their own level of understanding of what they were learning (Feeling of Knowing) or their lack of understanding (Judgment of Learning). When they did not understand, the used several effective fix-up strategies, such as rereading, making inferences, and knowledge elaboration. They also often expressed interest in the content. Students periodically monitored their progress toward goals, read their notes, and set new goals for the remaining time. Students also engaged in time and effort planning, noting how much time remained, asking the experimenter for the time, or adjusting learning strategies (e.g., skimming text when little time remained).

No SRL Training (NO SRL_T) Condition. In general, learners exhibited great variability in the way they regulated their learning. Some students in this condition 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 tended to use effective strategies to learn about the circulatory system. However, others did not set-up sub-goals or monitor their learning, and did not handle task difficulty and demands accordingly. They exhaustively searched the hypermedia module for content and recycled goals 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 strategies that would lead to deep understanding of the content. Learners would search for text, diagrams, and animation and read text out loud verbatim, without summarizing or paraphrasing. In many cases, they would read large segments of text and then ask the experimenter if they were on the right track. They would rarely summarize what they read, and when they did the summary was very superficial.

Question 3: Do students in different training conditions spend equal amounts of time on different representations of information to learn about the circulatory system? A MANOVA was conducted to determine whether learners in the training conditions differed in the amount of time they spent on each of the four representation types. Data were available for 126 participants; 5 tapes could not be coded due to video problems. There was a significant difference in the mean time that learners in each training condition spent on each type of representation (F [1, 125] = 10.41, $p < .05$). The results indicate small effect sizes for each representation type (ES = 0.02, 0.01, 0.05, and 0.14) for text, text and diagram, video, and externally constructed representations, respectively. Multiple pairwise comparison tests found significant differences between the training conditions for two out of the four representation types. Learners in the SRL_T condition spent significantly less time (t [125] = 2.64, $p < .05$) watching the video than those in the NO SRL_T condition (*Mean* = 2.4 min, *SD* = 2.7; *Mean* = 3.7 min, *SD* = 2.5, respectively). Learners in SRL_T condition spent significantly more time (t [125] = -4.53, $p < .05$) constructing their own representations than those in the NO SRL_T condition (*Mean* = 10.2, *SD* = 7.1 min; *Mean* = 4.6 min, *SD* = 6.6, respectively). However, all learners tended to read the same amount of text (t [125] = -1.66, $p > .05$; SRL_T *Mean* = 12.2 min, *SD* = 5.5; NO SRL_T *Mean* = 10.6 min, *SD* = 5.6) and the same amount of text and diagrams (t [125] = 1.17, $p > .05$; NO SRL_T *Mean* = 21.4 min, *SD* = 7.3; SRL_T *Mean* = 20.1 min, *SD* = 5.4) across conditions. Students in the SRL_T group spent significantly more time constructing external representations, learners in the NO SRL_T group spent significantly more time watching the video and there were no differences in time spent on text and text and diagrams.

Conclusion

We examined the effectiveness of self-regulated learning (SRL) training in facilitating students' learning with hypermedia as indicated by both performance and process data. Undergraduate students were randomly assigned to either a training condition on how to regulate their learning or a no training condition, and used a hypermedia environment to learn about the circulatory system. Students in the SRL_T group were given a 30-minute training period on the use of specific, empirically-based self-regulated learning (SRL) variables designed to foster their conceptual understanding. Pretest, posttest, and verbal protocol data were collected. Findings revealed that the SRL_T condition facilitated the shift in learners' mental models significantly more than did the NO SRL_T condition. Verbal protocol data indicated that this significant change in SRL_T students' conceptual understanding was based on the use of the SRL variables taught during training. SRL_T participants regulated their learning by planning and activating their prior knowledge, engaging in several metacognitive monitoring activities, using several effective strategies, handling task difficulties and demands by planning their time and effort, and expressing interest in the topic. SRL_T participants also differed in the amount of time spent on each representation of information.

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Table 1

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

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Table 2

Means (and Standard Deviations) for the Pretest and Posttest Learning Outcomes Measures by Training Condition.

	SRL Training (SRL_T) (n = 63)				No SRL Training (NO SRL_T) (n = 68)			
	Pretest		Posttest		Pretest		Posttest	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Essay and Flow Diagram (Mental Models)	6.0	2.9	10.4	2.2	6.0	2.8	8.7	2.7
Matching	60.8	26.7	82.0	17.0	54.9	26.3	73.0	22.3
Labeling	5.5	9.0	38.1	18.6	4.3	9.3	23.6	18.9

Table 3

Number and Proportion of Learners Using Self-Regulated Learning Variables Above the Median Proportion, by Training Condition.

