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Does Training on Self-Regulated Learning Facilitate Students' Learning With Hypermedia?

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The authors examined the effectiveness of self-regulated learning (SRL) training in facilitating college students' learning with hypermedia. Undergraduate students ($N = 131$) were randomly assigned to either a training condition or a control condition and used a hypermedia environment to learn about the circulatory system. Students in the SRL group were given a 30-min training session on the use of specific, empirically based SRL variables designed to foster their conceptual understanding; control students received no training. Pretest, posttest, and verbal protocol data were collected from both groups. The SRL condition facilitated the shift in learners' mental models significantly more than did the control condition; verbal protocol data indicated that this was associated with the use of the SRL variables taught during training.

Hypermedia environments have the potential to be powerful learning tools for fostering students' learning about complex topics. Hypermedia environments provide students with random, dynamic, nonlinear access to a wide range of information represented as text, graphics, animation, audio, and video (Jacobson & Archodidou, 2000; Jonassen, 1996). However, too few learners are skilled at regulating their learning to optimize what they learn (Hadwin & Winne, 2001). The majority of studies has shown that using hypermedia often leads to very little learning (see Dillon & Gabbard, 1998; Shapiro & Niederhauser, 2004). For the most part, these studies have found that students learn little with hypermedia environments and do not deploy key self-regulatory processes and mechanisms such as effective cognitive strategies and metacognitive monitoring during learning (see, e.g., Azevedo, Guthrie, & Seibert, 2004; Greene & Land, 2000; Hill & Hannafin, 1997). Although some have found success in improving students' self-regulated learning (SRL) with scaffolds and other instructional aids (Azevedo, Cromley, & Seibert, 2004), there is little empirical evidence as to whether students will gain conceptual understanding of complex topics if they are trained to regulate their learning. In the present study, we examined whether students who were trained to regulate their learning about the circulatory system using a hypermedia environment could gain a deep conceptual understanding of the topic.

Given the potential of hypermedia learning environments, we needed to investigate whether students could be trained to regulate their learning in these learning situations. We argued that training students to self-regulate while using hypermedia to learn about complex topics is likely to foster students' learning with these environments. This approach is an extension of studies examining the effectiveness of training students to regulate their learning in various content areas. Researchers have demonstrated the effectiveness of several approaches to regulating students' learning in several areas (see, e.g., Butler, 1998; Graham & Harris, 2003; Guthrie, Wigfield, & VonSecker, 2000; Magliano, Trabasso, & Graesser, 1999; Rosenshine & Meister, 1997; Wong, Harris, Graham, & Butler, 2003). We extended this general approach by training students to regulate their learning not only by using effective strategies but also by planning, monitoring, and handling task difficulties and demands. Increased research efforts are critical to understanding the effectiveness of training to regulate several aspects of learning complex topics with hypermedia.

Self-Regulated Learning and Hypermedia

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 both by personal characteristics of the learner and by contextual features of the environment (Pintrich, 2000). Thus, SRL models offer a comprehensive framework with which to examine how students learn and how they adapt during learning with hypermedia. Several researchers (Azevedo, Cromley, & Seibert, 2004; Azevedo, Cromley, Seibert, & Tron, 2003; Azevedo, Cromley, Thomas, Seibert, & Tron, 2003; Azevedo, Guthrie, & Seibert, 2004; Hadwin & Winne, 2001; Winne & Stockley, 1998) have begun to examine the role of students' ability

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to regulate several aspects of their cognition, motivation, and behavior during learning of complex topics with hypermedia. This 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 hypermedia environments, students are given access to a wide range of information represented as text, graphics, animation, audio, and video, which is structured in a nonlinear fashion (Jonassen, 1996). Learning in such an environment requires a learner to regulate his or her learning, that is, to make decisions about what to learn, how to learn it, how much to learn, how much time to spend on it, how to access other instructional materials, how to determine whether he or she understands the material, when to abandon or modify plans and strategies, and when to increase effort (Williams, 1996). Specifically, students need to analyze the learning situation, set meaningful learning goals, determine which strategies to use, assess whether the strategies are effective in meeting the learning goal, evaluate their emerging understanding of the topic, and determine whether the learning strategy is effective for a given learning goal. They need to monitor their understanding and modify their plans, goals, strategies, and effort in relation to contextual conditions (e.g., cognitive, motivational, and task conditions). Furthermore, depending on the learning task, they need to reflect on the learning episode and modify their existing understanding of the topic (Winne, 2001; Winne & Hadwin, 1998). Because of these demands and despite their potential for fostering learning, hypermedia environments may prove to be ineffective if learners do not regulate their learning. Researchers have recently begun to identify several problems associated with learners' inability to regulate their learning with hypermedia.

