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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=53) were randomly assigned to 1 of 3 scaffolding conditions (adaptive content and process scaffolding (ACPS), adaptive process scaffolding (APS), 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 ACPS and APS conditions were equally effective and facilitated the shift in learners' mental models significantly more than did the NS condition. Despite the effectiveness of adaptive scaffolding conditions in facilitating students' understanding, process data reveal differences in students' self-regulatory behavior during learning. Participants in the ACPS condition regulated their learning by engaging in help-seeking behavior and over-relying on the tutor to regulate their learning. Participants in the APS condition regulated their learning by planning, monitoring their emerging understanding, and using several strategies to learn and handle task difficulties. Learners in the NS condition were less effective at regulating their learning and exhibited great variability in self-regulation of their learning during the knowledge construction activity. ACPS participants also differed from the other two groups in the amount of time spent on each representation of information. An appendix describes the variables used to code participant behavior. (Contains 4 tables and 72 references.) (Author/SLD)

Online Process Scaffolding and Students' Self-Regulated Learning 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 = 53) were randomly assigned to one of three scaffolding conditions (adaptive content and process scaffolding [ACPS], adaptive process scaffolding [APS], 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 ACPS and APS conditions we equally effective and facilitated the shift in learners' mental models significantly more than did the NS condition. Despite the effectiveness of adaptive scaffolding conditions in facilitating students' understanding, process data revealed differences in students' self-regulatory behavior during learning. Participants in the ACPS condition regulated their learning by engaging in help-seeking behavior and over-relying on the tutor to regulate their learning. Participants in the APS condition regulated their learning by planning, monitoring their emerging understanding, used several strategies to learn and handle task difficulties. Learners in the NS condition were less effective at regulating their learning and exhibited great variability in self-regulation of their learning during the knowledge construction activity. ACPS participants also differed from the two other groups in the amount of time spent on each representation of information.

Online Process Scaffolding and Students' Self-Regulated learning with Hypermedia

Can hypermedia enhance students' learning by adapting to their individual needs? Technology-based learning environments are effective to the extent that they can adapt to the learning needs of individual learners by systematically and dynamically providing scaffolding and support during learning (Anderson, Corbett, Kordinger, & Pelletier, 1995; Derry & Lajoie, 1993; Koedinger, 2001; Lajoie & Azevedo, 2000; Shute & Psotka, 1996). The ability of these environments to provide adaptive, individualized scaffolding is based on an understanding of how learner characteristics, system features, and the mediating learning processes interact during learning. A critical aspect of providing individualized instruction is scaffolding, or instructional support in the form of guides, strategies, and tools which are used during learning to support a level of student understanding that would be impossible to attain if students learned on their own (Reiser, 2002). A fundamental goal of education and of learning with hypermedia is to understand what kinds of scaffolds are effective, and when to scaffold during learning in facilitating students' understanding of complex science topics (e.g., Jacobson & Archodidou, 2000). In this study, we examine how students' understanding of a complex science topic changes when they use hypermedia in three different scaffolding conditions to learn about the circulatory system.

Adaptive scaffolding has been used successfully in learning environments designed to teach students about well-structured tasks such as math and physics (e.g., Aleven & Koedinger, 2002; Anderson et al., 1995; Conati & VanLehn, 2000; Koedinger, 2001; Koedinger, Anderson, Hadley, & Mark, 1997). However, the recent widespread use of hypermedia environments has outpaced our understanding of *how* learners can learn effectively in such environments and *how* hypermedia can be designed to adapt to students' learning needs (Azevedo, 2002; Jacobson, Sugimoto, & Archodidou, 1996). The question of whether hypermedia environments can enhance students' learning remains unanswered because little research has been conducted on how certain types of instructional scaffolding may facilitate students' learning with hypermedia (Azevedo & Cromley, 2003; Jacobson et al., 1994, 1996). Empirical research in this area is critical in addressing the issue of how different scaffolding methods and underlying self-regulatory mechanisms facilitate students' understanding of complex materials when using hypermedia.

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; Williams, 1996). Learning about a complex science topic such as 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, 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 (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 (Azevedo, Guthrie, & Seibert, in press; Williams, 1996).

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. Research has shown that learners of all ages have difficulty regulating several aspects of their learning when they use hypermedia environments to learn about complex topics and therefore gain little conceptual understanding (Azevedo et al., in press; Azevedo, Verona, Cromley, & Pritchett, 2002; Azevedo & Cromley, 2003; Greene & Land, 2000, Hannafin & Land, 1997; Oliver & Hannafin, 2000; Wu, Krajcik, & Soloway, 2001).

Since learners have difficulty regulating several aspects of their learning in hypermedia learning 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 to Facilitate Students' Learning

Scaffolding is a critical component in facilitating students' learning about complex topics (Chi et. al, 1994; 2001). According to Vygotksy (1978/1934), learners should be guided or scaffolded by a more capable peer to solve a problem or carry out a task that would be beyond what they could accomplish independently. Traditionally, scaffolding in education has emphasized the role of dialogue and social interaction to foster a) comprehension and monitoring activities (e.g., Palinscar & Brown, 1984), b) student-generated self-explanations (e.g., Chi et al., 1994, 2000), c) instruction (e.g., telling the student a fact), d) cognitive scaffolding that helps the student solve a problem on his or her own (e.g., hinting) (e.g., Merrill, Reiser, Merrill, & Landes, 1995), and e) motivational scaffolding (e.g., feedback on student performance) (Lepper, Drake, & O'Donnell-Johnson, 1997), and f) tutor question-asking (e.g., Graesser, Bowers, Hacker, & Person, 1997). Despite the wealth of research on the effectiveness of scaffolding during tutoring in complex domains, we know very little how tutors' adaptive scaffolding can facilitate students' understanding of complex science topics. In addition, these lines of research have not used SRL as a comprehensive framework to analyze the complex interaction between phases and areas of learning, nor have they examined how scaffolding by a more experienced peer might assist a student to regulate his or her learning with a hypermedia environment and lead to a deep conceptual understanding of a complex science topic. (Winne & Perry, 2000). Furthermore, this empirical data can then be used to inform the design of adaptive hypermedia environments designed to foster students' understanding of such complex topics.

