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Exploring the fluctuation of motivation and use of self-regulatory processes during learning with hypermedia

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Abstract We collected think-aloud, pre-test, post-test, and motivation data from 43 undergraduates to examine the impact of conceptual scaffolds on the fluctuation of certain motivation constructs and use of self-regulatory processes during learning with hypermedia. Participants were randomly assigned to either the No Scaffolding (NS) or Conceptual Scaffolding (CS) condition. During the experimental session, each participant individually completed a pre-test on the circulatory system, a pre-task motivation questionnaire, one 30-min hypermedia learning task during which they learned about the circulatory system, a motivation questionnaire at three regular intervals during this learning task, a post-test on the circulatory system, and a post-task motivation questionnaire. Results indicated that while participants in both conditions gained declarative knowledge, participants who received conceptual scaffolds during learning demonstrated deeper understanding of the circulatory system on the post-test. In terms of self-regulatory processes, the results indicated that participants in the CS condition used significantly more planning processes during learning than participants in the NS condition. Additionally, participants in both conditions significantly decreased their use of strategies as they progressed through the learning task. Regarding motivation while learning with hypermedia, results indicated that participants in both conditions reported significantly increased levels of interest as they progressed through the learning task. Furthermore, participants in the CS condition reported the task as being easier and putting forth less effort than participants in the NS condition.

Keywords Self-regulated learning · Hypermedia · Motivation · Science · Scaffold · Mixed methods

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Introduction

Computer-based learning environment (CBLEs) have become more prevalent in the classroom (Lajoie and Azevedo 2006), and have been used as cognitive tools to help students learn about challenging topics (Azevedo 2005; Graesser et al. 2005; White and Fredriksen 2005). *Cognitive tools* are defined as tools that are developed with the aim of enhancing the cognitive capabilities of humans during problem solving, thinking, and learning (Derry and Lajoie 1993; Jonassen and Reeves 1996; Lajoie 2000; Lajoie and Azevedo 2006). The classic model of computers as cognitive tools in education has suggested the ''tutor, tool, and tutee'' approach (see Taylor 1980). This approach, as seen in earlier technologies, resulted in CBLEs designed to promote students' knowledge acquisition in well-defined tasks and domains such as geometry (e.g., Anderson et al. 1995; Koedinger 2001). Thus, traditional uses of technology have typically relied on students learning *from* the CBLE. This process involves the CBLE directing students and then assessing their learning (Shute and Ptsoka 1996). However, more recent CBLEs act as intellectual partners with the learner so that critical thinking and higher order learning can be facilitated (Jonassen and Reeves 1996). This approach allows students to learn *with* CBLEs by providing them a cognitive tool that supports knowledge construction and exploration (Jonassen and Reeves 1996).

Hypermedia is an example of a specific type of CBLE that supports knowledge exploration. As defined by Jonassen and Reeves (1996), hypermedia is a nonlinear, student-centered CBLE, which integrates multiple representations, including audio, video, animation, graphics, and/or text. Because students can access information of their choosing through the non-sequential format of information, they can pursue personal goals when learning with hypermedia. As such, this environment is different than multimedia (Mayer 2003). Furthermore, the inclusion of multiple representations makes this learning environment different than hypertext (Jacobson and Archodidou 2000; Jonassen and Reeves 1996). However, though hypermedia should foster students' active participation in the construction of knowledge (Williams 1996), empirical research has produced mixed results on the effectiveness of these learning environments. Research suggests that while hypermedia fosters knowledge development in some students (Jacobson and Archodidou 2000), other students have difficulty using these learning environments to develop knowledge (Azevedo et al. 2004c). In order to account for why some students have difficulty in using hypermedia to learn about challenging topics, researchers have recently focused on the role of self-regulatory processes in learning. This line of research has found that students' use of certain self-regulatory processes during learning with hypermedia may affect their knowledge development, especially in the absence of scaffolds (e.g., Azevedo and Cromely 2004).

Self-regulated learning theory (SRL)

Research using SRL theory to examine how students learn with hypermedia environments (e.g., Moos and Azevedo 2006) has defined self-regulated learning as learning that involves actively constructing an understanding of a topic/domain by using strategies and goals, regulating and monitoring certain aspects of cognition, behavior, and motivation, and modifying behavior to achieve a desired goal (Pintrich 2000). Based on this conceptualization, this line of research has typically focused on strategies, planning, and monitoring processes, and has found that students need to self-regulate their learning with hypermedia, including monitoring how much time to spend in different representations of information and when and how to modify strategies used in the hypermedia environment (Azevedo 2005; Shapiro 1999; Williams 1996). Furthermore, other SRL processes related to planning, such as prior knowledge activation (Pintrich 2000) and setting sub-goals, have been found to be related to learning challenging topics with hypermedia (Azevedo et al. 2005). However, some students do not use these SRL processes when learning with hypermedia, and thus have difficulty developing knowledge (Azevedo and Cromley 2004). In order to address the difficulties some students have in self-regulating their learning with hypermedia, research has examined the potential benefits of providing students with scaffolds during learning (e.g., Azevedo et al. 2004).