Variable	SRL Training (SRL_T) (n = 62)	No SRL Training (NO SRL_T) (n = 67)	χ^2	p
Planning				
Prior Knowledge Activation	**37 (60%)**[a]	27 (40%)	4.84	.028
Planning	**37 (60%)**[a]	26 (39%)	5.61	.018
Recycle Goal in Working Memory	0 (0%)	**35 (52%)**[b]	44.45	.000
Sub-Goals	26 (42%)	**38 (57%)**	2.81	.093
Monitoring				
Feeling of Knowing (FOK)	**44 (71%)**[a]	20 (30%)	21.78	.000
Judgment of Learning (JOL)	**39 (63%)**[a]	25 (37%)	8.44	.004
Monitoring Progress Toward Goals	**37 (60%)**[a]	27 (40%)	4.84	.028
Identify Adequacy of Information	21 (34%)	**43 (64%)**[b]	11.83	.001
Self-Questioning	**32 (52%)**	26 (39%)	2.13	.144
Content Evaluation	30 (48%)	**34 (51%)**	0.07	.789
Strategy Use				
Draw	**37 (60%)**[a]	27 (40%)	4.84	.028
Summarization	**37 (60%)**[a]	27 (40%)	4.84	.028
Taking Notes	**37 (60%)**[a]	27 (40%)	4.84	.028
Read Notes	**34 (55%)**[a]	15 (22%)	14.40	.000
Knowledge Elaboration	29 (47%)[a]	15 (22%)	8.52	.004
Coordinating Informational Sources	26 (42%)[a]	11 (16%)	10.25	.001
Find Location in Environment	21 (34%)[a]	12 (18%)	4.31	.038
Selecting New Informational Source	21 (34%)	**42 (63%)**[b]	10.70	.001
Goal-Directed Search	11 (18%)	**39 (58%)**[b]	22.22	.000
Free Search	21 (34%)	**39 (58%)**[b]	7.67	.006
Evaluate Content as Answer to Goal	3 (5%)	29 (43%)[b]	25.52	.000
Mnemonics	19 (31%)	11 (16%)	3.65	.056
Inferences	**34 (55%)**	30 (45%)	1.30	.253
Re-Reading	28 (45%)	**36 (54%)**	0.95	.331
Hypothesizing	6 (10%)	4 (6%)	0.21	.648
Read New Paragraph	6 (10%)	6 (9%)	0.02	.888
Memorization	8 (13%)	9 (13%)	0.01	.929
Task Difficulty and Demands				
Time and Effort Planning	**37 (60%)**[a]	27 (40%)	4.84	.028
Control of Context	19 (31%)	**45 (67%)**[b]	17.18	.000
Help Seeking Behavior	**36 (58%)**	28 (42%)	3.41	.065
Expect Adequacy of Information	19 (31%)	30 (45%)	2.73	.098
Task Difficulty	25 (40%)	19 (28%)	2.05	.152
Interest				
Interest Statement	**39 (63%)**[a]	25 (37%)	8.44	.004

Note: Degrees of freedom = 2 and n = 129 for all analyses.
Note. The **bold** type indicates the variable was used above the median proportion by more than 50% of participants.
[a] SRL_T group made the greatest contribution to chi-square for this variable.
[b] NO SRL_T group made the greatest contribution to chi-square for this variable.

Appendix A

Classes, Descriptions and Examples of the Variables Used to Code Learners' Self-Regulatory Behavior (from Azevedo, Guthrie, & Seibert, in press)

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	"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	"I'm looking for something that's going to discuss how things move through the system"
Prior Knowledge Activation	Searching memory for relevant prior knowledge either before beginning performance of a task or during task performance	"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	Restating the goal (e.g., question or parts of a question) in working memory (WM)	"...describe the location and function of the major valves in the heart"
Monitoring		
Judgment of Learning (JOL)	Learner becomes aware that they don't know or understand everything they read	"I don't know this stuff, it's difficult for me"
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	"... let me read this again since I'm starting to get it..."
Self-Questioning	Posing a question and re-reading to improve understanding of the content	[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	"I'm reading through the info but it's not specific enough for what I'm looking for"
Identify Adequacy of Information	Assessing the usefulness and/or adequacy of the content (reading, watching, etc.)	"...structures of the heart...here we go..."
Monitor Progress Toward Goals	Assessing whether previously-set goal has been met.	"Those were our goals, we accomplished them"

[1] All codes refer to what was recorded in the verbal protocols (i.e., what the students read, saw, and heard) during learning with the hypermedia environment.

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.	[Learner reads about location valves] then switches to watching the video to see their location
Coordinating Informational Sources	Coordinating multiple representations, e.g., drawing and notes.	"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.	"OK, now on to pulmonary"
Read Notes	Reviewing learner's notes.	"Carry blood away. Arteries—away."
Memorization	Learner tries to memorize text, diagram, etc.	"I'm going to try to memorize this picture"
Free Search	Searching the hypermedia environment without specifying a specific plan or goal	"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	Learner types in blood circulation in the search feature
Summarization	Summarizing what was just read, inspected, or heard in the hypermedia environment	"This says that white blood cells are involved in destroying foreign bodies"
Taking Notes	Copying text from the hypermedia environment	"I'm going to write that under heart"
Draw	Making a drawing or diagram to assist in learning	"...I'm trying to imitate the diagram as best as possible"
Re-reading	Re-reading or revisiting a section of the hypermedia environment	I'm reading this again.
Inferences	Making inferences based on what was read, seen, or heard in the hypermedia environment	...[Learner sees the diagram of the heart] and states "so the blood....through the ...then goes from the atrium to the ventricle... and then..."
Hypothesizing	Asking questions that go beyond what was read, seen or heard	"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	[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"
Mnemonic	Using a verbal or visual memory technique to remember content	Arteries—A for away
Evaluate Content as Answer to Goal	Statement that what was just read and/or seen meets a goal or sub-goal	[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.	"That's where we were."

Task Difficulty and Demands		
Time and Effort Planning	Attempts to intentionally control behavior	"I'm skipping over that section since 45 minutes is too short to get into all the details"
Help Seeking Behavior	Learner seeks assistance regarding either the adequateness of their answer or their instructional behavior	"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	"This is harder than reading a book"
Control of Context	Using features of the hypermedia environment to enhance the reading and viewing of information	[Learner double-clicks on the heart diagram to get a close-up of the structures]
Expectation of Adequacy of Information	Expecting that a certain type of representation will prove adequate given the current goal	"...the video will probably give me the info I need to answer this question"
Interest		
Interest Statement	Learner has a certain level of interest in the task or in the content domain of the task	"Interesting", "This stuff is interesting"

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