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ABSTRACT

This study examined the role of different scaffolding instructional interventions in facilitating students' shift to more sophisticated mental models as indicated by both performance and process data. Undergraduate students (n=51) were randomly assigned to use of one of three scaffolding conditions (adaptive scaffolding (AS), fixed scaffolding (FS), and no scaffolding (NS))and were trained to use a hypermedia environment to learn about the circulatory system. Pretest, posttest, and verbal protocol data were collected. Findings reveal that the AS condition facilitated the shift in learners' mental models significantly more than did the comparison conditions. Participants in the AS condition regulated their learning by activating prior knowledge, monitoring their emerging understanding by using several strategies, and engaging in adaptive help-seeking. Learners in the FS and NS conditions were less effective at regulating their learning and exhibited great variability in self-regulation of their learning during the knowledge construction activity. AS participants also differed in the amount of time spend on each representation of information. An appendix describes the variables used to code the data. (Contains 4 tables and 64 references.) (Author/SLD)

The Role of Co-Regulated Learning During Students' Understanding of Complex Systems with Hypermedia

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Abstract

We examined the role of different scaffolding instructional interventions in facilitating students' shift to more sophisticated mental models as indicated by both performance and process data. Undergraduate students ($N = 51$) were randomly assigned to one of three scaffolding conditions (adaptive scaffolding [AS], fixed scaffolding [FS], and no scaffolding [NS]) and were trained to use a hypermedia environment to learn about the circulatory system. Pretest, posttest, and verbal protocol data were collected. Findings revealed that the AS condition facilitated the shift in learners' mental models significantly more than did the other comparison conditions. Participants in the AS condition regulated their learning by activating prior knowledge, monitoring their emerging understanding by using several strategies, and engaging in adaptive help-seeking. Learners in the FS and NS conditions were less effective at regulating their learning and exhibited great variability in self-regulation of their learning during the knowledge construction activity. AS participants also differed in the amount of time spent on each representation of information.

The Role of Co-Regulated Learning During Students' Understanding of Complex Systems with Hypermedia

Hypermedia environments have the potential to enhance students' understanding of complex topics such as the circulatory system. However, research indicates that students experience certain difficulties in regulating their learning when they use hypermedia environments to learn about complex topics (Azevedo, Guthrie, & Seibert, *in press*; Brush & Saye, 2001; Jacobson & Archodidou, 2000; Land & Greene, 2000). Researchers have therefore attempted to facilitate students' learning of complex topics by using scaffolds, or instructional aids, designed to support students' understanding. Scaffolds are tools, strategies, and guides that can support students in regulating their understand of complex topics when using hypermedia. Although there are many descriptive studies of how scaffolds have been used in technology-based learning environments to support complex learning (e.g., Jackson, Krajcik, & Soloway, 2000), there is little empirical evidence that deals specifically with *which* types of scaffolds are effective in assisting students to regulate their learning with hypermedia. In the present study, we examine whether different scaffolding methods are effective in facilitating students' ability to regulate their learning about the circulatory system using a hypermedia environment.

Self-Regulated Learning and Hypermedia

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 non-linear fashion (Jonassen, 1996). Learning about a complex science topic (e.g., the circulatory system) with a hypermedia environment requires that a student make certain instructional decisions such as what and how to learn, as well as use several learning skills. Specifically, students need to analyze the learning situation, set meaningful learning goals, determine which strategies to use, asses 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 (cognitive, motivational, and task conditions), and, depending on the learning task, reflect on the learning episode (Hadwin & Winne, 2001; Winne, 2001; Winne & Hadwin, 1998; Winne & Stockley, 1998). Therefore, learning in such a complex environment requires a learner to regulate his or her learning—i.e., to make decisions about what to learn, how to learn it, how much time to spend on it, how to access other instructional materials, and to determine whether he or she understands the material (Williams, 1996).

Recent research has shown that learners have difficulty regulating several aspects of their learning when they use hypermedia environments to learn about complex topics and therefore learn little from these environments (Azevedo et al., in press; Azevedo & Cromley, 2003; Greene & Land, 2000, Hannafin & Land, 1997). Self-regulated learning (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 (Pintrich, 2000). Models of self-regulation (e.g., Pintrich, 2000; Schunk, 2001; Winne, 2001; Winne & Hadwin, 1998; Zimmerman, 2000) describe a recursive cycle of cognitive activities central to learning and knowledge construction activities. SRL models suggest that learning problems with hypermedia may occur because students are not actively and efficiently managing their own learning (Boekaerts, Pintrich, & Zeidner, 2000; Paris & Paris, 2001; Winne, 2001; Winne & Hadwin, 1998; Winne & Perry, 2000; Zimmerman & Schunk, 2001). Students also may not be metacognitively, motivationally, and behaviorally active during the learning process (Zimmerman, 1986). They may not generate the thoughts, feelings, and actions necessary to attain their learning goals.

Since learners have difficulty regulating several aspects of their learning in complex technology-based environments, one question is to empirically determine whether providing different types of scaffolding would enhance learners' understanding of a complex science topic. Based on the documented difficulties with regulating learning in hypermedia, we examined how we could scaffold students' learning and therefore allow them to develop a deep conceptual understanding of a complex topic (i.e., the circulatory system). We can then use the results to design adaptive hypermedia environments capable of providing individualized instruction and enhancing conceptual understanding of complex topics.