Scaffolding involves providing assistance to students on an as-needed basis, fading the assistance as learner competence increases (Hogan & Pressley, 1997). Scaffolds are tools, strategies, and guides which are used by human and artificial tutors, teachers, and animated pedagogical agents during learning to support students' understanding, which would be impossible to attain if they learned on their own (Atkison, 2002; Graesser, Wiemer-Hastings, Wiemer-Hastings, Kreuz, & the Tutoring Research Group, 2000; Koedinger, 2001; Reiser, 2002). While the use of scaffolds in intelligent tutoring systems (ITSs) and intelligent learning environments (ILEs) 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 in hypermedia environments.

Researchers have recently begun to embed scaffolds in hypermedia environments to scaffold students' learning (e.g., Azevedo, Verona, Cromley, & Pritchett, 2002; Jacobson & Archodidou, 2000; Hannafin, Hill, & Land, 1997; Hannafin & Land, 2000). For example, Vye, Schwartz, Bransford, Barron, Zech and CTGV (1998) have used *conceptual scaffolds* in the form of 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. White, Shimoda, and Frederiksen (2000) used embedded *metacognitive scaffolds* tools in the form of learning agents, each of which supported students with various phases of the science inquiry cycle (e.g., hypothesizing, data collection, data analysis, report writing, and presenting their results) to help students self-regulate the underlying processes associated with managing learning. Azevedo, Verona and Cromley (2001) used *procedural scaffolds* to assist students in determining which resources in a Web-based simulation (e.g., graphs, scatterplots) could facilitate their learning about environmental science issues. Lajoie and colleagues (Lajoie & Azevedo, 2000; Lajoie, Azevedo, & Flesizer, 1998; Lajoie, Guerrera, Munsie, & Lavigne, 2001) used *strategic scaffolds* in three environments (BioWorld, SICUN tutor, and the RadTutor) to expose students to a multitude of problem solving solutions by having them compare their solutions with those of more experienced peers or experts.

Despite the potential learning benefits of using embedded scaffolds in hypermedia, their effectiveness is difficult to determine, since most of these environments include more than one type of scaffolding (e.g., Jackson et al., 2000; Lajoie et al., 2001; Oliver & Hannafin, 2000; Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001; White et al., 2000).

Using Scaffolding to Facilitate Students' Self-Regulating Learning with Hypermedia

Several studies have provided evidence that when students learn about complex topics with hypermedia in the absence of scaffolding they show poor ability to regulate their learning, which leads to a failure to gain a conceptual understanding of the topics (Azevedo, et al., in press; Azevedo, Verona, & Cromley, 2001; 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 suggests that introducing scaffolds might facilitate the level of conceptual understanding for those who did not show learning gains.

Fixed scaffolds are static and are not adaptable to meet individual students' learning needs. Recent research on fixed scaffolds with hypermedia has yielded mixed results. Some studies have produced positive results (e.g., Azevedo, Ragan, Cromley, & Pritchett, 2002; 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 (Aleven & Koedinger, 2002; Conati & VanLehn, 1999; Luckin & duBoulay, 1999; 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 (Azevedo & Cromley, 2003; Biemans, & Simons, 1995; Kao & Lehman, 1997; Kramarski & Hirsch, 2003) have recently provided evidence to support the notion that adaptive scaffolding in biology, geography, algebra, and statistics leads to enhanced student understanding in hypermedia environments.

For example, Azevedo and Cromley (2003) recently conducted a study to determine whether adaptive scaffolding was effective in facilitating students' ability to regulate their learning of complex science topics with hypermedia. The students were randomly assigned to one of three scaffolding conditions (adaptive scaffolding, fixed scaffolding, and no scaffolding) and were trained to use a hypermedia environment to learn about the circulatory system. Results indicate that students in the adaptive scaffolding condition (learning with the aid of a tutor) developed a significantly deeper conceptual understanding of the science topic, but relied extensively on the tutor to regulate their learning. Learners in the other two conditions learned significantly less and were also less effective at regulating their learning and exhibited great variability in self-regulation of their learning during the knowledge construction activity.

Overview of the Current Study and Hypotheses

In this study, we investigated the effectiveness of three different scaffolding methods for facilitating undergraduate students' ability to regulate their learning with hypermedia and also investigated *why* and *how* 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 content and process scaffolding [ACPS], adaptive process scaffolding [APS], and no scaffolding [NS]. In order to orient the reader each condition is described below. In the *adaptive content and process scaffolding (ACPS)* condition, students were provided with an overall learning goal. They had access to a tutor who provided two types of adaptive scaffolding during learning—*content scaffolding*, i.e., assessing the students' emerging understanding of the circulatory system to ensure that they met their overall learning goal—and *process scaffolding*—i.e., scaffolding students' learning 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 two types of scaffolding were used dynamically and adaptively by the tutor during learning to ensure that the learner reached the overall learning goal. We hypothesized that there would be a significant increase in students' conceptual understanding, but that students would not be as generative as in the APS and NS conditions because they would over-rely on the tutor's scaffolding in facilitating their regulatory learning behavior and their conceptual understanding. 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 *adaptive process scaffolding (APS) condition*, the students were given the same overall learning goal and also had access to a tutor. This condition was identical to the ACPS condition, but the tutor only provided *process scaffolding*—i.e., scaffolded students 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, based on their assessment of the students' emerging understanding but never provided content scaffolding. We hypothesized that, compared to the students in the ACPS, there would be a significant smaller 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. This control condition resembles the one used by Azevedo and colleagues' (Azevedo et al., 2003). 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, that they would spend similar amounts of time reading text, and text and diagrams, and that they would spend a disproportionate amount of time watching the video and less time constructing their own representations of the topic.