Conceptual scaffolds in learning with hypermedia

Students often face difficulties when learning about challenging sciences topics, such as the circulatory system (Chi 2005), with hypermedia. Though students may develop an understanding of definitions and facts (declarative knowledge; Azevedo 2005; Graesser et al. 2005; McCrudden et al. 2005), they have much more difficulty understanding interrelationships between definitions, properties of concepts, and facts (conceptual knowledge; Chi 2000, 2005; Markman and Gentner 2000). For example, when undergraduates learn about the circulatory system with hypermedia, they often demonstrate an understanding of where the heart's key components are located (e.g., the location of the right atrium and right ventricle), but have much more difficulty demonstrating how these components work together to pump blood throughout the body (Moos and Azevedo 2006). In other words, while students may be able to develop declarative knowledge when learning with hypermedia, they have much more difficultly developing conceptual knowledge. In keeping with current literature on conceptual knowledge and learning with multimedia and hypermedia (Mayer 1994; Sharp et al. 2006), conceptual knowledge of the circulatory system was operationally defined by mental models in this study.

In order to address difficulties students have in developing conceptual knowledge when learning with hypermedia, research has examined the potential benefit of providing them with scaffolds. Scaffolding was originally conceptualized as support that assists students with elements of a task that are beyond their capacity, and helps them concentrate on elements of task that are within their range of competence (Wood and Middleton 1975; Wood et al. 1976). Various types of scaffolding exist, and can be characterized by the methods in which they are provided (Hannafin et al. 1999), ranging from static prompts embedded in the environment (Puntambekar and Hubscher 2005) to instructors (e.g., human tutor; Azevedo et al. 2005). Scaffolds can also serve several purposes, including assisting students in learning about the environment (e.g., procedures), how to adapt to individual instructional contexts (e.g., engaging in adaptive help-seeking), about one's own learning processes (e.g., self-regulated learning), and developing domain knowledge (e.g., conceptual scaffolding; Azevedo 2005). This study focused on conceptual scaffolds because of the documented difficulties students have in developing conceptual understanding of the circulatory system with hypermedia (e.g., Azevedo et al. 2005). Scaffolds that are designed to foster students' understanding of interrelationships between concepts and properties have been labeled as conceptual scaffolds (Graesser et al. 2005; White and Frederisken 2005). Some research suggests that conceptual scaffolds have the potential to assist students when they are learning about conceptually rich domains with hypermedia (Hannafin et al. 1999) because this type of support aids students in understanding the conceptual organization of the domain more readily (Shapiro 1999, 2000).

Furthermore, previous research has demonstrated that some students have difficulty using key SRL processes (Winne 2005) and fail to gain deep conceptual knowledge of challenging topics when they are learning with hypermedia in the absence of conceptual scaffolds (Azevedo et al. 2004a; Greene and Land 2000; Hill and Hannafin 2001; Land and Greene 2000). Because of these difficulties students face when learning with hypermedia and the challenges of applying traditional conceptions of scaffolds to recent technological advances, examining the role of conceptual scaffolds in learning with hypermedia has become a critical issue (Azevedo 2005; Pea 2004; Puntambekar and Hubscher 2005). Empirical research has examined the potential benefit of providing students with a variety of conceptual scaffolds. For example, some research has found that the provision of conceptual scaffolds, in the form of structured interactive overviews, fosters conceptual knowledge development for students with low prior knowledge of the topic (Shapiro 1999, 2000).

Another potentially beneficial form of conceptual scaffolding is the provision of guiding questions during the learning task. This type of conceptual scaffold is theoretically grounded in the elaborative interrogation literature, which suggests that asking students to answer higher-ordered questions encourages them ''to connect new information in their own richly developed knowledge base'' (Willoughby and Wood 1994, p. 139). As suggested by Martin and Pressley (1991), effectively asking students to answer questions during learning allows them to anchor newly acquired knowledge in prior knowledge. While empirical research has demonstrated that asking students higher-order questions during learning is associated with declarative knowledge development (Ozgungor and Guthrie 2004), less empirical research has examined how higher-ordered questions foster other types of knowledge development (McDaniel and Donnelly 1996; Seifert 1993), especially in the context of learning with hypermedia.