The Role of Scaffolding in Facilitating Self-Regulated Learning with Hypermedia

Scaffolding involves providing assistance to students on a needed basis, fading the assistance as their competence increases (Hogan & Pressley, 1997). Scaffolds are tools, strategies, and guides which are used during learning to support students' understanding, which would be impossible to attain if they learned on their own (Reiser, 2002). According to Hannafin, Land, and Oliver (1999), there are four types of scaffolds used in hypermedia environments: (1) conceptual, (2) metacognitive, (3) procedural, and (4) strategic. *Conceptual scaffolds* are designed to provide guidance about what knowledge to consider during problem solving. For example, Vye, Schwartz, Bransford, Barron, Zech and CTGV (1998) used hints, prompts, and suggestions of key content for students to consider and also had the main character "think aloud" to help students focus on content relevant to solving problems in *The Adventures of Jasper Woodbury*. *Metacognitive scaffolds* are designed to help students self-regulate the underlying processes associate with managing learning. White, Shimoda, and Frederiksen (2000) used embedded metacognitive tools in the form of learning agents, each of which supported students with the various phases of the science inquiry cycle (e.g., hypothesizing, data collection, data analysis, report writing, and presenting their results). *Procedural scaffolds* assist students with learning how to use resources or tools which are built into the environment. Azevedo, Verona and Cromley (2001) used procedural scaffolds to assist students in determining which RiverWeb resources (e.g., graphs, scatterplots) could facilitate their learning about environmental science issues. *Strategic scaffolds* make students aware of different techniques for solving problems. Lajoie and colleagues (Azevedo & Lajoie, 1998; Lajoie, Azevedo, & Fleiszer, 1998; Lajoie, Guerrera, Munsie, & Lavigne, 2001) used strategic scaffolds to expose students to a multitude of problem solving solutions by having them compare their solutions with those of more experienced peers or experts. Most of these environments include more than one type of scaffolding to facilitate students' understanding of complex topics (e.g., Jackson et al., 2000; Lajoie et al., 2001; Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001; White et al., 2000).

While the use of scaffolds in hypermedia environments is not a novel concept, there is a lack of empirical evidence regarding the effectiveness of various types of embedded scaffolds to support students' self-regulated learning of complex topics. These theoretically-grounded scaffolds have been embedded in environments and have been successful in scaffolding students' learning (e.g., Jacobson & Archodidou, 2000; Hannafin, Hill, & Land, 1997; Hannafin & Land, 2000).

Several studies have provided evidence that learning about complex topics with hypermedia in the absence of scaffolds hinders students' ability to regulate their learning and thus leads to a failure to gain a conceptual understanding of the topics (Azevedo, et al., in press; Greene & Land, 2000; Hill & Hannafin, 1999; Land & Greene, 2000). For example, 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 (e.g., summarization) and ineffective (e.g., memorizing) 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, that the ability to learn about complex systems is associated with the deployment of certain SRL mechanisms during learning, and that introducing scaffolds might facilitate the conceptual understanding of those who did not show learning gains.

Recent research on the effectiveness of fixed scaffolds used to support students' learning with hypermedia has yielded mixed results. Fixed scaffolds are static and are not adaptable to meet individual students' learning needs. Some studies have produced positive results regarding the effectiveness of fixed scaffolds in supporting students' learning with hypermedia (e.g., Chang, Sung, & Chen, 2001; Jacobson & Archodidou, 2000; Jacobson, Sugimoto & Archodidou, 1996; Reiser et al., 2001; Shapiro, 2000). In contrast, other studies have produced evidence indicating that fixed scaffolds do not enhance students' learning with hypermedia environments (e.g., Brush & Saye, 2001; Saye & Brush, 2002; Yang, 1999, McManus, 2000). For example, Azevedo, Ragan, Cromley, & Pritchett (2002) examined the role of different conceptual scaffolding instructional conditions for high school students' understanding of ecological systems with RiverWeb, a web-based hypermedia environment. The students were randomly assigned to one of two conceptual scaffolding instructional conditions (teacher-set goals or learner-generated sub-goals) and used the environment during a three-week curriculum on environmental science. Results indicate that students who generated their own learning goals had a significantly larger shift in their mental models and were also much better at regulating their learning than were the students who used teacher-set goals. These researchers argue that fixed scaffolds are not always effective because they are not adaptable and therefore do not address students' learning needs nor do they support students' regulatory behavior when using hypermedia. The static nature of fixed scaffolds stands in stark contrast with adaptive scaffolds.

Adaptive scaffolding may be more beneficial for supporting students' self-regulated learning because it adjusts to meet students' learning needs. Adaptive scaffolding requires a teacher or tutor to continuously diagnose the student's emerging understanding and provide timely support during learning (Merrill, Reiser, Merrill, & Landes, 1995). However, research on the effectiveness of adaptive scaffolding needs to be experimentally tested before it can be embedded into a hypermedia environment. A few studies have begun to address the effectiveness of providing students' with adaptive scaffolds to facilitate their regulatory behavior and thus enhance their learning with hypermedia. Adaptive scaffolding requires a delicate balance of negotiation between providing support while continuing to foster a student's own self-regulatory behavior (e.g., planning, setting learning goals, monitoring their emerging understanding, using effective strategies, handling task difficulties and demands) during learning. A few studies (Biemans, & Simons, 1995; Kao & Lehman, 1997; Kramarski & Hirsch, 2003) have recently provided evidence to support the notion that adaptive scaffolding in geography, algebra, and statistics leads to enhanced student understanding in hypermedia environments.