Overall, the literature indicates that adaptive 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 adaptive scaffolding during learning with hypermedia environments. We have adopted an approach similar to that of other cognitive scientists and human tutoring researchers, analyzing what kinds of scaffolds are effective in learning with hypermedia and how they affect students' self-regulatory skills, we will then use the results of our research to determine which scaffolds should be embedded in hypermedia environments to foster students' SRL of complex science topics.

Method

Participants

Participants were 53 undergraduate students (44 women and 9 men) from a large mid-Atlantic university who received extra credit in their Educational Psychology course for their participation. Their mean age was 22.4 years and mean GPA was 3.12. Fifty-three percent ($n = 28$) were seniors, 19% ($n = 10$) were juniors, 15% ($n = 8$) were sophomores, and 13% ($n = 7$) 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 (53 students randomly assigned to one of three scaffolding conditions—adaptive content and process scaffolding [ACPS], adaptive process scaffolding [APS], and no scaffolding [NS]) with a think-aloud protocol methodology (Ericsson & Simon, 1993). There were 17 participants in the NS and ACPS conditions and 19 participants in the APS condition.

Measures

Paper-and-pencil materials consisted of a consent form, a participant questionnaire, a pretest, and a posttest. All of the paper-and-pencil materials, except for the consent form and questionnaire, were constructed in consultation with a nurse practitioner who is also a faculty member at a school of nursing in a large mid-Atlantic university. Prior to taking part, all participants signed a letter that stated the purpose of the study and gave their informed consent. The participant questionnaire solicited information concerning age, sex, current GPA, number and title of undergraduate biology courses completed, and experience with biology and the circulatory system. There were four parts to the pretest: (1) a sheet on which students were asked to match 16 words with their corresponding definitions related to the circulatory system (matching), (2) a color picture of the heart on which students were asked to label 20 components labeling), (3) an outline of the human body on which students were asked to draw the path of blood throughout the body (ensuring that the path included the heart, lungs, brain, feet, and hands) (flow), and (4) another sheet which contained the instruction, *"Please write down everything you can about the circulatory system"* (essay). The pretest and posttest were identical.

Hypermedia Environment

During the experimental phase the participants used Microsoft 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.

Script for the Adaptive Process Content Scaffolding (ACPS)and Adaptive Process Scaffolding (APS) Conditions.

The instructions for the ACPS and APS conditions were identical. Prior to the experiment, the experimenters and the nurse practitioner designed a tutor script for the two conditions. The tutors received extensive training on the general aspects of self-regulated learning (SRL) based on Pintrich's (2000) and Winne and Hadwin's (1998, 2001) models of SRL, and was familiar with our research findings (Azevedo et al., 2001, 2002). In addition, we designed a 4-page script for the tutors which contained 1) a copy of Pintrich's (2000, p. 454) table of the phases and areas of SRL, and 2) a 2-page table with a list of SRL variables (with corresponding descriptions and examples), which we have found that self-regulated learners enact when using a hypermedia environment to learn about the circulatory system (based on Azevedo et al., 2001, 2002). The SRL variables included planning (planning, sub-goals, prior knowledge activation), monitoring (feeling of knowing, judgment of learning, self-questioning, content evaluation, identifying the adequacy of information), strategies (selecting new informational source, summarization, re-reading, and knowledge elaboration), task difficulty and demands (time and effort planning, task difficulty, and control of context), and interest.

Procedure

Participants were randomly assigned to one of three groups: ACPS, APS, 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 the answers on the pretest and did not have access to any instructional materials. Third, the experimenter provided instructions for the learning task. The following instructions were read and presented to the participants in writing.

No 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.*"

Adaptive Process Scaffolding (APS) Condition. In the adaptive process scaffolding condition, learners went over the script (previously described) with the experimenter for approximately 30 minutes before receiving instructions about the learning session. During the learning session, the tutor used the script to foster the student's self-regulation by assisting the student with the different phases (planning, monitoring, controlling, and reflecting) and areas (cognition, motivation, self, and context) of SRL, while engaged in the learning session. In the APS condition, the tutor did not provide any circulatory system content scaffolding for the student during the learning session. Tutor did not answer student questions.

Adaptive Content and Process Scaffolding (ACPS) Condition. The tutor script and instructions for the adaptive content and process scaffolding condition were identical to the tutor script and instructions (previously described) for the APS condition. The tutor provided adaptive self-regulatory scaffolding by aiding the student in planning, monitoring, and using strategies, similar to the APS condition. In addition to the adaptive process scaffolding, the tutor provided adaptive content scaffolding about the circulatory system by explaining concepts, elaborating on details, giving examples to aid student understanding, and answering student questions while the student was in the learning session. Specifically, the tutor scaffolded the learners' emerging understanding by adaptively assisting them in planning their learning, suggesting strategies and monitoring activities, motivating them (by providing positive feedback, negative feedback, offering encouragement), providing them with choices over instructional content, and ensuring that each learner covered the three learning sub-goals presented to students in all three instructional conditions.