Recent research has indicated that because of students' inability to regulate their learning with hypermedia, use of such environments rarely leads to deep conceptual understanding of complex topics (see, e.g., Greene & Land, 2000; Hannafin & Land, 1997; Jacobson & Archodidou, 2000; Kozma, Chin, Russell, & Marx, 2000; Shapiro, 1998, 1999, 2000). These studies have indicated that students have difficulties regulating aspects of their cognitive system (e.g., failure to activate relevant prior knowledge), difficulties regulating features of the hypermedia (e.g., coordination of and access to multiple representations of information, determination of an adequate instructional sequence), and difficulties regulating the mediation of learning processes (e.g., lack of planning and creation of subgoals, failure to engage in metacognitive monitoring of their emerging understanding of the topic, use of ineffective strategies). We argued that successful learning with these complex environments would require learners to self-regulate their learning. Given the importance of students' regulation of their learning with hypermedia, a next logical step in this area was to investigate the effectiveness of training learners' self-regulatory strategies with the goal of enhancing their learning with hypermedia. In the present study, we examined whether training in SRL was effective in facilitating students' ability to regulate their learning about the circulatory system using a hypermedia environment.

SRL Training and Learning With Hypermedia

Despite the importance of self-regulation for learning with hypermedia, there has been relatively little empirical research on students' SRL with such complex technology-based learning environments. Recent studies have either attempted to identify the strategies learners use during learning with these environments (see, e.g., Greene & Land, 2000; Hill & Hannafin, 1997) or to identify the effectiveness of embedded strategies in these environments (see, e.g., McManus, 2000). The latter set of studies has attempted to identify the effectiveness of embedded SRL strategies such as advance organizers, navigation maps, note-taking, and search tools (see, e.g., Eom & Reiser, 2000; Hartley, 2001; McManus, 2000; Shapiro, 2000; Young, 1996). Overall, these studies indicate that high-self-regulating learners tend to outperform (but not significantly) low-self-regulating learners in hypermedia environments. In general, learners tend not to plan or activate their prior knowledge, rarely use metacognitive monitoring processes, use ineffective strategies, and exhibit difficulties in handling task difficulties and demands (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004).

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 (see, 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, and Seibert (2004) 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. The 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 subgoals 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 subgoals 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 not all students were capable of regulating their learning with hypermedia, that some were led to inferior learning gains, and that those who did learn deployed certain key SRL mechanisms during learning.

A subsequent study by Azevedo, Cromley, and Seibert (2004) examined the effect of different scaffolding interventions on facilitating students' understanding of a complex topic. Fifty-one students were randomly assigned to one of three conceptual scaffolding instructional conditions (no scaffolding, fixed scaffolding, and adaptive scaffolding). Learners in the adaptive-scaffolding condition, in which 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 condition and the fixed-scaffolding condition (who were given a list of expert-set subgoals to guide their learning) were less effective at regulating their learning and exhibited great variability in self-regulating their learning during the knowledge construction activity. Similar to Azevedo, Guthrie, and Seibert (2004), this study by Azevedo, Cromley, and Seibert provides additional evidence that not all students are capable of regulating their learning with hypermedia, that this inability leads to inferior learning gains, and that these same students fail to deploy certain key SRL mechanisms during learning.

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 led us to the present study, in which we examined whether students can be trained to regulate their learning about complex systems with hypermedia. In this study, we extended Azevedo and colleagues' (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004) research to empirically test whether their results could be used to train students to use self-regulating variables to learn about the circulatory system 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? We focused on two research questions: (a) Does training students to regulate their learning influence their ability to shift to a more sophisticated mental model of the circulatory system? and (b) How does SRL training influence students' ability to regulate their learning from hypermedia?

On the basis of Winne and colleagues' (Winne, 2001; Winne & Hadwin, 1998) model of SRL and current empirical research on students' SRL with hypermedia (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004), we created two experimental conditions—an SRL training condition and a no-training control (C) condition. In the SRL training condition, students received a 30-min training session on how to regulate their learning of the circulatory system when using a hypermedia environment. Prior to the experiment, we designed a four-page script for the SRL training condition. It contained a table showing phases and areas of SRL, a diagram illustrating a simplified model of SRL, and a table with a list of SRL variables, which Azevedo, Cromley, and Seibert (2004) 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. In the C condition, we wanted to determine whether students could learn about a complex science topic given the same general learning goal but without the benefit of training on how to regulate their learning.

With regard to the first research question, we hypothesized that the SRL training condition would lead to a significant shift in students' conceptual understanding (from pretest to posttest). In contrast, we hypothesized that, in comparison with the SRL training condition, the C condition would lead to no significant shift in students' conceptual understanding. We used mental models to measure students' conceptual understanding both prior to and immediately following the instructional intervention. A mental model is an internal mental representation of some domain or situation that supports understanding, problem solving, reasoning, and prediction in complex, knowledge-rich domains, including the circulatory system (see, e.g., Azevedo, Cromley, & Seibert, 2004; Chi, de Leeuw, Chiu, & LaVancher, 1994; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001; Vosniadou & Brewer, 1992). A mental model can be measured in several ways, such as by assigning quality ratings for an essay that explains how a complex system works or by coding answers to a semistructured interview.

As for the second research question, we hypothesized that during learning about the circulatory system, students in the SRL training condition would deploy the SRL key variables they had been trained to use in the training session. In contrast, we hypothesized that, in comparison with the SRL training condition, in the C condition, there would be significantly fewer participants who would frequently use key SRL variables (taught to the SRL training condition students).

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 3.2. Fifty-one percent ($n = 67$) were seniors, 28% ($n = 36$) were juniors, 12% ($n = 16$) were sophomores, and 9% ($n = 12$) were freshmen. None of the students were biology majors, and the pretest confirmed that all participants had average or little knowledge of the circulatory system.