It may seem intuitive that providing students with guiding questions during learning is a more effective instructional technique than not providing them with any type of scaffold, especially when they are asked to learn about a challenging topic with hypermedia. However, while some research has found that this type of scaffold fosters knowledge development (e.g., Jonassen et al. 1986; Hartley and Sydes 1997), other research has found limited benefit of providing students with guiding questions during learning with hypermedia. For example, Azevedo and colleagues (2005) found that young students who received conceptual scaffolding, in the form of 10 domain specific questions designed to guide their learning about the circulatory system, demonstrated lower conceptual learning gains from pre- to post-test and used fewer key SRL processes during learning than students who did not receive scaffolding. Lajoie (2005) suggested that students who do not receive scaffolding when learning with hypermedia need to work harder in constructing conceptual knowledge, and therefore develop conceptual knowledge more readily because they are required to use more SRL processes during learning. However, it should be noted that this study was conducted with adolescents, and it is presently unclear how conceptual scaffolds, in the form of guiding questions, affect undergraduates' learning processes and outcomes with hypermedia. As such, one goal of this current study was to examine how conceptual scaffolds, in the form of asking undergraduates higher-ordered questions during learning, are associated with learning outcomes (i.e., declarative *and* conceptual knowledge) and learning processes (i.e., use of SRL during learning) with hypermedia.

Role of motivation in learning with hypermedia

While the majority of research on learning with hypermedia has focused almost exclusively on the cognitive factors, little has been done to examine the contributing motivational factors (Lepper and Woolverton 2004; Zimmerman and Tsikalas 2005). Motivation has been operational defined as, ''physiological processes involved in the direction, vigor, and persistence of behavior'' (Bergin et al. 1993, p. 437), and research has identified a number of fundamental constructs related to motivation (see Greene and Ackerman 1995; Murphy and Alexander 2000). As highlighted by Murphy and Alexander (2000), researchers have empirically examined a vast array of motivational constructs, and the lexicon within these lines of research can vary. As their review clearly articulated, there is a need for research to examine theoretically grounded constructs of motivation.

Pintrich furthered the discussion of what constructs should be measured by suggesting that factors directly linked to the learning context may support and direct behavior (Pintrich 2003). For example, Boekaerts (2002) suggested that situation-specific task appraisals (i.e., task usefulness, perceived task difficulty, and interest in task) and domain and task specific learning intentions (i.e., intended effort towards task) are valid measures of motivation. Variables related to students' task appraisal and learning intentions may affect students' ''direction, vigor, and persistence of behavior'' (Bergin et al. 1993, p. 437), and thus should be considered in motivation research. Furthermore, it has been suggested that students' task specific appraisal and learning intentions may affect how they self-regulate their learning with hypermedia (Lepper and Woolverton 2004; Zimmerman and Tskikalas 2005). Though a student may have the capacity to use specific SRL processes, the student's appraisal of the task (e.g., ''the task is too hard'' or ''the task is not interesting'') and/or their learning intention (''I am not going to try that hard'') may determine if SRL processes are actually used while learning with hypermedia (Lepper et al. 1993).

Though research has empirically examined the role of various motivation constructs in learning with CBLEs, these studies have tended to focus on specific types of technology environments (e.g., Internet and simulations; Holladay and Quiñones 2003) and specific constructs of motivation (e.g., goal orientation and self-efficacy; Moos and Azevedo 2006). However, little empirical research has examined variables related to students' appraisal of the task (i.e., perceived task usefulness, perceived task difficulty, and interest in task) and their task specific learning intentions (i.e., intended effort towards task) in the context of learning with hypermedia. Thus, one goal of this current study was to examine these variables (as proposed by Boekaerts 2002) in the context of learning with hypermedia.

Furthermore, there is currently a need for more research that continues to empirically examine specific constructs of motivation and other self-regulatory processes *during* learning in various tasks and learning activities. As suggested by some researchers (see Perry et al. 2000), self-regulatory processes should be examined *during* learning because SRL is an ongoing process that unfolds within particular contexts (Azevedo 2005; Boekaerts et al. 2000; Moos and Azevedo 2006). Thus, in order to empirically capture students' self-regulatory processes during learning, data should be collected over different time episodes during the study (Perry 1998; Winne and Perry 2000; Winne and Jamieson-Noel 2003).

Current study

This study empirically examined students' self-regulatory processes (cognitive *and* motivational processes) during learning with hypermedia. Using process data from think-aloud methodology (Ericsson 2006; Ericsson and Simon 1994), this study measures the fluctuation of various SRL processes (strategy use, planning, monitoring, and handling task difficulties) during learning with hypermedia in the presence and absence of conceptual scaffolds. Thus, this study examined both *which* SRL processes students used and *when* students used these processes during learning. In addition, this study used a previously developed motivation questionnaire (Boekaerts 2002) to examine the impact of conceptual scaffolds on students' motivation before and during learning. The three research questions addressed in this study are: (1) To what extent do different scaffolding conditions affect students' learning about the circulatory system? (2) To what extent do different scaffolding conditions affect the fluctuation of self-regulation during learning with hypermedia?, and (3) To what extent do different scaffolding conditions affect the fluctuation of motivation during learning with hypermedia?