Following the instructions, a practice task was administered to encourage all participants to give extensive self-reports on what they were inspecting and reading in the hypermedia environment and what they were thinking about as they learned. The experimenter reminded participants to keep verbalizing when they were silent for more then three seconds (e.g., "say what you are thinking"). All participants were reminded of the global learning goal ("*Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body*") as part of their instructions for learning about the circulatory system. Participants had access to the instructions (which included the learning goal) during the learning session. 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, 52] = 2.05, $p > .05$; ACPS $M = 45.0$ min, $SD = 0.0$; APS $M = 44.9$ min, $SD = 0.3$; NS $M = 44.6$ min, $SD = 0.9$). 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 used to analyze the students' and tutors' regulatory behavior, and the inter-rater reliability measures.

Coding and scoring the students' mental models. Our analyses focused on the shifts in participants' mental models across the three scaffolding 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; Azevedo, Cromley, & Seibert, 2003; Chi, 2000; Chi, de Leeuw, Chiu, & LaVancher, 1994; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001).

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 of the model, 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 section on the posttest and their flow diagram. In addition, we expanded Chi and colleagues' (1994; 2000) original six general types of mental models and strategically embedded six more, resulting in 12 models which represent the progression from no understanding to the most accurate understanding: (1) no understanding, (2) basic global concepts, (3) basic global concepts with purpose, (4) basic single loop model, (5) single loop with purpose, (6) advanced single loop model, (7) single loop model with lungs, (8) advanced single loop model with lungs, (9) double loop concept, (10) basic double loop model, (11) detailed double loop model, and (12) advanced double loop model. The mental models accurately reflect biomedical knowledge provided by the nurse practitioner. A complete description of the necessary features for each mental model is provided in Table 1.

Insert Table 1 about here

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

Scoring the students' answers on the matching task and labeling of the heart diagram. We scored the matching task by giving each student either a 1 (for a correct match between a concept and its corresponding definition) or a 0 (for an incorrect match between a concept and definition) on his/her pretest and posttest (range 0-16). Similarly, we scored the heart diagram by giving each student either a 1 (for each correctly labeled component of the heart) or a 0 (for each incorrect label) on his/her pretest and posttest (range 0-20). The scores for each student's pretest and posttest on the matching task and heart diagram were tabulated separately and used in subsequent analyses.

Time spent in multiple representations of information. A graduate student watched the video recording of each participant and recorded the time each learner spent on each representation (text, text and diagram, 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 measured and used in subsequent analyses.

Segmenting and coding students' verbalizations. The raw data collected from this study consisted of 2,377 minutes (39.6 hr) of audio and video tape recordings from the 53 participants, who gave extensive verbalizations while they learned about the circulatory system. During the first phase of data analysis, a graduate student transcribed the audio tapes and created a text file for each participant. Transcripts were prepared for all 53 participants. This phase of the data analysis yielded a corpus of 1,533 single-spaced pages (*M* = 28.9 pages per participant) with a total of 303,634 words (*M* = 5,729 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 is critical in order for the experimenter to later code the learners' and tutors' SRL behavior.

Coding learners' and tutors' self-regulatory behavior. We used Azevedo and colleagues' (in press; 2003) 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; 2003) 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, control of [hypermedia] context). 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 latter were derived from both students' and tutors' self-regulatory behavior (e.g., tutor-initiated instructional methods [TI] and varying levels of tutor scaffolding [TS] designed to enhance students' understanding) while learning with a hypermedia environment.

The classes, descriptions and examples (from the protocols) of the planning, monitoring, strategy use, task difficulty and demands, and interest variables used for coding the learners' and tutors' self-regulatory behavior are presented in Appendix A. Each code can be applied to the learner, to tutor direct instruction, or to tutor scaffolding of that variable.

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 6,387 segments (*M* = 38 per student transcript, and M = 41 tutor codes per session) with corresponding SRL variables. A graduate student coded the transcriptions by assigning each coded segment one of the SRL variables presented in Appendix A (see inter-rater reliability below).

Inter-Rater Reliability Measures. Inter-rater reliability was established by recruiting and training a graduate student to use the description of the mental models developed by Azevedo et al. (in press). The graduate student was instructed to independently code all 106 selected protocols (pre- and posttest descriptions of the circulatory system from each participant) using the 12 mental models of the circulatory system. There was agreement on 101 out of a total of 106 student descriptions yielding a reliability coefficient of .95. Similarly, inter-rater reliability was established for the coding of the learners' and tutors' regulatory behavior by comparing the individual coding of the same graduate student, who was trained to use the coding scheme, with that of one of the experimenters. She was instructed to independently code 3,787 randomly selected protocol segments of tutor and student (59% of the 6,387 coded segments with corresponding SRL variables). There was agreement on 3,758 out of 3,787 segments yielding a reliability coefficient of .99. Inconsistencies were resolved through discussion between the experimenters and the student.

Results

Question 1: Do scaffolding conditions influence students' ability to shift to a more sophisticated mental model of the circulatory system? We used a 3 (condition: adaptive content and process scaffolding [ACPS], adaptive process scaffolding [APS], no scaffolding [NS]) X 2 (time: pretest, posttest) mixed design to analyze the shift in learners' mental models and scores on the matching and labeling tasks. For all three analyses the first factor, Scaffolding condition, was a between-subjects factor; the second factor, Time, was a within-subjects factor. The number of participants in each cell is 17 for the NS condition, 19 for the APS condition and 17 for the ACPS condition 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, $F(1, 51) = 85.28$, $MSE = 3.85$, $p < .05$, and a significant interaction between condition and time, $F(2, 50) = 8.63$, $MSE = 3.85$, $p < .05$. One-way ANOVAs showed no significant difference between the conditions at pretest, $F(2, 50) = .19$, $p > .05$, but there were differences at posttest, $F(2, 50) = 13.17$, $p < .05$. The results indicate that the ACPS condition led to the highest mean "jump," or improvement, in students' mental models. On average, students in the ACPS condition "jumped" 5.4 ($SD = 3.4$) mental models from pretest to posttest. Students in the APS condition "jumped" a mean of 3.7 ($SD = 2.5$) mental models from pretest to posttest. Students in the NS condition jumped considerably less ($M = 1.5$, $SD = 1.8$). A priori Fisher's Least Significant Difference (LSD) tests showed that ACPS was significantly greater than NS ($p < .05$), and APS was significantly greater than NS ($p < .05$), but ACPS and APS did not differ from each other (p > .05). The means and standard deviations are presented in Table 2.