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: (a) a sheet on which students were asked to match 16 words with their corresponding definitions related to the circulatory system (matching); (b) a color picture of the heart on which students were asked to label 20 components (labeling); (c) 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 (d) another sheet which contained the instruction "Please write down everything you can 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" (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-in. 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 informational sources—text, static diagrams, photographs, and a digitized animation depicting the functioning of the circulatory system. Together, these three articles comprise 16,900 words, 18 sections, 107 hyperlinks, and 35 illustrations. During learning, participants were allowed to use all of the features incorporated in Encarta, such as the search functions, hyperlinks, and multiple sources of information, and were allowed to navigate freely within the environment. For example, a student who had set a goal to learn more about systemic circulation could find the relevant section of Encarta either by using the "find" function anywhere in Encarta or, if he or she was already in the circulatory system section, by using the "find in this article" search function or linking to it from the table of contents.

Script for the SRL Training Condition

Prior to the experiment, we designed a script for the learners assigned to the SRL training condition. The four-page script contained (a) a copy of Pintrich's (2000, p. 454) table of the phases and areas of SRL, (b) a one-page diagram illustrating the experimental session (based on Butler, 1997, p. 3), and (c) a two-page table with a list of SRL variables (with corresponding descriptions and examples) identical to Appendix A, based on Azevedo, Guthrie, and Seibert (2004) and Azevedo, Cromley, and Seibert (2004). The SRL variables include planning (planning, subgoals, 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, rereading, and knowledge elaboration), task difficulty and demands (time and effort planning, task difficulty, and control of context), and interest.

Procedure

Roger Azevedo 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 min 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 also presented to the participants in writing.

Control condition. For the C 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 condition. In the SRL training condition, Roger Azevedo spent 30 min training each participant how to regulate his or her learning of the circulatory system with the hypermedia environment before giving the learning instructions. First, he spent approximately the initial 10 min using the first page of the script, explaining to the participant the different phases and areas of regulation described in the Pintrich (2000, p. 454) table, and giving several examples of how this table could be used as a guiding framework during learning. Second, the next 10 min were spent presenting and describing to the student a diagram, which illustrated a simplified model of SRL based on Butler (1997, p. 3). This diagram clarified the complex interrelationships between students' knowledge, beliefs, and strategic approaches to learning tasks and various processes students engage in during SRL based on task definition, monitoring, strategy selection and use, and other dynamic processes that a student could potentially use during SRL. The last 10 min of the training session were spent describing each SRL variable presented on the third and fourth pages of the script and giving the student an operational definition of each. This was followed by presenting an example of each of the variables based on actual examples from previous students who had participated in our studies (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004). For example, students were told the following: "Prior knowledge activation is an important SRL variable for learning about the circulatory system. It involves searching memory for relevant prior knowledge either before beginning performance of a task or during task performance. An example of using prior knowledge activation during learning with hypermedia to learn about the circulatory system might be that I remember the role of red blood cells from my high school science classes." This was done for all 17 SRL variables found on the third and fourth pages of the script. Roger Azevedo answered any and all student questions during this training session. The instructions for the SRL training condition were identical to those for the C condition (see above) 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. Roger Azevedo reminded participants to keep verbalizing when they had been silent for more than 3 s (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 min to use the hypermedia environment to learn about the circulatory system. We remained nearby but did not answer any questions. There was no significant difference in the time spent using the hypermedia environment to learn about the circulatory system, $F(1, 129) = 1.75$, $p > .05$ (SRL training group $M = 44.0$ min, $SD = 1.7$; C group $M = 44.4$ min, $SD = 1.4$). Participants 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 min to complete the posttest. All participants independently completed the posttest in 30 min without their notes or any other instructional materials by writing their answers on the sheets provided by Roger Azevedo.

Coding and Scoring

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 interrater agreement.

Mental models. Our analyses focused on the shifts in participants' mental models based on the different training interventions. One goal of our research was to capture the initial and final mental models 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 referred to the correctness and completeness in regard to the local features of each component, the relationships among the local features of each component, and the relationships among the local features of different components.

We followed Chi et al.'s (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 his or her statements on the essay section on the pretest as well as from the student's flow diagram. Similarly, a student's final mental model of how the circulatory system works was derived from his or her statements on the essay section on the posttest and his or her flow diagram.

We expanded Chi and colleagues' (Chi, 2000; Chi et al., 1994) original 6 general types of mental models and strategically embedded 6 more, resulting in 12 models that represented the progression from no understanding to the most accurate 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 reflected biomedical knowledge provided by a consulting nurse practitioner. A complete description of the necessary features for each mental model is provided in Appendix B.

We scored students' pretest and posttest mental models by assigning the numerical value associated with a particular mental model as described in Appendix B. For example, a student who stated that blood circulates would be given a mental model of 2. In contrast, a student who stated that blood circulates, that the heart is a pump, and that vessels such as arteries and veins are used to transport blood would be given a mental model of 4. These values for each student's pretest and posttest mental models were recorded and used in a subsequent analysis to determine the shift in their conceptual understanding (see *Interrater agreement*, below).