Method

Participants

Forty-three undergraduate education majors from a large public university located outside a mid-Atlantic city in the United States participated in this study. The participants received extra credit in their classes for participating in this study. Their average age was 21.53 ($SD = 3.46$); there were 31 women (72%) and 12 men (28%). The pre-test indicated that the majority of participants had little prior knowledge of the topic for the learning task (circulatory system).

Research design

The participants were randomly assigned to one of two conditions: No Scaffolding (NS; $n = 21$) or Conceptual Scaffolding (CS; $n = 22$). All participants were individually tested in a university lab. A pre-test–post-test design was used with a think-aloud protocol methodology (Ericsson 2006; Ericsson and Simon 1994).

Measures

Motivation measures

In addition to a paper-and-pencil consent form completed prior to the start of the study, participants completed the On-line Motivation Questionnaire (OMQ; Boekaerts 2002). This self-report motivation measure consists of two questionnaires, a pre- and post-task motivation questionnaire, and both questionnaires are answered on a four-point Likert-format. The pre-task motivation questionnaire contains 22 questions measuring three dimensions of participants' motivation: emotions, task appraisals, and learning intentions. The post-task motivation questionnaire consists of 19 questions measuring four dimensions of participants' motivation: emotions, assessment of their performance, reported effort, and attributions. During construction and initial use of the OMQ, Boekaerts (2002) reported that the test–retest reliability ranged from .48 to .82 and the internal consistency (as measured by the Cronbach's alpha) was higher than .70 for all scales, except result assessment. Boekaerts (2002) asserted that, ‘‘the values [for the test–retest] are in accordance with the assumption of context-sensitivity of the constructs’’ (Boekaerts 2002, p. 106). According to Boekaerts (2002), the range of the test–retest scores was not completely unexpected given the context-sensitivity of some of constructs in the questionnaires.

In addition to completing the pre- and post-task portion of the OMQ, participants responded to four motivation questions from the OMQ at three regular intervals during the learning task. The four motivation questions were: (1) How useful do you consider this task? (2) How easy is this task for you? (3) How interesting do you find this task? and (4) How much effort are you putting into this task? These four motivation questions were answered on the same four-point Likert format as the OMQ, ranging from 1 (not at all) to 4 (very much). While participants completed the entire pre- and post-task portion of the OMQ, this study aimed to examine the impact of conceptual scaffolds on situation-specific task appraisals (i.e., task usefulness, perceived task difficulty, and interest in task) and domain and task specific learning intentions (i.e., intended effort towards task). Thus, this study focused on the participants' responses to the above four motivation questions from the pre-task portion of the OMQ, during learning, and the post-task portion of the OMQ.

Conceptual and declarative knowledge measures

Participants also completed a pre-test and post-test on the circulatory system. The pre- and post-test were identical and comprised of two parts: (a) a sheet on which participants were asked to match 13 words with their corresponding definitions (matching task measuring declarative knowledge) and (b) a sheet which contained the instruction, *‘‘Please write down everything you can about the circulatory system. Be sure to include all the parts and their purpose, explain how they work both individually and together, and also explain how they contribute to the healthy functioning of the body’’* (mental model essay measuring conceptual knowledge). The directions for the mental model essay are intentionally open-ended as they are intended to capture students' declarative, inferential, and procedural knowledge of the circulatory system. This essay question is based on extensive empirical work by Azevedo and colleagues (e.g., Azevedo and Cromley 2004; Azevedo et al. 2004a, 2005), and is drawn from extensive research by Chi and colleagues (Chi et al. 1994; Chi 2000, 2005) on students' conceptual understanding of the circulatory system. Both of the declarative knowledge and conceptual knowledge measures have been used in previous studies examining how students learn about the circulatory system with hypermedia, and have been shown to be both reliable and valid measures of students' declarative and conceptual knowledge of the circulatory system (see Azevedo et al. 2005). In sum, the participants completed two sections on the pre-test (one measuring declarative knowledge and the other measuring conceptual knowledge), and two sections on the post-test (one measuring declarative knowledge and the other measuring conceptual knowledge).

Materials

Hypermedia environment

During the learning task, participants used Microsoft Encarta Reference Suite™ (2003) to learn about the circulatory system. This hypermedia environment contains three relevant articles to the circulatory system, and these articles are comprised of 16,900 words, 35 illustrations, 107 hyperlinks, and 18 sections. Participants could freely search all of Encarta while learning about the circulatory system.