Insert Table 2 about here

Matching task. A 3 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, $F(1, 51) = 31.86$, $MSE = 316.57$, $p < .05$, but no significant interaction between condition and time, $F(2, 50) = .939$, $MSE = 316.57$, $p > .05$. The results indicate that the learners in all three scaffolding conditions improved their scores on the matching task from pretest to posttest (see Table 2).

Labeling task. A 3 X 2 repeated measures ANOVA on the pretest and posttest data showed a significant main effect of time, $F(1, 51) = 301.04$, $MSE = 88.78$, $p <.05$, and a significant interaction between condition and time, $F(2, 50) = 20.82$, $MSE = 88.78$, $p <.05$. Participants in all conditions significantly improved their scores on the labeling task from pretest to posttest. One-way ANOVAs showed no significant difference between the conditions at pretest, $F(2, 50) = 1.59$, $p > .05$, but there were differences at posttest, $F(2, 50) = 14.30$, $p < .05$. A priori LSD tests showed that ACPS was significantly different from NS (p < .05), and ACPS was significantly different from APS (p < .05), but APS and NS did not differ from each other (p > .05). The results indicate that the ACPS condition led to the highest mean improvement on the labeling task. On average, students in the ACPS condition increased 42.1% ($SD = 15.1$) from pretest to posttest. Students in the APS and NS conditions increased considerably less, a mean of 26.84% ($SD = 13.1$) and 24.1%, $SD = 15.8$, respectively, from pretest to posttest (see Table 2).

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 from hypermedia? In this section we present the results of a series of chi-square analyses that were performed to determine whether there were significant differences in the distribution of students' and tutors' 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 related to *planning, monitoring, strategy use, handling task difficult and demands,* and *interest.* The number of learners using each SRL variable above the median proportion across conditions and the results of the chi-squares tests are presented in Table 3.

Insert Table 3 about here

Student Moves

Student use of 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 scaffolding conditions (see Table 3 for all chi-square results). Overall, a significantly larger number of students in the APS condition planned their learning by making a plan. By contrast, the learners in the NS condition planned their learning by creating sub-goals and recycling goals in their working memory. A chi-square analysis did not reveal significant difference in the number of participants who activated prior knowledge above the median proportion across the conditions.

Student use of 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 scaffolding conditions (see Table 3). Students in the ACPS condition monitored their learning by using feeling of knowing (FOK). Learners in the APS condition monitored their learning by judging their learning (JOL) and self-questioning. In contrast, learners in the NS condition engaged in content evaluation. Two chi-square analyses did not reveal significant differences in the number of participants who monitored their progress toward goals or identified the adequacy of information above the median proportion across the three conditions.

Student use of strategies. Chi-square analyses revealed significant differences in the number of participants who used 8 of the 17 strategies above the median proportion across the scaffolding conditions (see Table 3). A significantly larger number of learners in the APS condition used coordinating informational sources, taking notes, drawing, and reading notes to learn about the circulatory system. In contrast, a large proportion of learners in the NS condition learned by engaging in free search and goal-directed search of the hypermedia environment, rereading, and selecting new informational sources. Nine chi-square analyses did not reveal significant differences in the number of participants who, across conditions, used memorization, inferences, hypothesizing, knowledge elaboration, evaluating the content as the answer to the goal, find location in the environment, summarizing, mnemonics, or reading a new paragraph above the median proportion (see Table 3).

Student handling of task difficulty and demands. Chi-square analyses revealed significant differences in the number of participants who used four of the five variables related to handling task difficulties and demands above the median proportion across the scaffolding conditions (see Table 3). A large proportion of learners in the ACPS condition handled task difficulties by using help-seeking behavior. In contrast, the students in the APS condition dealt with task difficulty and demands by planning their time and effort, controlling the hypermedia environment to enhance the reading and viewing of information, and expecting the adequacy of information. The chi-square analyses did not reveal significant differences in the number of participants who, across conditions, used task difficulty above the median proportion (see Table 3).

Student interest. A Chi-square analysis revealed a significant large number of learners in the NS condition expressed interest in the topic (above the median frequency) during learning compared to the other conditions (see Table 3).

Tutor Moves

In addition to the students' use of SRL variables, we also coded the tutors' regulatory behavior, either through tutor-initiated direct instruction (TI) or tutor scaffolding (TS). Because each tutor worked with more than one student, the unit of analysis is not the tutor, but the tutoring session (one experimental session with one student). In the APCS condition, 71.9% of tutor moves were Tutor Initiated (TI), whereas in the APS condition, only 55.7% were. The distribution of moves in the ACPS condition is significantly different from the null (χ^2 [1, $N = 54$] = 19.18, $p < .05$), whereas the distribution for the APS condition was not significantly different from the null (χ^2 [1, $N = 54$] = 1.30, $p > .05$), We therefore combined TI and TS moves for the analyses of differences in use of SRL variables so as not to confound the method of delivery (TI vs. TS) with actual differences in use of SRL variables.

The number of tutoring sessions across conditions when SRL variables were used above the median and the results of the chi-squares tests are presented in Table 4.

Insert Table 4 about here

Tutor use of planning. Chi-square analyses revealed significant differences in the number of tutoring sessions that used two of the three[ii] planning variables above the median proportion across the scaffolding conditions (see Table 4 for all chi-square results). Overall, a significantly larger number of tutoring sessions in the ACPS condition included activating prior knowledge. By contrast, a significant large number of tutoring sessions in the APS condition included making a plan. A chi-square analysis did not reveal significant difference in the number of tutoring sessions that used creating sub-goals above the median proportion across the conditions.