Matching task and 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) on his or 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 or 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.

Students' verbalizations. The raw data collected from this study consisted of 5,571 min (93 hr) of audio- and videotape 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 audiotapes and created a text file for each participant. Transcripts were prepared for 129 of the 131 participants; two tapes could not be transcribed because of poor audio quality. This phase of the data analysis yielded 3,113 single-spaced pages ($M = 24.1$ pp. 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 videotape recording of the participant. The original text file was updated. This process was critical for our later coding of the students' SRL behavior.

Learners' self-regulatory behavior. Azevedo and colleagues' (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004) model of SRL was used to analyze the students' self-regulatory behavior. This model is based on several recent models of SRL (Pintrich, 2000; Winne, 2001; Winne & Hadwin, 1998; Winne & Perry, 2000; Zimmerman, 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 extends these key elements to capture the major phases of self-regulation. These are (a) planning and goal setting, activation of perceptions and knowledge of the task and context, and relationship of the self to the task; (b) monitoring processes that represent metacognitive awareness of different aspects of the self, task, and context; (c) efforts to control and regulate different aspects of the self, task, and context; and (d) various kinds of reactions and reflections on the self and the task and/or context. The 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 think-aloud 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' (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004) SRL model to resegment 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. Jennifer G. Cromley coded the transcriptions by assigning each coded segment one of the SRL variables presented in Appendix A.

Interrater agreement. Interrater agreement was established by training Jennifer G. Cromley to use the description of the mental models developed by Azevedo et al. (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004). She was instructed to independently code all the pretest and posttest essays 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 an interrater agreement of 95%. Similarly, interrater reliability was established for the coding of the learners' self-regulated behavior by comparing the individual coding of Cromley, who was trained to use the coding scheme, with that of Roger Azevedo. Cromley 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 an interrater agreement of 98% (Cohen's $\kappa = .99$). Inconsistencies were resolved through discussion between us.

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, C) $\times$ 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, and time was a within-subjects factor. The number of participants in each cell was 63 for the SRL training condition and 68 for the C condition for all analyses pertaining to this question.

Shift in mental models. A 2 $\times$ 2 repeated measures analysis of variance (ANOVA) on the pretest and posttest data showed a significant main effect of time, $F(1, 129) = 191.78$, $MSE = 4.189$, $p < .05$, $\eta^2 = 0.60$, and a significant interaction between condition and time, $F(2, 128) = 10.714$, $MSE = 4.189$, $p < .05$, $\eta^2 = 0.08$. Independent sample t tests found no significant differences between the conditions at pretest, $t(130) = .022$, $p > .05$, but there were differences at posttest, $t(130) = -3.861$, $p < .05$, $\eta^2 = 0.68$. The results indicate that the SRL training condition led to the highest mean jump, or improvement, in students' mental models from pretest to posttest. Students in the SRL training condition jumped an average of 4.4 ($SD = 2.9$) mental models from pretest to posttest. In contrast, students in the C condition jumped considerably less ($M = 2.7$, $SD = 2.6$). The means and standard deviations are presented in Table 1.

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

Table 1
Means and Standard Deviations for the Pretest and Posttest Learning Measures by Training Condition

	SRL training condition (n = 63)				Control condition (n = 68)			
	Pretest		Posttest		Pretest		Posttest	
Learning measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*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

Note. SRL = self-regulated learning.

Labeling task. A 2 × 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, $F(1, 129) = 319.06$, $MSE = 138.39$, $p < .05$, $\eta^2 = 0.71$, and a significant interaction between condition and time, $F(2, 128) = 20.817$, $MSE = 138.39$, $p < .05$, $\eta^2 = 0.14$. 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, $t(129) = -4.42$, $p < .05$, $\eta^2 = 0.78$. The results indicate that the SRL training condition led to a higher mean improvement on the labeling task. On average, students in the SRL training condition increased their scores by 32.6% (SD = 17.0) from pretest to posttest. In contrast, students in the C condition increased considerably less (M = 19.3%, SD = 16.7; see Table 1).

The second purpose of our research was to examine how learners in different training conditions regulated 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 we performed to determine whether there were significant differences in the distribution of students' use of SRL variables across the two conditions.[1] 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 difficulty and demands, and interest. The number of learners using each SRL variable above the median proportion across conditions, the corresponding results of the chi-square tests, and the raw frequencies for each SRL variable recorded and coded from the think-aloud protocols are presented in Table 2.

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 2 for all chi-square results). Overall, a significantly larger number of students in the SRL training condition planned their learning by activating their prior knowledge and by planning. By contrast, the learners in the C 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 2). Students in the SRL training condition monitored their learning by using feeling of knowing, judging their learning, and monitoring their progress toward goals. In contrast, learners in the C 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 2). A significantly larger number of learners in the SRL training condition used drawing, summarizing, taking notes, reading notes, knowledge elaboration, coordinating informational sources, and finding location in the environment to learn about the circulatory system. In contrast, a large proportion of learners in the C condition learned by selecting new informational sources, engaging in free search and in 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

[1] 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 next 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 6 times out of 47 utterances, or on 12.77% of her moves. Across all participants, the median proportion for content evaluation was 2.99%, placing S16 above the median proportion for content evaluation. By contrast, Participant S53 used content evaluation once out of 100 moves, or on 1.00% of her moves, placing her below the median proportion for content evaluation. We then conducted a 2 × 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.