Conceptual scaffolds

While all participants had access to a global learning goal (*make sure you lean about the different parts and their purpose, how they work both individually and together, and how they support the human* body) during learning with hypermedia, participants randomly assigned to the CS condition received the following five guiding questions during learning with hypermedia: (1) What are the most important things the circulatory system does to keep us alive? (2) How do the parts of the circulatory system do those important things you just mentioned? (3) When blood leaves the right side of the heart it goes to one place, and when the blood leaves the left side of the heart it goes to a different place. What does the blood do when it leaves the right side of the heart? (4) What does the blood do when it leaves the left side of the heart? and (5) Imagine you are a blood cell in the right side of the heart. Explain all the parts you would go through to leave and eventually get back to the right side of the heart. These five questions were designed in consultation with a veteran science teacher who is familiar with the content provided in the hypermedia environment. Additionally, these higher-ordered questions were based on previous work (Azevedo et al. 2004b), and were designed to foster students' conceptual knowledge of the circulatory system.

Procedure

Each participant was individually tested by the first author in a university laboratory. Participants were first given as much time as needed to complete the consent form, and then given 15 min to complete the pre-test on the circulatory system. After completing the pre-test, participants were given a 5-min training session and walkthrough of the hypermedia environment, in which the most relevant articles for the topic of the learning task were identified. They also practiced navigating and accessing multiple representations (text, static diagrams, and digitized video clip). Following this walkthrough of the hypermedia environment, the researcher provided instructions for the learning task. For the NS condition, the instructions were: ''*You are being presented with an electronic encyclopedia, which contains textual information, static diagrams, and a digitized video clip of the circulatory system. We are trying to learn more about how students learn from electronic encyclopedias. Your task is to learn all you can about the circulatory system in 30 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. Throughout the 30 minutes, you will be periodically asked to indicate how you feel about the learning task. In order for us to understand how you learn about the circulatory system, we ask you to ''think aloud'' continuously while you read and search Encarta. Say everything you are thinking and doing. 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 and doing while you are working on this task.*'' The instructions for the CS condition included the above information in addition to a statement indicating that five guiding questions would be provided during the 30 min learning task.

After receiving the instructions, the participants were given five minutes to complete the pre-task portion of the OMQ (Boekaerts 2002). Next, the participants were given 30 min to learn about the circulatory system with the hypermedia environment. During the learning task, the five guiding questions were presented sequentially to participants in the CS condition. These participants proceeded through the questions at their own pace and could return to a previously answered question at any point during the learning task. These questions were placed to the right of the computer on a small stand and were always visible to the students throughout the 30-min learning task. Students in the NS condition did not have access to these questions. The participants' verbalizations during the 30 min learning task were recorded and later used to analyze their self-regulated learning.

At three regular intervals during the 30 min learning task (8, 16, and 24 min), participants in both conditions were asked to answer the four motivation questions. At the designated time interval, these questions appeared on the computer screen, and the participant answered by clicking on a Likert scale ranging from 1 (not at all) to 4 (very much). After submitting their responses to these questions, the participants returned to learning about the circulatory system. These three intervals divided the 30 min learning task into four time episodes: Time 1 (0–8 min), Time 2 (8–16 min), Time 3 (16–24 min) and Time 4 (24–30 min). Though exploratory in nature, this approach allowed for the examination of how motivation and SRL fluctuated over these different time episodes of the learning task. Furthermore, it was necessary to ensure that the data points were consistent across participants, and thus using time intervals was judged to be the best option.

Immediately following the 30-min learning task, participants were given 15 min to complete the post-test. They independently completed the post-test without their notes, other instructional materials, or the hypermedia environment. Lastly, the participants were given 5 min to complete the post-task portion of the OMQ (Boekaerts 2002).

Coding and scoring

In this section, the coding and scoring of the participants' answers to the matching task and mental model essay are described. In addition, the scheme used to analyze the participants' use of self-regulatory processes during learning is provided. Finally, inter-rater agreement is discussed.[1]

Matching task

For the matching task, a participant received 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) for each item on both his or her pre-test and post-test (range 0–13). This part of the pre-test and post-test was designed to measure the participants' declarative knowledge of the circulatory system.