Overall, the literature indicates that scaffolding is critical for students' ability to regulate their learning and can therefore enhance the learning of complex topics while using hypermedia. However, the mixed results from studies examining the role of fixed scaffolds and the relatively few studies on the effectiveness of adaptive scaffolding do not provide clear directions for the types of scaffolds needed, how they support students' regulatory behavior, and how they impact students' learning of complex topics. In this study, we investigate whether students' understanding of complex systems can be fostered by providing different types of conceptual scaffolding during learning with hypermedia environments.

Overview of Current Study and Hypotheses

In this study, we investigated the effectiveness of different scaffolding methods for facilitating undergraduate students' ability to regulate their learning with hypermedia and also investigated *why* different types of scaffolding were differentially effective. We focus on three research questions: (1) Do different scaffolding conditions influence students' ability to shift to more sophisticated mental models of the circulatory system? 2) How do different scaffolding conditions influence students' ability to regulate their learning? 3) Do students in different scaffolding conditions spend equal amounts of time on different representations of information while learning about the circulatory system? We used a hypermedia environment and three experimental conditions to investigate these questions.

Based on Winne and colleagues' (Winne & Hadwin, 1998; Winne, 2001) model of SRL and the existing empirical literature on scaffolding and on learning with hypermedia we created three scaffolding conditions— adaptive scaffolding [AS], fixed scaffolding [FS], and no scaffolding [NS]. In the *adaptive scaffolding (AS)* condition, students were provided with an overall learning goal. They had access to a tutor who provided adaptive scaffolding by helping them enact various aspects of self-regulated learning (SRL), such as planning their learning, monitoring their emerging understanding, using different strategies to learn about the circulatory system, handling task difficulties and demands, and assessing their emerging understanding. These SRL variables were used dynamically and adaptively by the tutor during learning. We hypothesized that there would be a significant increase in students' conceptual understanding, but that students would not be as generative as in the FS and NS conditions because they would over-rely on the tutor's scaffolding. We also hypothesized that they would spend significantly more time constructing their own representations, significantly less time watching the animation and the same amount of time reading text, and text and diagrams.

In the *fixed scaffolding (FS) condition*, the students were given the same overall learning goal and a list of ten domain-specific questions. These were designed to scaffold their conceptual understanding of the circulatory system by providing a fixed list of sub-goals which an expert would use to learn about the system. We hypothesized that there would be no significant shift in students' conceptual understanding (from pretest to posttest). We also hypothesized that they would use several SRL variables to regulate their learning with the hypermedia environment and that they would vary in the amount of time spent on each type of representation available in the hypermedia environment.

In the *no scaffolding* (NS) condition, we wanted to determine whether students could learn about a complex science topic in the absence of any scaffolding. Based on Winne and colleagues' (1998, 2001) SRL model and our previous research, we hypothesized that there would be no significant shift in students' conceptual understanding (from pretest to posttest). We also hypothesized that students would use several SRL variables to regulate their learning with the hypermedia environment and that they would vary in the amount of time spent on each type of representation available in the hypermedia environment.

Method

Participants

Participants were 51 undergraduate students (38 women and 13 men) from a large mid-Atlantic university who received extra credit in their Educational Psychology course for their participation. Their mean age was 22 years and mean GPA was 3.2. 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 comparison group design (51 students randomly assigned to one of three scaffolding conditions—Adaptive Scaffolding [AS], Fixed Scaffolding [FS], and No Scaffolding [NS]) with a think-aloud protocol methodology (Ericsson & Simon, 1993). There were 17 participants in each condition.

Measures

The 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 the third author, a nurse practitioner who is also a faculty member at a school of nursing in a large mid-Atlantic university. Prior to taking part, all participants signed a letter that stated the purpose of the study and gave their informed consent. The participant questionnaire solicited information concerning age, sex, current GPA, number and title of undergraduate biology courses completed, and experience with biology and the circulatory system. There were four parts to the pretest: (1) a sheet on which students were asked to match 16 words with their corresponding definitions related to the circulatory system (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 posttest was identical to the pretest.

Hypermedia Environment

During the experimental phase the participants used Microsoft Encarta's 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 (i.e., circulatory system, blood, and heart), which contained 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 functions, hyperlinks, and multiple representations of information, and were allowed to navigate freely within the environment.

Procedure

Participants were randomly assigned to one of three groups: AS, FS, and NS. 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 their 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 Scaffolding (NS) Condition. For the NS 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 use hypermedia environments to learn 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 and the equipment. Please remember that it is very important to say everything that you are thinking while you are working on this task.*"

Fixed Scaffolding (FS) Condition. The instructions for the FS condition were identical to those for the NS condition, except that learners were presented with and instructed to use a list of ten domain-specific sub-goals, designed with the nurse practitioner (the third author), to guide their learning of the circulatory system. The ten sub-goals are presented in Table 1.