Tutor use of monitoring. Chi-square analyses revealed significant differences in the number of tutoring sessions that used four out of five variables related to monitoring above the median proportion across the scaffolding conditions (see Table 4). A significant large number of tutoring sessions in the ACPS condition included monitoring of learning by using feeling of knowing (FOK). A significant large number of tutoring sessions in the APS condition used monitoring of their learning by identifying the adequacy of information, monitoring progress toward goals, and content evaluation. A chi-square analysis did not reveal significant difference in the number of tutoring sessions that used judgment of learning (JOL) above the median proportion across the conditions.

Tutor use of strategies. Chi-square analyses revealed significant differences in the number of number of tutoring sessions that used 8 of the 14 strategies above the median proportion across the scaffolding conditions (see Table 4). A significantly larger number of tutoring sessions in the ACPS condition included knowledge elaboration, inferences, mnemonics, and summarizing. Tutoring sessions in the APS condition used coordinating informational sources, taking notes, reading notes, and reading a new paragraph to learn about the circulatory system. Six chi-square analyses did not reveal significant differences in the in the number of tutoring sessions that, across conditions, used selecting new informational sources, drawing, find location in the environment, rereading, goal-directed search, or evaluating the content as the answer to the goal above the median proportion (see Table 4).

Tutor handling of task difficulty and demands. Chi-square analyses revealed significant differences in the number of tutoring sessions that used three of the four variables related to handling task difficulty and demands above the median proportion across the scaffolding conditions (see Table 4). A large number of tutoring sessions in the APS condition handled task difficulties by controlling the hypermedia environment to enhance the reading and viewing of information, planning their time and effort, and acknowledging task difficulty. One chi-square analysis did not reveal significant differences in the number of tutoring sessions, across conditions, that used expecting the adequacy of information above the median proportion (see Table 4).

Tutor use of interest and motivation. A significant large proportion tutoring sessions in the ACPS condition included expression of interest in the topic and feedback above the median frequency during learning compared to the APS condition (see Table 4).

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

Adaptive content and process scaffolding (ACPS) condition. In general, the tutor began by asking learners to review the overall learning goal from the instruction sheet and then asked them to set goals for their 45-minute learning episode, involving one or more learning sub-goals. Students typically began by reading the overview of the circulatory system, then read about chambers of the heart, blood components, and systemic and pulmonary circulation. The tutor then often asked students to draw a diagram of the heart and the major blood vessels that carry blood to and from the chambers. Students frequently took notes on the flow of blood through the heart, technical terms (e.g., alveoli), and other new information.

Students would often summarize what they had read, restate information that had been read previously, and activate relevant prior knowledge. They frequently commented on their own level of understanding of what they were learning (Feeling of Knowing). When they did not understand, the tutor often provided extensive elaborations from her own prior knowledge about the circulatory system. She often made inferences about the content, provided mnemonics (e.g., “Arteries, ‘A’ for 'away'") to help students remember content, and asked students to summarize what they had read. Students used several effective strategies, such as drawing, summarizing, and making inferences. They often sought help from the tutor, coupled with statements about the difficulty of the task.

Adaptive process scaffolding (APS) condition. In general, the tutor began by asking learners to review the overall learning goal from the instruction sheet and then asked them to make a plan for their 45-minute learning episode. Students typically set specific goals, then began reading about the circulatory system. The tutor often encouraged students to take notes on what they were reading, and to coordinate informational sources (e.g., read text about the flow of blood, then explain what they had read using the accompanying diagram). As they read, students often engaged in self-questioning. Students also engaged in Judgment of Learning (JOL) and re-reading to clarify misunderstandings.

The tutor also suggested ways of using the environment (scrolling up or down, using the "back" button), suggested specific representations, and suggested which representations might not be useful. Students often followed this advice, and also asked the tutor for help.

The tutor periodically asked students to monitor their progress toward goals, read over their notes, plan their time, and use skimming (i.e., read a new paragraph) strategies when little time remained. Students, in response, often monitored progress toward goals, read their notes, and engaged in time and effort planning.

No scaffolding (NS) condition. In general, learners in this condition exhibited great variability in the way they regulated their learning. Some students in this condition approached the knowledge construction activity by setting up sub-goals and sometimes activating prior knowledge, they also monitored progress toward goals and used many effective strategies to learn about the circulatory system. However, many students did not monitor their own learning; their monitoring activity was focused on the adequacy (or inadequacy) of the environment to answer their questions. They used a combination of ineffective free search and effective goal-directed search strategies and recycled goals in working memory. They did not engage in planning (i.e., coordination of multiple goals), failed to integrate and elaborate the instructional content available in the hypermedia module, and did not engage in strategies that would lead to deep understanding of the content. Learners would skip among text, diagrams, and animation frequently, and read text out loud verbatim, setting the goal of memorizing content from the environment. They often re-read content and took notes, but rarely re-read those notes. Although they engaged in time and effort planning, this was with regard to sub-goals, not an overall plan for learning.