Mental models

In keeping with current literature on conceptual knowledge and learning with multimedia and hypermedia (Mayer 1994; Sharp et al. 2006), conceptual knowledge of the circulatory system was operationally defined by mental models in this study. The second part of the pre-test and post-test was the mental model essay, which was designed to measure the

[1] Data from six participants was not included in the SRL data analysis due to incomplete measures (CS = 19; NS = 18)

Table 1 Features for each mental model category (based on Azevedo et al. 2005)

Mental model category		
Low	Intermediate	High
• Blood circulates • Describes ''purpose''—oxygen/nutrient transport • Heart as pump • Vessels (arteries/veins) transport • Mentions one of the following: electrical system, transport functions of blood, details of blood cells	• Blood circulates • Describes ''purpose''—oxygen/nutrient transport • Heart as pump • Vessels (arteries/veins) transport • Mentions one of the following: electrical system, transport functions of blood, details of blood cells • Mentions Lungs as a ''stop'' along the way	• Blood circulates • Describes ''purpose''—oxygen/nutrient transport • Heart as pump • Vessels (arteries/veins) transport • Mentions one of the following: electrical system, transport functions of blood, details of blood cells • Describes loop: heart—body—heart—lungs-heart • Structural details described: names vessels, describes blood flow through valves

participants' conceptual knowledge of the circulatory system. We examined the participants' mental model of the circulatory system using Azevedo and colleagues' method (Azevedo and Cromley 2004; Azevedo et al. 2004a, b, 2005), which is based on Chi and colleagues' research (Chi et al. 1994; Chi 2000, 2005). The coding scheme consists of three mental model categories, which represent the progression from a low level of understanding to a high level of understanding of the circulatory system (see Table 1). The categories for the mental models were designed to capture qualitative, not quantitative changes, in participants' understanding of the circulatory system. A participant was placed in the ''low'' mental model category if he or she did not demonstrate an understanding above a single-loop path of the circulatory system, and did not mention the lungs. A participant with an ''intermediate'' understanding of the circulatory system demonstrated he or she understood that the circulatory system was a single loop with lungs. Finally, a participant placed in the ''high'' mental model category demonstrated he or she understood the double-loop concept of the circulatory system. Due to the qualitative nature of the mental models used to measure participants' understanding of the circulatory system (for pre- and post-test), we examined whether there was a statistically significant relation between group and the distribution of participants' mental models at pre- and post-test.

Self-regulatory processes

A think-aloud protocol methodology (Ericsson 2006; Ericsson and Simon 1994) was used to capture participants' use of SRL processes during learning. Modified codes developed by Azevedo et al. (2004a) were used to code the participants' verbalizations. Their model was based on several recent models of SRL (Pintrich 2000; Winne 2001; Winne and Hadwin 1998; Winne and Perry 2000; Zimmerman 2000, 2001). This model includes key components of Pintrich's (2000) formulation of self-regulation as a four-phase process and extends these key components to capture the major phases of self-regulation. The coding scheme used in this study was modified from Azevedo et al. (2004a) to capture the SRL processes used by the participants in this particular study. The modified coding scheme includes 27 SRL processes from the four SRL categories of *planning, monitoring, strategy use*, and *handling task difficulty* (See Appendix A for list of SRL codes). The *planning* category consists of goal setting, planning, prior knowledge activation, recycling goals into working memory, and time and effort planning. The *monitoring* category consists of content evaluation, feeling of knowing, identifying adequacy of information, judgment of learning, monitoring progress towards goal, monitoring use of strategies, and self-questioning. The *strategy use* category consists of coordinating informational sources, drawing, finding locating in environment, free searching, goal-directed searching, memorizing, reading notes, re-reading, selecting new informational source, summarizing, taking notes, using inferences, and using mnemonic devices. The *handling task difficulty* category consists of control of context, task difficulty, and time and effort planning.

The verbal data collected via the think-aloud methodology (Ericsson 2006; Ericsson and Simon 1994) was used to analyze the participants' use of SRL processes during learning with hypermedia. The raw data collected from this study consists of 1,290 min (21.5 h) of audio recordings from 43 participants who gave extensive verbalizations while learning about the circulatory system. During the first phase of data analysis, the audio tapes were transcribed by the first author and a text file was created for each student. This phase of the data analysis yielded a total of 357 double-spaced pages ($M = 8.3$ pages per participant).

All of the transcriptions were then coded by assigning one of the SRL variables to each coded segment (see Appendix B for example of a page from a coded transcript). This phase of data analysis yielded a total of 1,536 coded SRL segments for all participants ($M = 41.5$ per participant). After coding each transcription, the individual SRL codes were then collapsed into one of the four corresponding SRL categories (*planning*, *monitoring*, *strategy use*, or *handling task difficulties*). In addition, each SRL code was identified as occurring in one of four time episodes during the 30-min learning task: Time 1 (0–8 min), Time 2 (8–16 min), Time 3 (16–24 min) and Time 4 (24–30 min). For example, during the first eight minutes of the learning task, participant UG24 had two coded goal setting (*planning*), two coded prior knowledge activation (*planning*), three coded take notes (*strategy use*), one summarization (*strategy use*), two coded selection of new informational sources (*strategy use*), one coded identify adequacy of information (*monitoring*), and three coded feelings of knowing (*monitoring*). Based on these coded SRL processes, this participant had four plan codes, six strategy use codes, and four monitoring codes in Time 1 (0–8 min).