Insert Table 1 about here

Adaptive Scaffolding (AS) Condition. The instructions for the AS condition were identical to those for the FS condition, however, learners had access to a tutor (the third author) who would help them learn about the circulatory system during the learning session by providing adaptive scaffolding; assisting the learner to plan their learning, monitor their emerging understanding, use different strategies to learn, and handle task difficulties and demands, while covering the same ten sub-goals provided to the participants in the FS condition.

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. All participants had access to the instructions (which included the learning goal) during the learning session. Participants in the FS condition also had access to the

10 sub-goals, while participants in the AS condition had access to the tutor. All participants 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 [2, 48] = 0.93, $p > .05$; AS M = 44.4 min, SD = 0.7; FS M = 43.7 min, SD = 1.3; NS M = 44.2 min, SD = 2.0). 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 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 we used to analyze the students' and tutor's 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 scaffolding instructional interventions. A mental model is an internal mental representation of some domain or situation that supports understanding, problem solving, reasoning, and prediction in knowledge-rich domains including the circulatory system (e.g., Azevedo et al., in press; Azevedo & Cromley, 2003, Chi, 2000; Chi, de Leeuw, Chiu, & LaVancher, 1994; Chi, Siler, Jeong, Yamauchi, & Hausmann, 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 on the pretest essay 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 of the posttest and their flow diagram. We expanded Chi's original (1994; 2000) six general types of mental models and strategically embedded six more, resulting in 12 models which represent the progression from no 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 2.

Insert Table 2 about here

We scored students' pretest and posttest mental models by assigning the numerical value associated with the mental models described in Table 2. 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) (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, animation, and externally constructed representations) while learning with the hypermedia environment. We recorded when each participant did 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 2,203 minutes (37 hr) of audio and video tape recordings from the 51 participants, who gave extensive verbalizations while they learned about the circulatory system. During the first phase of data analysis, a graduate student transcribed the audio tapes and created a text file for each participant. This phase of the data analysis yielded a corpus of 1,212 single-spaced pages ($M = 24.2$ pages per participant) with a total of 260,884 words ($M = 5,218$ words per participant). 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 was critical in order for the experimenters to later code the learners' and tutor's SRL behavior.

Coding learners' and tutor's regulatory behavior. We used Azevedo and colleagues' (in press) model of SRL for analyzing the participants' 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 extends 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. Azevedo and colleagues' (in press) 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 model also includes behavior of the tutor in terms of providing tutor-initiated instructional methods and tutor-scaffolded behavior, varying the levels of scaffolding designed to enhance students' understanding while learning with a hypermedia environment.

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' and tutor's 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 7,327 segments (M = 143.7 per participant) with corresponding SRL variables. A graduate student coded the transcriptions by assigning each coded segment with one of the SRL variables presented in Table 3 (see inter-rater reliability below).

Inter-rater reliability. 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) (see Table 2). She was trained to independently code all 102 selected protocols (pre- and posttest descriptions of the circulatory system from each participant) using the 12 mental models of the circulatory system previously described and presented in Table 2. There was agreement on 92 out of a total of 102 student descriptions, yielding a reliability coefficient of .90. Similarly, inter-rater reliability was established for the coding of the learners' and tutor's regulatory behavior by comparing the individual coding of the same graduate student, who was trained to use the coding scheme (see Table 3) with that of one of the experimenters. She was instructed to independently code 2,488 randomly selected protocol segments (31% of the 7,327 coded segments with corresponding SRL variables). There was agreement on 2,442 out of 2,488 segments yielding a reliability coefficient of .98. Inconsistencies were resolved through discussion between the experimenters and the student.

Results

Question 1: Do different scaffolding conditions influence students' ability to shift to more sophisticated mental models of the circulatory system? We used a 3 (condition: adaptive scaffolding [AS], fixed scaffolding [FS], and no scaffolding [NS]) X 2 (time: pretest, posttest) mixed design to analyze changes in students' conceptual understanding by examining the shift in learners' mental models, and scores on the matching and labeling tasks. For all analyses the first factor, Scaffolding Condition, was a between-groups factor; the second factor, Time, was a within-subjects measure. The number of participants in each cell is 17 for all analyses pertaining to this question.

Shift in mental models. A 3 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, $F(1, 50) = 88.11$, $MSE = 3.37$, $p < .05$, and a significant interaction between condition and time, $F(2, 50) = 7.79$, $MSE = 26.23$, $p < .05$. Simple main effect analyses found no significant differences between the conditions at pretest, but there were differences at posttest ($F[2, 48] = 5.62$, $p < .05$). A follow-up LSD test showed that the shift in the AS condition was significantly greater than the FS and NS conditions ($p < .05$), which were not significantly different from each other ($p > .05$). The results indicate that the AS condition led to the highest mean "jump," or improvement, in students' mental models. On average, students in the AS condition "jumped" 5.4 ($SD = 2.8$) mental models from pretest to posttest. In contrast, students in the FS and NS conditions jumped considerably less ($M = 2.1$, $SD = 1.5$; and $M = 2.7$, $SD = 2.2$, respectively). The means and standard deviations are presented in Table 3.

Insert Table 3 about here

Matching task. A 3 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, $F(1, 50) = 29.48$, $MSE = 8.50$, $p < .05$, but no significant interaction between condition and time, $F(2, 50) = 1.30$, $MSE = 40.12$, $p > .05$. Learners in all three conditions significantly improved their scores on the matching task from pretest to posttest (see Table 3).