Question 3: Do students in different scaffolding conditions spend equal amounts of time on different representations of information to learn about the circulatory system? We conducted 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. Data were available for 50 participants; 3 tapes could not be coded due to video problems. There was a significant difference in the mean time that learners in each scaffolding condition spent on each type of representation (F [1, 52] = 7.22, $p < .05$). Followup ANOVAs showed significant differences between the scaffolding conditions for three out of the four representation types. We set $\alpha = 0.006$ for all follow-up comparisons to compensate for the 9 pairwise comparisons. Learners in the ACPS condition spent significantly less time ($M = 0.03$, $SD = 0.1$) (F [2, 50] = 20.02, $p < .05$) watching the video than those in the NS and APS conditions ($M = 4.4$ min, $SD = 2.9$; $M = 3.5$ min, $SD = 2.3$, respectively); who did not differ from each other. Learners in the NS condition spent significantly less time ($M = 4.5$, $SD = 6.9$) (F [2, 50] = 7.02, $p < .006$) constructing their own representations than those in the APS and ACPS conditions ($M = 11.9$ min, $SD = 5.9$; $M = 12.8$ min, $SD = 7.9$, respectively); who did not differ from each other. Despite the overall statistically significant differences (F [2, 50] = 4.09, $p < .006$) in the amount of time spent reading text, the follow-up comparisons failed to reach significance (at $\alpha = 0.006$). These results indicate that learners tended to read the same amount of text (ACPS *M* = 14.5 min, *SD* = 6.5; APS *M* = 9.9 min, *SD* = 3.1; NS *M* = 10.9 min, *SD* = 4.5). Similarly, all learners tended to read the same amount of text and diagrams (F [2, 50] = 3.03, $p < .006$; ACPS *M* = 18.7 min, *SD* = 54; APS *M* = 18.4 min, *SD* = 4.7 NS *M* = 22.9 min, *SD* = 7.2) across conditions.

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 ACPS and APS conditions we equally effective and facilitated the shift in learners' mental models significantly more than did the NS condition. Despite the effectiveness of adaptive scaffolding conditions in facilitating students' understanding, process data revealed differences in students' self-regulatory behavior during learning. Participants in the ACPS condition regulated their learning by engaging in help-seeking behavior and over-relying on the tutor to regulate their learning. Participants in the APS condition regulated their learning by planning, monitoring their emerging understanding, used several strategies to learn and handle task difficulties. Learners in the NS condition were less effective at regulating their learning and exhibited great variability in self-regulation of their learning during the knowledge construction activity. ACPS participants also differed from the two other groups in the amount of time spent on each representation of information.

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Table 1

Necessary Features for Each Type of Mental Model.

1. No understanding

2. Basic Global Concepts
- blood circulates

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

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

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

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

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

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

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

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

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

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

Table 2

Means (and Standard Deviations) for the Pretest and Posttest Learning Outcome Measures by Scaffolding condition.

	Adaptive Content and Process Scaffolding (ACPS) (n = 17)				Adaptive Process Scaffolding (APS) (n = 19)				No Scaffolding (NS) (n = 17)			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Essay and Flow Diagram (Mental models)	5.3	3.5	10.8	2.2	5.9	2.4	9.6	2.7	5.4	2.1	6.9	1.8
Matching	61.4%	31.6	83.5%	14.3	54.9%	22.7	78.6%	22.9	52.9%	25.5	65.8%	22.8
Labeling	7.1%	10.3	51.5%	9.8	4.7%	10.2	31.6%	16.2	1.7%	3.8	25.9%	16.8

Table 3

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

Variable	Adaptive Content and Process Scaffolding (ACPS) (n = 17)	Adaptive Process Scaffolding (APS) (n = 19)	No Scaffolding (NS) (n = 17)	χ^2	*p*
Planning					
Planning	6 (35%)	**14 (74%)**[b]	4 (24%)	10.12	0.006
Sub-Goals	0 (0%)	**12 (63%)**	**15 (88%)**[c]	28.25	0.000
Recycle Goal in Working Memory	0 (0%)	0 (0%)	3 (18%)[c]	6.73	0.034
Prior Knowledge Activation	**11 (65%)**	9 (47%)	6 (35%)	2.98	0.226
Monitoring					
Feeling of Knowing (FOK)	**14 (82%)**[a]	**10 (53%)**	2 (12%)	17.10	0.000
Judgment of Learning (JOL)	**9 (53%)**	**14 (74%)**[b]	3 (18%)	11.43	0.003
Self-Questioning	0 (0%)	**12 (63%)**[b]	8 (47%)	16.16	0.000
Content Evaluation	1 (6%)	**13 (68%)**	**14 (82%)**[c]	20.57	0.000
Identify Adequacy of Information	4 (24%)	9 (47%)	**12 (71%)**	5.87	0.053
Monitoring Progress Toward Goals	5 (29%)	**12 (63%)**	**10 (59%)**	4.71	0.095
Strategy Use					
Coordinating Informational Sources	2 (12%)	**17 (89%)**[b]	5 (29%)	24.41	0.000
Taking Notes	2 (12%)	**15 (79%)**[b]	**10 (59%)**	16.83	0.000
Draw	8 (47%)	**14 (74%)**[b]	4 (24%)	9.07	0.011
Read Notes	1 (6%)	**13 (68%)**[b]	5 (29%)	15.71	0.000
Selecting New Informational Source	0 (0%)	**11 (58%)**	**16 (94%)**[c]	30.70	0.000
Re-Reading	0 (0%)	**14 (74%)**	**13 (76%)**[c]	26.02	0.000
Free Search	2 (12%)	5 (26%)	**13 (76%)**[c]	16.79	0.000
Goal-Directed Search	1 (6%)	1 (5%)	6 (35%)[c]	7.97	0.019
Inferences	**9 (53%)**	6 (32%)	**11 (65%)**	4.09	0.129
Hypothesizing	1 (6%)	3 (16%)	0 (0%)	3.31	0.192
Memorization	1 (6%)	4 (21%)	5 (29%)	3.17	0.205
Find Location in Environment	**9 (53%)**	7 (37%)	5 (29%)	2.06	0.357
Knowledge Elaboration	7 (41%)	**10 (53%)**	5 (29%)	1.99	0.369
Evaluate Content as Answer to Goal	0 (0%)	1 (5%)	0 (0%)	1.82	0.402
Summarization	**10 (59%)**	9 (47%)	7 (41%)	1.09	0.579
Read New Paragraph	1 (6%)	2 (11%)	2 (12%)	0.39	0.825
Mnemonics	4 (24%)	5 (26%)	5 (29%)	0.15	0.927
Task Difficulty and Demands					
Help Seeking Behavior	**16 (94%)**[a]	9 (47%)	1 (6%)	26.51	0.000
Time and Effort Planning	1 (6%)	**17 (89%)**[b]	**9 (53%)**	25.13	0.000
Control of Context	3 (18%)	**14 (74%)**[b]	**10 (59%)**	11.90	0.003
Expect Adequacy of Information	0 (0%)	8 (42%)[b]	5 (29%)	8.92	0.012
Task Difficulty	**9 (53%)**	9 (47%)	7 (41%)	0.47	0.790
Interest					
Interest Statement	8 (47%)	6 (32%)	**13 (76%)**[c]	7.39	0.025