Table 2

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

Class and variable	SRL training (n = 62) Raw frequencies	SRL training (n = 62) No. of learners above *Mdn* proportion (percentage above *Mdn* proportion)	Control condition (n = 67) Raw frequencies	Control condition (n = 67) No. of learners above *Mdn* proportion (percentage of learners above *Mdn* proportion)	χ^2	p
Planning						
Prior knowledge activation	[406]	**37 (60%)**[a]	[222]	27 (40%)	4.84	.028
Planning	[67]	**37 (60%)**[a]	[51]	26 (39%)	5.61	.018
Recycle goal in working memory	[0]	0 (0%)	[212]	**35 (52%)**[b]	44.45	< .001
Subgoals	[301]	26 (42%)	[340]	**38 (57%)**	2.81	.093
Monitoring						
Feeling of knowing	[729]	**44 (71%)**[a]	[248]	20 (30%)	21.78	< .001
Judgment of learning	[494]	**39 (63%)**[a]	[300]	25 (37%)	8.44	.004
Monitoring progress toward goals	[126]	**37 (60%)**[a]	[77]	27 (40%)	4.84	.028
Identify adequacy of information	[83]	21 (34%)	[129]	**43 (64%)**[b]	11.83	.001
Self-questioning	[89]	**32 (52%)**	[62]	26 (39%)	2.13	.144
Content evaluation	[186]	30 (48%)	[229]	**34 (51%)**	0.07	.789
Strategy use						
Draw	[103]	**37 (60%)**[a]	[46]	27 (40%)	4.84	.028
Summarization	[943]	**37 (60%)**[a]	[605]	27 (40%)	4.84	.028
Taking notes	[186]	**37 (60%)**[a]	[137]	27 (40%)	4.84	.028
Read notes	[88]	**34 (55%)**[a]	[38]	15 (22%)	14.40	< .001
Knowledge elaboration	[53]	29 (47%)[a]	[26]	15 (22%)	8.52	.004
Coordinating informational sources	[85]	26 (42%)[a]	[18]	11 (16%)	10.25	.001
Find location in environment	[29]	21 (34%)[a]	[17]	12 (18%)	4.31	.038
Selecting new informational source	[113]	21 (34%)	[190]	**42 (63%)**[b]	10.70	.001
Goal-directed search	[18]	11 (18%)	[142]	**39 (58%)**[b]	22.22	< .001
Free search	[39]	21 (34%)	[127]	**39 (58%)**[b]	7.67	.006
Evaluate content as answer to goal	[3]	3 (5%)	[105]	29 (43%)[b]	25.52	< .001
Mnemonics	[63]	19 (31%)	[21]	11 (16%)	3.65	.056
Inferences	[171]	**34 (55%)**	[129]	30 (45%)	1.30	.253
Rereading	[244]	28 (45%)	[269]	**36 (54%)**	0.95	.331
Hypothesizing	[10]	6 (10%)	[5]	4 (6%)	0.21	.648
Read new paragraph	[7]	6 (10%)	[7]	6 (9%)	0.02	.888
Memorization	[20]	8 (13%)	[14]	9 (13%)	0.01	.929
Task difficulty and demands						
Time and effort planning	[120]	**37 (60%)**[a]	[55]	27 (40%)	4.84	.028
Control of context	[76]	19 (31%)	[225]	**45 (67%)**[b]	17.18	< .001
Help-seeking behavior	[667]	**36 (58%)**	[168]	28 (42%)	3.41	.065
Expect adequacy of information	[33]	19 (31%)	[67]	30 (45%)	2.73	.098
Task difficulty	[55]	25 (40%)	[35]	19 (28%)	2.05	.152
Interest						
Interest statement	[104]	**39 (63%)**[a]	[114]	25 (37%)	8.44	.004

Note. Degrees of freedom = 2 and n = 129 for all analyses. The bold type indicates the variable was used above the median proportion by more than 50% of participants. SRL = self-regulated learning.
[a] SRL training group made the greatest contribution to chi-square for this variable. [b] Control group made the greatest contribution to chi-square for this variable.

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 2).

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 2). A large proportion of learners in the SRL training condition handled task difficulties by planning their time and effort. In contrast, the students in the C 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 experienced task difficulty above the median proportion (see Table 2).

Interest. A significantly large proportion of learners in the SRL training condition expressed interest in the topic (above the median frequency) during learning, compared with the C condition (see Table 2).

Discussion

Our results show that hypermedia can be used to enhance learners' understanding of complex topics if they are trained to regulate their learning. We have empirically demonstrated the effectiveness of SRL training in facilitating students' learning as indicated by both performance and process data. Training students to self-regulate their learning on the basis of a 30-min training period on the use of specific empirically based SRL variables designed to foster conceptual understanding led to significant increases in their understanding of the circulatory system. Verbal protocols provide evidence that learners who receive SRL training can effectively deploy the key SRL processes and mechanisms that lead to significant shifts in their mental models.