Labeling task. A 3 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, $F(1, 50) = 185.67$, $MSE = 96.32$, $p < .05$, and a significant interaction between condition and time, $F(2, 50) = 28.91$, $MSE = 281.12$, $p < .05$. The simple main effect analysis showed no significant differences between the conditions at pretest, but there were significant differences at posttest ($F[1, 48] = 164.26$, $p < .05$). The results indicate that the AS condition led to the highest mean improvement on the labeling task. On average, students in the AS condition increased their scores from 7.1% to 51.5% (a difference of 44.4%) from pretest to posttest. In contrast, students in the FS and NS conditions increased considerably less ($M = 8.28\%$, $SD = 13.4$; and, $M = 26.8\%$, $SD = 11.2$, respectively) (see Table 3).

A second purpose of our research was to examine how learners in different scaffolding 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 do different scaffolding conditions influence students' ability to regulate their learning? 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 three scaffolding conditions[i]. 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 of *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 4.

Insert Table 4 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 three scaffolding conditions (see Table 4 for all chi-square results). Overall, a significantly larger number of students in the AS condition planned their learning by activating their prior knowledge. By contrast, the learners in the FS condition planned by recycling goals in their working memory, and those in the NS condition planned their learning by creating sub-goals. A chi-square analysis did not reveal a significant difference in the number of participants who used planning above the median proportion across the three 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 three conceptual scaffolding conditions (see Table 4). Students in the AS condition monitored their learning by using feeling of knowing (FOK), judging their learning (JOL), and never engaged in self-questioning. In contrast, students in the FS condition monitored their learning mainly by evaluating the content of the hypermedia environment and identifying the adequacy of information. Learners in the NS condition monitored their learning by using a combination of the six monitoring methods to learn about the circulatory system. A chi-square analysis did not reveal significant difference in the number of participants who monitored their progress toward goals above the median proportion across the three conditions.

Strategies. Chi-square analyses revealed significant differences in the number of participants who used seven of the 17 strategies above the median proportion across the three scaffolding conditions (see Table 4). A significantly larger number of learners in the AS condition used find location in the environment to learn about the circulatory system. In contrast, a large number of learners in the FS condition learned by engaging in goal-directed search, and evaluating the content as the answer to the goal. Three chi-square analyses also revealed significant differences in the median frequency of use of mnemonics, reading notes, and coordinating multiple representations, due to the fact that none of the learners in the FS condition used these strategies to learn about the circulatory system. A large number of learners in the NS condition learned by taking notes, re-reading, selecting new informational sources, and engaging in free search of the hypermedia environment. Seven chi-square analyses did not reveal significant differences in the in the number of participants who, across conditions, used summarization, inferences, drawing, hypothesizing, knowledge elaboration, reading new paragraph, and memorization of instructional material (see Table 4).

Task difficulty and demands. Chi-square analyses revealed significant differences in the number of learners who used SRL variables related to task difficulty and demands above the median proportion across the three conceptual scaffolding conditions (see Table 4). A large number of learners in the AS condition handled task difficulties by seeking help from the tutor. In contrast, the students in the NS condition dealt with task difficulty and demands by planning their time and effort and controlling the hypermedia environment to enhance the reading and viewing of information. Similarly, learners in the FS condition also controlled the context and had expectations that a certain type of representation would prove adequate, given their goals.

Interest. A chi-square analysis revealed a significant difference in the number of learners who reported interest across the three scaffolding conditions (see Table 4). A significant large number of learners in the NS condition indicated interest above the median proportion during learning compared to AS and FS participants.

In the next section we present a qualitative description of how a "typical" learner in each of the three conditions regulated their learning of the circulatory system, based on the verbal protocols.

Adaptive Scaffolding (AS) Condition. The patterns of SRL variable use by participants in the AS condition were typified by 3033. We coded a total of 81 moves for her. A high proportion of her verbalizations were monitoring, such as Feeling of Knowing (FOK) (23% of her moves vs. a median of 6% for all participants) and Judgment of Learning (JOL) (15% vs. 7%), mostly in response to the tutor's questions, such as "Does that make sense?" She engaged in a high proportion of Prior Knowledge Activation (10% vs. 5%), especially as the tutoring session went on and the tutor prompted her to recall what she had learned at the beginning of the session. She also engaged in high levels of Help-Seeking Behavior (17% vs. 7%). Unlike many participants in the AS condition, who had long conversations that did not include the hypermedia environment and therefore "lost their place", she never needed to use Find Location in Environment.

However, like other AS participants, she never engaged in Self-Questioning. Like all participants, she engaged in a high proportion of Summarizing (25%).

Fixed Scaffolding (FS) Condition. Moves for the FS condition were typified by participant 3016. Of her 47 moves, a high proportion were searches related to the researcher-provided goals, both effective Goal-Directed Search (13% of her moves vs. a median of 2% for all participants) and ineffective Free Search (13% vs. 0%). She sometimes Recycled the Goal in Working Memory (4% vs. 0%). Her monitoring focused on evaluating whether the information in the environment was relevant to the question, either affirmatively (Identify Adequacy of Information [4% vs. 1%], Expectation of Adequacy of Information [8% vs. 0%]) or negatively (Content Evaluation [13% vs. 3%]). She also used the ineffective strategy of Evaluating Content as Answer to Goal (e.g., "What I just read, that's the answer.") Unlike many participants in the FS condition, she never used Control of Context nor did she Take Notes. However, like other FS participants, she never used Mnemonics or Memorized, nor did she Read Notes. Even though the experimenter in her condition was not able to answer questions, she nonetheless engaged in some Help-Seeking Behavior (6% vs. 7%).