Note: Degrees of freedom = 2 and n = 53 for all analyses.

Note. The **bold** type indicates the variable was used above the median frequency by more than 50% of participants.

[a] ACPS group made the greatest contribution to chi-square for this variable.

[b] APS group made the greatest contribution to chi-square for this variable.

[c] NS group made the greatest contribution to chi-square for this variable.

Table 4

Number and Proportion of Tutoring Sessions in which Self-Regulated Learning Variables (TI and TS) Were Used Above the Median Proportion, by Scaffolding Condition.

Variable	Adaptive Content and Process Scaffolding (ACPS) (n = 17)	Adaptive Process Scaffolding (APS) (n = 19)	χ^2	*p*
Tutor Use of Planning				
Prior Knowledge Activation	**16 (94%)**[a]	1 (5%)	32.21	0.000
Planning	1 (6%)	**16 (84%)**[b]	25.08	0.000
Sub-Goals	6 (35%)	**12 (63%)**	2.79	0.095
Tutor Use of Monitoring				
Feeling of Knowing (FOK)	**17 (100%)**[a]	1 (5%)	32.21	0.000
Identify Adequacy of Information	0 (0%)	**18 (95%)**[b]	32.21	0.000
Monitoring Progress Toward Goals	3 (18%)	**15 (79%)**[b]	13.49	0.000
Content Evaluation	5 (29%)	**13 (68%)**[b]	5.46	0.019
Judgment of Learning (JOL)	2 (12%)	2 (11%)	0.00	1.000[c]
Tutor Use of Strategies				
Knowledge Elaboration	**17 (100%)**[a]	0 (0%)	36.00	0.000
Inferences	**17 (100%)**[a]	1 (5%)	32.21	0.000
Mnemonics	**16 (94%)**[a]	0 (0%)	32.19	0.000
Summarization	**12 (71%)**[a]	6 (32%)	5.46	0.019
Coordinating Informational Sources	0 (0%)	**18 (95%)**[b]	32.21	0.000
Read Notes	3 (18%)	**13 (68%)**[b]	9.37	0.002
Taking Notes	3 (18%)	**12 (63%)**[b]	7.65	0.006
Read New Paragraph	5 (29%)	**13 (68%)**[b]	5.46	0.019
Selecting New Informational Source	**10 (59%)**	7 (37%)	1.74	0.187
Draw	**10 (59%)**	8 (42%)	1.00	0.317
Find Location in Environment	7 (41%)	**11 (58%)**	1.00	0.317
Re-Reading	**9 (53%)**	9 (47%)	0.11	0.738
Goal-Directed Search	8 (47%)	9 (47%)	0.00	0.985
Evaluate Content as Answer to Goal	1 (6%)	1 (5%)	0.00	1.000[c]
Tutor Use of Task Difficulty and Demands				
Control of Context	0 (0%)	**18 (100%)**[b]	32.21	0.000
Time and Effort Planning	1 (6%)	**17 (89%)**[b]	25.08	0.000
Task Difficulty	3 (18%)	**14 (74%)**[b]	11.31	0.001
Expect Adequacy of Information	5 (29%)	9 (47%)	1.22	0.270
Tutor Use of Interest and Motivation				
Interest Statement	**15 (88%)**[a]	3 (16%)	18.84	0.000
Feedback (Positive Feedback, Negative Feedback, encouragement, OK)	**15 (88%)**[a]	3 (16%)	18.84	0.000

Note: Degrees of freedom = 1 and n = 36 for all analyses. Certain student codes (e.g., Help Seeking Behavior) have no corresponding tutor code. The **bold** type indicates the variable was used by the tutor above the median frequency in more than 50% of tutoring sessions.

[a] ACPS group made the greatest contribution to chi-square for this variable.

[b] APS group made the greatest contribution to chi-square for this variable.

[c] Yates correction applied.

Appendix A

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

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

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

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

Task Difficulty and Demands

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

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

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[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 participant'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 2005 used Feeling of Knowing (FOK) 20 times out of 87 utterances, or 22.99% of her moves. Across all participants, the median proportion for FOK was 11.45%, placing participant 2005 above the median frequency for FOK. By contrast, participant 3120 used FOK 8 times out of 102 moves, or 7.84% of her moves, placing her below the median proportion for FOK. We then conducted a 3 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.

For tutors, we similarly converted raw counts of all SRL variables (summing Tutor Instruction and Tutor Scaffolding codes) for each strategy, using the total of all tutor utterances as the denominator. We then calculated the median proportion for each variable, identified for each tutoring session whether that variable was used above or below the median proportion across all sessions, and conducted a 2 x 2 chi-square analysis for each self-regulatory variable.

[ii] Note that certain codes, such as "Recycle Goals in Working Memory" were never used by tutors.

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