With regard to the first research question, the results of this study show that students in the SRL training condition gained a deeper understanding than did C students when using a hypermedia environment to learn about complex science topics. The shift in their mental model (from pretest to posttest) was significantly greater than for those in the C condition. There was a large effect size (0.68) for condition on the students' posttest mental models. We conclude that students can be trained to regulate their learning with hypermedia by engaging in several key processes and mechanisms related to SRL, such as planning, monitoring, and enactment of effective strategies. This finding is consistent with previous research indicating that learners trained to regulate aspects of their learning have demonstrated significant learning gains in a variety of domains and tasks, such as reading in science (see, e.g., Guthrie et al., 2000). More importantly, this finding contributes to the literature on learning with hypermedia by demonstrating that training, aimed at teaching students to regulate the complex SRL processes and mechanisms, leads to superior learning gains during learning with hypermedia. Furthermore, it shows that a variety of empirically based SRL strategies lead to superior learning gains.

In our study, the students who did not receive SRL training gained significantly less conceptual understanding during learning about a complex science topic with a hypermedia environment. Our results indicate that providing students with an overall learning goal and no training on how to regulate their learning leads to inferior shifts in conceptual understanding. This finding is consistent with the majority of studies on nonlinear, random-access hypermedia environments with flexible access and a high degree of learner control (see, e.g., Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004; Greene & Land, 2000; Jacobson & Archodidou, 2000).

As for the students' performance on the matching and labeling tasks, our results indicate that, similar to previous studies (e.g., Azevedo, Cromley, & Seibert, 2004), all students gained declarative knowledge as measured by the matching task. We hypothesize that all students gained some declarative knowledge because learners in both conditions spent three quarters of their learning time reading text and text and diagrams embedded in the hypermedia. As for the labeling task, students in the SRL training condition significantly outperformed students in the C condition. There was a large effect size (0.78) for condition on the students' posttest labeling task. We hypothesize that students in the SRL training condition learned significantly more on the labeling task because part of their training described the benefits of using effective strategies such as drawing their own picture of the heart, taking notes, and coordinating multiple representations of information.

With regard to the second research question, our extensive think-aloud protocols indicate that not only did the learners in the SRL training condition gain a deeper conceptual understanding but they also more frequently deployed the SRL processes taught them to effectively regulate their learning with hypermedia. The verbal protocols provided process data to indicate that students used the SRL processes, and the chi-square analyses, together with the product data, show that the use of these processes led to significant increases in students' understanding of the science topic. They regulated their learning by planning (prior knowledge activation, planning), metacognitively monitoring their cognitive system (judging their learning, feeling of knowing) and their progress toward goals, deploying effective strategies (drawing, summarizing, taking notes, reading notes, elaborating knowledge, coordinating informational sources, and finding location in the hypermedia environment), handling task difficulty and demands (time and effort planning), and expressing interest in the topic.

These findings are consistent with previous research on using trace methodologies to examine SRL processes used by learners during learning (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004; Hadwin & Winne, 2001; Winne & Stockley, 1998). They also highlight current theoretical and methodological concerns among SRL researchers that more research is required to understand the interrelatedness and dynamics of SRL variables during learning—the cognitive, motivational/affective, behavioral, and contextual factors deployed during the cyclical and iterative phases of planning, monitoring, control, and reflection (see, e.g., Pintrich, 2000; Winne, 2001; Winne & Jamieson-Noel, 2002; Winne, Jamieson-Noel, & Muis, 2002). Furthermore, we agree with Hadwin, Winne, Stockley, Nesbit, and Woszczyna (2001) that "if *adaptation* [italics added] is the hallmark of SRL, data consisting only of self-report questionnaire items and scales that aggregate responses [measuring students' self-regulated skills] independently of time and context may weakly reflect, and may even distort, what SRL is" (p. 486). This is definitively the case in the area of learning with hypermedia, where research has tended to focus only on learning gains and not on the learning process (see, e.g., Eom & Reiser, 2000; McManus, 2000; Young, 1996).

In our study, allowing students to use hypermedia without SRL training led to them attempting to regulate their learning by using inefficient planning activities (e.g., recycling goals in their memory), monitoring the content of the hypermedia system by identifying the adequacy of the information provided, using a variety of inefficient strategies to learn about the circulatory system (e.g., engaging in free search), and handling task difficulties and demands by focusing on features of the hypermedia environment to enhance the reading and viewing of information. That is, poor learners were externally focused, as opposed to self-regulating learners, who monitored their own cognitive systems and their progress toward goals. These findings are also consistent with the emerging results of recent SRL studies on learning with hypermedia (see, e.g., Azevedo, Guthrie, & Seibert, 2004). This study provides evidence that in an open-ended hypermedia task, learners define the task differently; they may or may not decide to plan their learning and activate prior knowledge or to monitor their learning, use effective strategies, and generate interest to sustain the learning activity (Hadwin & Winne, 2001).

Instructional Implications of SRL Training for Teaching and Learning With Hypermedia

Our results have implications for the design of hypermedia environments intended to foster students' learning of complex topics. One direct application of these results would be for teachers to train their students to regulate their learning with hypermedia by using our SRL script. By doing this, they might facilitate their students' learning of complex science topics when hypermedia environments are used in the classroom or at home for researching topics for school assignments.