No Scaffolding (NS) Condition. Participant 3071 showed a pattern typical for the NS condition. Of her 49 codes, she verbalized a high proportion of Sub-Goals (12% of her moves vs. a median of 2% for all participants), which was not surprising since she had to structure her own learning session. A high proportion of her verbalizations were searches related to those sub-goals, but these included both effective Goal-Directed Search (4% vs. 2%) and ineffective Free Search (8% vs. 0%). Unlike many participants in the NS condition, she never Monitored Progress Towards Goals, but she did engage in Content Evaluation (4% vs. 3%), deciding that the information in the environment would not help her meet her self-set goals. She used several effective strategies, frequently Rereading (10% vs. 2%), Selecting a New Informational Source (8% vs. 1%), and Taking Notes (2% vs. 0%). She engaged in some Time and Effort Planning (2% vs. 0%) and Control of Context (3% vs. 0%) and occasionally expressed Interest (4% vs. 0%). Like all participants, she engaged in a high proportion of Summarizing (20%).

Question 3: Do students in different scaffolding 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 scaffolding conditions differed in the amount of time they spent on each of the four representation types. There was a significant difference in the mean time that learners in each scaffolding condition spent on each type of representation (F [2, 48] = 12.79, $p < .05$). Post hoc analyses found significant differences between the three scaffolding conditions for three out of the four representation types. For text and diagram (F [2, 48] = 5.75, $p < .05$), video (F [2, 48] = 16.98, $p < .05$), and externally constructed representations (F [2, 48] = 32.62, $p < .05$). However, all learners tended to read the same amount of text across conditions (F [2, 48] = 1.95, $p > .05$). Additional follow-up pairwise analyses revealed that students in the NS condition spent significantly more time on text and diagrams than did those both the FS and AS conditions (M = 24.4 min, SD = 4.9; M = 19.4 min, SD = 5.7; M = 18.7 min, SD = 5.4, respectively). Learners in the NS condition spent significantly more time watching the video than those in the FS condition, who spent significantly more time than did those in the AS condition (M = 4.2 min, SD = 2.9; M = 3.8 min, SD = 2.7; M = 0.04 min, SD = 0.12, respectively). In contrast, the learners in the AS condition spend significantly more time (M = 12.8 min, SD = 7.9) on constructing external representations of the content presented in the hypermedia environment than those in both the NS and FS condition (*M* = 2.5 min, *SD* = 2.8; *M* = 0.2 min, *SD* = 0.4, respectively), who did not differ from each other.

Conclusion

We examined the role of different scaffolding instructional interventions in facilitating students' shift to more sophisticated mental models as indicated by both performance and process data. Undergraduate students were randomly assigned to one of three scaffolding conditions and were trained to use a hypermedia environment to learn about the circulatory system. Pretest, posttest, and verbal protocol data were collected. Findings revealed that the AS condition facilitated the shift in learners' mental models significantly more than did the other comparison conditions. Participants in the AS condition regulated their learning by activating prior knowledge, monitoring their emerging understanding by using several strategies, and engaging in adaptive help-seeking. Learners in the FS and NS conditions were less effective at regulating their learning and exhibited great variability in self-regulation of their learning during the knowledge construction activity. AS participants also differed in the amount of time spent on each representation of information.

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Table 1

Sub-Goals Used in the Fixed Scaffolding (FS) Condition.

1. Name the components of blood.

2. Describe the function of each type of cell found in blood.

3. Draw and describe the path one drop of blood takes as it travels through the heart.

4. Describe the location and function of the major (mechanical) valves in the heart.

5. List the support structures of the heart.

6. The heart is a pump that requires electrical impulses to keep it beating. Name the hearts' four major electrical structures.

7. Describe the flow of electricity through the heart.

8. The heart is only one part of the circulatory system. Name all the structures involved in circulating blood.

9. Describe the movement of blood through the circulatory system, naming all the organs involved. You may use paper and pencil to assist if necessary.

10. Identify at least 3 major functions of the circulatory system.

Table 2

Necessary Features for Each Type of Mental Model.

1. No understanding

2. Basic Global Concepts
- blood circulates

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

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

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

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

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

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

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

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

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

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

Table 3

Means (and Standard Deviations) for the Pretest and Posttest Learning Outcomes Measures by Scaffolding Conditions.