Motivation

As with the scoring of the participants' use of SRL processes during learning, the participants' responses to the four motivation questions were gathered at different time episodes: Prior to learning with hypermedia (pre-task portion of OMQ), Time 1 of the learning task (8 min), Time 2 of the learning task (16 min), Time 3 of the learning task (24 min), and immediately following the learning task (post-task portion of OMQ). The scoring of these motivation questions followed the established scoring scheme used for the OMQ (see Boekaerts 2002).

Inter-rater agreement

Inter-rater reliability was established for the coding of the participants' SRL by comparing the individual coding of the first author, who was trained to use an adapted version of

Azevedo et al.'s (2005) coding scheme, with that of the second author (for complete details of coding scheme, see Azevedo and Cromley 2004). Both authors coded blind to the condition. Thirty-five percent of the transcripts ($n = 13$) were used for inter-rater reliability, and there was agreement on 1,496 out of 1,536 coded SRL segments, yielding a reliability coefficient of .97.

Inter-rater reliability was also established for the coding of the participants' mental model essays on the pre- and post-test. The first author and a science teacher independently scored the participants' pre- and post-test mental model essays by assigning the numerical value associated with the mental models described in Table 1. The values for each participant's pre- and post-test mental model were recorded and used to determine if the mental model scores differed between condition at pre- and post-test. The first author scored all of the participants' mental models from the pre- and post-test, and a science teacher familiar with the mental model coding scheme independently recoded 33% of the participants' pre- and post-test mental model essays ($n = 28$). There was agreement on 27 out of 28 scored essays, yielding an inter-rater reliability of .96. Disagreements on the mental model scoring and coding of SRL processes were resolved through discussion.

Lastly, inter-rater reliability was established for the participants' answers to the pre- and post-test matching task. The first author scored all of the participants' answers to the pre-test and post-test matching task, and the science teacher recoded 100% of the participants' answers to the pre- and post-test matching task ($n = 86$). There was agreement on 86 out of 86 scored matching tasks, yielding an inter-rater reliability of 1.00.

Results

Question 1: to what extent do different scaffolding conditions affect participants' learning about the circulatory system?

Participants' declarative knowledge gains were analyzed using repeated measures ANOVA with time (pre-test matching score and post-test matching score) as a within subjects factor, and scaffolding conditions (No Scaffolding and Conceptual Scaffolding) as a between-subjects factor. The sphericity assumption was met for this analysis. The main effect of time was significant, $F(1, 37) = 37.346$, $p < .001$, $\eta^2 = .48$, the main effect of conditions was not significant ($p > .05$), and the interaction between time and condition was not significant ($p > .05$; see Table 2). This result indicated that the matching post-test score was significantly higher than the matching pre-test score for participants in both conditions. In other words, participants from both conditions significantly increased their declarative knowledge of the circulatory system during the 30-min learning hypermedia task.

We used two 3 × 2 (mental model by condition) χ^2 tests to analyze participants' conceptual understanding of the circulatory system before and after learning with hypermedia. We first examined the participants' mental models on the pre-test. This χ^2 test revealed a non-significant difference in the frequency distribution of the participants' mental model by condition (χ^2 [2, $N = 37$] = 1.35, $p > .05$; see Table 3). This result indicated that the distribution of pre-test mental model scores was not statistically significantly different between conditions. Fifteen (83%) of the participants in the NS condition and 15 (79%) of the participants in the CS condition had a low mental model on the pre-test. We then examined the participants' mental models on the post-test. The χ^2 test revealed a significant difference in the frequency distribution of the participants' mental model by condition (χ^2 [2, $N = 37$] = 10.714, $p < .01$; see Table 3). This result indicated

Table 2 Percentage correct (and standard deviation) on matching task on pre- and post-test, by condition

	Condition	
	No scaffolding % (*SD*)	Conceptual scaffolding % (*SD*)
Pre-test	56.04 (6.50)	56.29 (6.35)
Post-test	82.78 (5.04)	74.82 (4.93)

Table 3 Distribution (and percentage) of participants in mental model categories on pre-test and post-test essay, by condition