A second application would be for instructional designers to incorporate specific embedded scaffolds in hypermedia environments designed to foster students' conceptual understanding of complex topics. The hypermedia environment could present several questions (similar to our pretest measures) at the onset of the learning task to measure students' current understanding and to activate any prior knowledge. This type of testing would need to be repeated during the learning task to continually monitor students' understanding and to periodically activate their prior knowledge. A planning net could be included to allow students to plan their learning activities by accessing general (expert-set) domain-specific learning goals and corresponding instructional hypermedia material. During learning, students would be able to access the two lists and compare them with their current goal(s). As for monitoring, the system could encourage a student to engage in two specific monitoring activities (i.e., feeling of knowing and judging their learning) related to knowledge and monitoring progress toward goals. A more demanding challenge would be to have the hypermedia environment facilitate a student's SRL by monitoring his or her progress toward goals. Because of current technological limitations, students' use of effective strategies (those used by learners who received SRL training, such as summarizing and taking notes) could be scaffolded within a hypermedia environment by providing online prompts, possibly from an embedded animated pedagogical agent (Mayer, Dow, & Mayer, 2003). Another technological challenge would be posed if the hypermedia environment was responsible for detecting a student's use of ineffective strategies (those used by learners who did not receive SRL training, such as free search) and could provide prompts and feedback designed to discourage the students from using them. Time and effort planning supports could include a monitoring mechanism that would display a list of goals, marking ones that have not been completed and indicating the time remaining. On the basis of that amount of time, the environment could recommend which goals and strategies (e.g., rereading vs. skimming) the student should focus on for the remaining time. Another technological challenge would be posed in assessing a student's level of interest in the topic or task. In sum, our empirical results challenge current approaches to the design of hypermedia intended to foster conceptual understanding by supporting learners' SRL (Azevedo, 2002).

Limitations

To date, there has been very little research on the educational potential of hypermedia environments. Therefore, in assessing the instructional value of this technology, we recommend keeping in mind that psychologists are at a very early stage of understanding how students learn with these environments. The conclusions we have drawn are limited by the participants' low prior knowledge and the nature of the hypermedia environment. It is possible that medium- or high-prior-knowledge students would have benefited differentially from our conditions; these questions should be explored in future research. Also, the learning environment consisted of a commercially based hypermedia environment that students are using in schools and homes to learn about complex science topics. We further note that even though Roger Azevedo was present in both conditions, the results for the training condition might be due to additional exposure (i.e., the 30-min training session) that the students had with him. More research is also needed to determine how different training methods can enhance students' ability to regulate their learning. In addition, a comprehensive understanding of learning with hypermedia can be achieved by conducting research that converges process data (i.e., tracing online SRL variables) with product data (learning outcomes) in complex topics. We conducted multiple chi-square tests on the SRL process data without correction for overall significance, which may be appropriate for an exploratory analysis. However, we acknowledge the need for the refinement of current statistical methods to analyze process data. An examination of the role of multiple representations of information in hypermedia environments is also needed vis-à-vis how a student regulates his or her learning. In sum, future research in this area has the potential to advance the current understanding of SRL and training methods as regards facilitating students' understanding of complex topics and informing the design of adaptive hypermedia systems.

References

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

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29,* 344–370.

Azevedo, R., Cromley, J. G., Seibert, D., & Tron, M. (2003, April). *The role of co-regulated learning during students' understanding of complex systems with hypermedia.* Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Azevedo, R., Cromley, J. G., Thomas, L., Seibert, D., & Tron, M. (2003, April). *Online process scaffolding and students' self-regulated learning with hypermedia*. Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Azevedo, R., Guthrie, J. T., & Seibert, D. (2004). The role of self-regulated learning in fostering students' conceptual understanding of complex systems with hypermedia. *Journal of Educational Computing Research, 30,* 87–111.

Butler, D. (1997, March). *The roles of goal setting and self-monitoring in students' self-regulated engagement of tasks.* Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Butler, D. (1998). The strategic content learning approach to promoting self-regulated learning: A report of three studies. *Journal of Educational Psychology, 90,* 682–697.

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

Dillon, A., & Gabbard, R. (1998). Hypermedia as educational technology: A review of the quantitative research literature on learner comprehension, control, and style. *Review of Educational Research, 68,* 322–349.

Eom, W., & Reiser, R. (2000). The effects of self-regulation and instructional control on performance and motivation in computer-based instruction. *International Journal of Instructional Media, 27,* 247–257.

Graham, S., & Harris, K. (2003). Students with learning disabilities and the process of writing; A meta-analysis of SRSD studies. In H. L. Swanson, K. R. Harris, & S. Graham (Eds.), *Handbook of learning disabilities* (pp. 323–344). New York: Guilford Press.

Greene, B., & Land, S. (2000). A qualitative analysis of scaffolding use in a resource-based learning environment involving the World Wide Web. *Journal of Educational Computing Research, 23,* 151–179.

Guthrie, J. T., Wigfield, A., & VonSecker, C. (2000). Effects of integrated instruction on motivation and strategy use in reading. *Journal of Educational Psychology, 92,* 331–341.