	Scaffolding Conditions					
	Adaptive Scaffolding (AS) (n = 17)		Fixed Scaffolding (FS) (n = 17)		No Scaffolding (NS) (n = 17)	
	Pretest M (SD)	Posttest M (SD)	Pretest M (SD)	Posttest M (SD)	Pretest M (SD)	Posttest M (SD)
Essay and Flow Diagram (Mental Models)	5.4 (3.5)	10.8 (2.2)	6.1 (3.2)	8.2 (2.8)	5.8 (2.2)	8.5 (2.2)
Matching	61.4 (31.7)	84.8 (28.2)	48.2 (27.9)	83.5 (14.3)	61.0 (27.2)	71.3 (17.3)
Labeling	7.1 (10.3)	51.5 (9.8)	4.1 (10.0)	12.4 (16.7)	2.6 (6.1)	29.4 (16.0)

Table 4

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

Variable	Adaptive Scaffolding (AS) (n = 17)	Fixed Scaffolding (FS) (n = 17)	No Scaffolding (NS) (n = 17)	χ^2	*p*
Planning					
Prior Knowledge Activation	**14 (82%)**[a]	3 (18%)	8 (47%)	14.28	.001
Recycle Goal in Working Memory	0 (0%)	**16 (94%)**[b]	2 (12%)	39.15	.000
Sub-Goals	4 (29%)	7 (41%)	**14 (82%)**[c]	12.40	.002
Planning	6 (35%)	1 (6%)	5 (29%)	4.58	.101
Monitoring					
Judgment of Learning (JOL)	**13 (76%)**[a]	4 (24%)	8 (47%)	9.57	.008
Feeling of Knowing (FOK)	**16 (94%)**[a]	3 (18%)	7 (41%)	20.87	.000
Self-Questioning	0 (0%)[a]	4 (24%)	8 (47%)	10.46	.005
Content Evaluation	0 (0%)	**15 (88%)**[b]	**10 (59%)**	27.46	.000
Identify Adequacy of Information	2 (12%)	**15 (88%)**[b]	8 (47%)	19.93	.000
Monitoring Progress Toward Goals	8 (47%)	6 (35%)	**11 (65%)**	2.98	.225
Strategy Use					
Find Location in Environment	**9 (53%)**[a]	3 (18%)	1 (6%)	10.74	.005
Goal-Directed Search	0 (0%)	**15 (88%)**[b]	**10 (59%)**	27.46	.000
Evaluate Content as Answer to Goal	0 (0%)	**15 (88%)**[b]	2 (12%)	35.12	.000
Mnemonics	4 (24%)	0 (0%)[b]	7 (41%)	8.58	.014
Read Notes	1 (6%)	0 (0%)[b]	6 (35%)	10.27	.006
Coordinating Informational Sources	2 (12%)	0 (0%)[b]	5 (29%)	6.29	.043
Taking Notes	3 (18%)	2 (12%)	**10 (59%)**[c]	10.77	.005
Re-Reading	5 (29%)	7 (41%)	**13 (76%)**[c]	8.16	.017
Selecting New Informational Source	0 (0%)	8 (47%)	**16 (94%)**[c]	30.29	.000
Free Search	2 (12%)	**10 (59%)**	**13 (76%)**[c]	15.22	.000
Summarization	**10 (59%)**	6 (35%)	**9 (53%)**	2.04	.361
Inferences	**9 (53%)**	5 (29%)	**11 (65%)**	4.39	.111
Draw	8 (47%)	7 (41%)	6 (35%)	0.49	.784
Hypothesizing	1 (6%)	1 (6%)	0 (0%)	1.04	.594
Knowledge Elaboration	7 (41%)	2 (12%)	8 (47%)	5.47	.065
Read New Paragraph	1 (6%)	0 (0%)	2 (12%)	2.13	.346
Memorization	1 (6%)	0 (0%)	4 (24%)	5.77	.056
Task Difficulty and Demands					
Help Seeking Behavior	**16 (94%)**[a]	**9 (53%)**	0 (0%)	30.29	.000
Control of Context	3 (18%)	**11 (65%)**[b]	**11 (65%)**[c]	10.04	.007
Expect Adequacy of Information	0 (0%)	**12 (71%)**[b]	4 (24%)	20.40	.000
Time and Effort Planning	4 (24%)	3 (18%)	**12 (71%)**[c]	12.25	.002
Task Difficulty	**9 (53%)**	7 (41%)	3 (18%)	4.70	.095
Interest					
Interest Statement	**9 (53%)**	1 (6%)	**14 (82%)**[c]	20.31	.000

Note: Degrees of freedom = 2 and n = 51 for all analyses.
Note. The **bold** type indicates the variable was used above the median proportion by more than 50% of participants.
[a]AS group made the greatest contribution to chi-square for this variable.
[b]FS group made the greatest contribution to chi-square for this variable.
[c]NS group made the greatest contribution to chi-square for this variable.

Appendix A

Classes, Descriptions and Examples of the Variables Used to Code Learners' and Tutor's Regulatory Behavior (based on 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	**Student:** "First I'll look around to see the structure of environment and then I'll go to specific sections of the circulatory system" **Tutor Scaffolding:** "What are you going to do?" **Tutor Instruction:** "Read this and then we'll go into the next section"
Goals	Consist either of operations that are possible, postponed, or intended, or of states that are expected to be obtained. Goals can be identified because they have no reference to already-existing states	**Student:** "I'm looking for something that's going to discuss how things move through the system" **Tutor Scaffolding:** "So what part are you going to start with, do you think?" **Tutor Instruction:** "We have to go find the answer to that"
Prior Knowledge Activation	Searching memory for relevant prior knowledge either before beginning performance of a task or during task performance	**Student:** "It's hard for me to understand, but I vaguely remember learning about the role of blood in high school" **Tutor Scaffolding:** "And then what happens in the lungs?" **Tutor Instruction:** "Remember, it's inside the blood vessel"
Recycle Goal in Working Memory	Restating the goal (e.g., question or parts of a question) in working memory (WM)	**Student:** "...describe the location and function of the major valves in the heart"
Monitoring		
Judgment of Learning (JOL)	Learner becomes aware that they don't know or understand everything they read	**Student (JOL):** "I don't know this stuff, it's difficult for me" **Tutor Instruction:** "We already read that"
Feeling of Knowing (FOK)	Learner is aware of having read something in the past and having some understanding of it, but not being able to recall it on demand	**Student:** "... let me read this again since I'm starting to get it..." **Tutor Scaffolding:** "Which side of the heart would be doing that work?" **Tutor Instruction):** "You're pretty comfortable with that part."
Self-Questioning	Posing a question and re-reading to improve understanding of the content	**Student:** [Learner spends time reading text] and then states "what do I know from this?" and reviews the same content

[1] All codes refer to what was recorded in the verbal protocols (i.e., read, seen, or heard in the environment and/or during discussions).

Content Evaluation	Monitoring content relative to goals	**Student:** "I'm reading through the info but it's not specific enough for what I'm looking for" **Tutor Scaffolding:** "Did it say there were platelets, too?" **Tutor Instruction:** "This is mostly history. I don't know if we're really interested that much"
Identify Adequacy of Information	Assessing the usefulness and/or adequacy of the content (reading, watching, etc.)	**Student:** "...structures of the heart...here we go..." **Tutor Instruction:** "So it's pretty important."
Monitor Progress Toward Goals	Assessing whether previously-set goal has been met.	**Student:** "Those were our goals, we accomplished them" **Tutor Scaffolding:** "Are we getting to some of these questions that they asked?" **Tutor Instruction:** "That's pretty much what you needed to know"
Strategy Use		
Selecting a New Informational Source	The selection and use of various cognitive strategies for memory, learning, reasoning, problem solving, and thinking. May include selecting a new representation, coordinating multiple representations, etc.	**Student:** [Learner reads about location valves] then switches to watching the video to see their location **Tutor Scaffolding:** "Well, you want to look at the heart again?" **Tutor Instruction:** "Go back [to the diagram and] look at that guy"
Coordinating Informational Sources	Coordinating multiple representations, e.g., drawing and notes.	**Student:** "I'm going to put that [text] with the diagram"
Read New Paragraph	The selection and use of a paragraph different from the one the student was reading.	**Student:** "OK, now on to pulmonary" **Tutor Instruction:** "Read . . .the first couple of sentences in each one of the paragraphs."
Review Notes	Reviewing learner's notes.	**Student:** "Carry blood away. Arteries—away."
Memorization	Learner tries to memorize text, diagram, etc.	**Student:** "I'm going to try to memorize this picture"
Free Search	Searching the hypermedia environment without specifying a specific plan or goal	**Student:** "I'm going to the top of the page to see what is there"
Goal-Directed Search	Searching the hypermedia environment after specifying a specific plan or goal	**Student:** Learner types in blood circulation in the search feature **Tutor Scaffolding:** "Try writing electrical" [in the search feature] **Tutor Instruction:** "Heartbeat—that would probably be it"
Summarization	Summarizing what was just read, inspected, or heard in the hypermedia environment	**Student:** "This says that white blood cells are involved in destroying foreign bodies" **Tutor Scaffolding:** "If you were to . . . re-describe that . . . ?" **Tutor Instruction:** "It's for oxygen and nutrient exchange."
Taking Notes	Copying text from the hypermedia environment	**Student:** "I'm going to write that under heart" **Tutor Scaffolding:** "I use shortcuts . . . RA for right atrium" **Tutor Instruction:** "Don't write down everything"

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

Task Difficulty and Demands

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

Expectation of Adequacy of Information	Expecting that a certain type of representation will prove adequate given the current goal	**Student (EA):** "...the video will probably give me the info I need to answer this question" **Tutor Instruction (TIEA):** "Click on the heart because I think it helps sometimes to see those structures"
Motivation		
Interest Statement	Learner has a certain level of interest in the task or in the content domain of the task	**Student:** "Interesting", "This stuff is interesting" **Tutor Instruction:** "Yeah, it's amazing!"
Positive feedback	Tutor tells learner his or her statement was correct, or repeating learner's correct statement.	**Tutor:** "Uh huh."
Negative feedback	Tutor tells learner his or her statement was incorrect.	**Tutor:** "No."
OK	Ambiguous feedback from tutor; could be a response to a correct or incorrect statement.	**Tutor:** "OK"
Encouragement	Tutor makes encouraging statement to learner.	**Tutor:** "That will become clearer as we go on."
Choice	Tutor offers learner a choice of next steps.	**Tutor:** "What do you want to do first?"

[i] 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 3026 used Goal-Directed Search (GDS) 4 times out of 88 utterances, or 4.55% of her moves. Across all participants, the median proportion for GDS was 1.85%, placing participant 3026 above the median proportion for GDS. By contrast, participant 3050 used GDS once out of 77 moves, or 1.30% of her moves, placing her below the median proportion for GDS. 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.

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