Hadwin, A., & Winne, P. (2001). CoNoteS2: A software tool for promoting self-regulation. *Educational Research and Evaluation, 7,* 313–334.

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

Hannafin, M. J., & Land, S. M. (1997). The foundations and assumptions of technology-enhanced student-centered learning environments. *Instructional Science, 25,* 167–202.

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

Hill, J., & Hannafin, M. (1997). Cognitive strategies and learning from the World Wide Web. *Educational Technology Research and Development, 45*(4), 37–64.

Jacobson, M., & Archodidou, A. (2000). The design of hypermedia tools for learning: Fostering conceptual change and transfer of complex scientific knowledge. *Journal of the Learning Sciences, 9,* 149–199.

Jonassen, D. (1996). *Computers as mind tools for schools*. Columbus, OH: Merrill.

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,* 105–144.

Magliano, J., Trabasso, T., & Graesser, A. (1999). Strategic processing during comprehension. *Journal of Educational Psychology, 91,* 615–629.

Mayer, R., Dow, G., & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology, 95,* 806–813.

McManus, T. (2000). Individualizing instruction in a Web-based hypermedia learning environment: Nonlinearity, advanced organizers, and self-regulated learners. *Journal of Interactive Learning Environments, 11,* 219–251.

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

Rosenshine, B., & Meister, C. (1997). Cognitive strategy instruction in reading. In S. A. Stahl & D. A. Hayes (Eds.), *Instructional models in reading* (pp. 85–107). Mahwah, NJ: Erlbaum.

Shapiro, A. M. (1998). Promoting active learning: The role of system structure in learning from hypertext. *Human–Computer Interaction, 13,* 1–35.

Shapiro, A. M. (1999). The relevance of hierarchies to learning biology from hypertext. *Journal of the Learning Sciences, 8,* 215–243.

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

Shapiro, A. M., & Niederhauser, D. (2004). Learning from hypertext: Research issues and findings. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (2nd ed, pp. 605–620). Mahwah, NJ: Erlbaum.

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

Williams, M. (1996). Learner control and instructional technologies. In D. Jonassen (Ed.), *Handbook of research on educational communications and technology* (pp. 957–983). New York: Scholastic.

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* (2nd ed., pp. 153–189). Mahwah, NJ: Erlbaum.

Winne, P. H., & Hadwin, A. (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., & Jamieson-Noel, D. (2002). Exploring students' calibration of self-reports about study tactics and achievement. *Contemporary Educational Psychology, 27,* 551–572.

Winne, P. H., Jamieson-Noel, D., & Muis, K. (2002). Methodological issues and advances in researching tactics, strategies, and self-regulated learning. In P. Pintrich & M. Maehr (Eds.), *New directions in measures and methods* (pp. 121–156). Amsterdam: JAI Press.

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

Winne, P. H., & Stockley, D. (1998). Computing technologies as sites for developing self-regulated learning. In D. Schunk & B. Zimmerman (Eds.), *Self-regulated learning: From teaching to self-reflective practice* (pp. 106–136). New York: Guilford Press.

Wong, B., Harris, K., Graham, S., & Butler, D. (2003). Cognitive strategies instruction research in learning disabilities. In H. L. Swanson, K. R. Harris, & S. Graham (Eds.), *Handbook of learning disabilities* (pp. 383–402). New York: Guilford Press.

Young, J. D. (1996). The effect of self-regulated learning strategies on performance in learner controlled computer-based instruction. *Educational Technology Research and Development, 44*(2), 17–27.

Zimmerman, B. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. 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* (2nd ed., pp. 1–37). Mahwah, NJ: Erlbaum.

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

Appendix A

Classes, Descriptions, and Examples of the Variables Used to Code Learners' Self-Regulatory Behavior (Based on Azevedo, Cromley, & Seibert 2004)

Class & variable	Description[a]	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 subgoals.	"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.	"Describe the location and function of the major valves in the heart."
Monitoring		
Judgment of learning	Learner becomes aware that he or she doesn't know or understand everything he or she reads.	"I don't know this stuff, it's difficult for me."
Feeling of knowing	Learner is aware of having read something in the past and having some understanding of it, but is not able to recall it on demand.	"Let me read this again since I'm starting to get it. . . ."
Self-questioning	Posing a question and rereading 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."
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 *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."
Rereading	Rereading 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."

(*Appendixes continue*)

Appendix A (*continued*)

Class & variable	Description[a]	Example
Strategy use (*continued*)		
Evaluate content as answer to goal	Statement that what was just read and/or seen meets a goal or subgoal.	Learner reads text: "So, I think that's the answer to this question."
Find location in environment	Statement about where in environment learner has 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 his or her answer or 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, or (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."

[a] 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.

Appendix B

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.
   - Describes "purpose"—oxygen/nutrient transport.
6. **Single Loop—Advanced**
   - Blood circulates.
   - Heart as pump.
   - Vessels (arteries/veins) transport.
   - Describes "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.
   - Describes "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.
   - Describes "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.
- Describes "purpose"— oxygen/nutrient transport.
- Describes loop: heart–body–heart–lungs–heart.

11. Double Loop—Detailed

- Blood circulates.
- Heart as pump.
- Vessels (arteries/veins) transport.
- Describes "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.
- Describes "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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