	Condition	
	No scaffolding (n = 18)	Conceptual scaffolding (n = 19)
Mental model category at pre-test		
Low	15 (83%)	15 (79%)
Intermediate	3 (17%)	3 (17%)
High	0 (0%)	1 (4%)
Mental model category at post-test		
Low	10 (56%)	2 (11%)
Intermediate	5 (28%)	5 (26%)
High	3 (17%)	12 (63%)

that the distribution of students in the NS condition and CS condition statistically significantly differ on their mental model scores for the post-test. Of the 19 students in the CS condition, 12 (63%) had a high mental model on their post-test, five (26%) had an intermediate mental model on their post-test, and only two (11%) had a low mental model on their post-test score. On the other hand, of the 18 students in the NS condition, only three (18%) had a high mental model on their post-test, five (28%) had an intermediate mental model on their post-test, while 10 (56%) had a low mental model on their post-test score. Based on these results, it can be inferred that while a majority of participants from the CS and NS condition had low mental models of the circulatory system on the pre-test, there were more participants from the CS condition that had a high mental model of the circulatory system on the post-test.[2]

Question 2: to what extent do different scaffolding conditions affect the fluctuation of self-regulation during learning?

The participants' SRL was analyzed in separate repeated measures ANOVAs with the frequencies of coded SRL processes at four different times during the 30-min learning task (Time 1: 0–8 min, Time 2: 8–16 min, Time 3: 16–24 min, and Time 4: 24–30 min) as a

[2] As a validity check of the post-test measures, a one-way ANOVA was used, with post-test mental models (low, intermediate, and high) as the between-subjects factor and post-test matching scores as a within subjects factor. Significant differences were found, F (2, 36) = 9.701, $p < .001$. A post-hoc Scheffé test showed that the participants who had a high mental model at post-test had a significantly higher post-test matching score ($M_{\text{matching score}} = 11.43$) than both participants who had an intermediate mental model at post-test ($M_{\text{matching score}} = 8.70$; $p = .018$), and participants who had a low mental model at post-test ($M_{\text{matching score}} = 6.50$; $p = .003$).

within-subjects factor, and scaffolding conditions (No Scaffolding [NS] and Conceptual Scaffolding [CS]) as a between-subjects factor. Four separate analyses were conducted for each of the four SRL categories: Strategy Use, Planning, Monitoring, and Handling Task Difficulty. The sphericity assumption was met for all analyses.

Strategy use

The main effect of time on the participants' strategy use was significant, $F(1, 35) = 8.782$, $p < .001$, $\eta^2 = .20$, the main effect of condition was not significant ($p > .05$), and the interaction between time on strategy use and condition was not significant ($p > .05$). Bonferroni pairwise comparison indicated that while participants across both conditions used similar frequencies of strategies at Times 1, 2, and 3, they statistically significantly decreased their use of strategies during Time 4, on average ($p < .01$; see Fig. 1). Further examination of the frequency of the individual strategies helps explain which processes are related to the decrease of strategy use during the 30 min learning task (see Table 4). For example, participants from both conditions decreased their selection of new informational sources in the hypermedia environment and took fewer notes towards the end of the 30-min learning task.

Planning

The main effect of time on the participants' planning was not significant ($p > .05$), the main effect of conditions on planning was significant, $F(1, 35) = 9.905$, $p = .003$, $\eta^2 = .22$, and the interaction between time on planning and condition was not significant ($p > .05$). Results indicated that, on average, participants in the CS condition used statistically

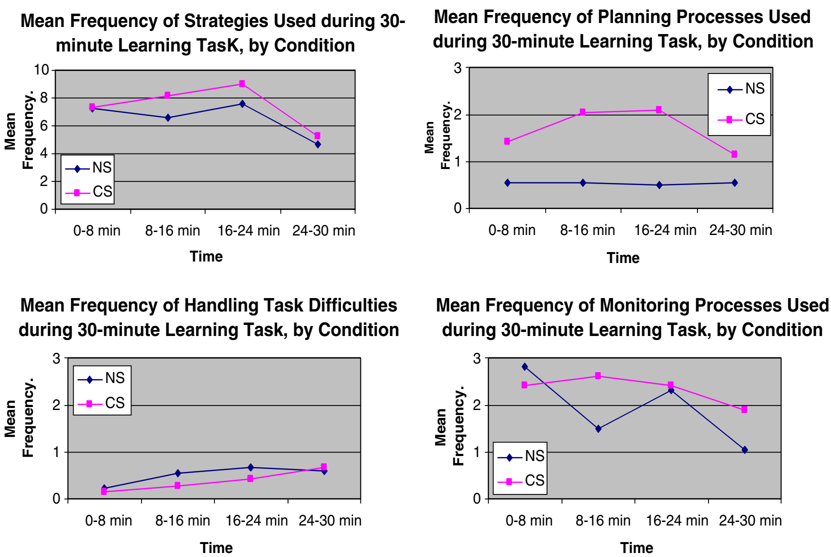

Fig. 1 Mean frequency of SRL processes used during the 30-min learning task, by condition. *Note*: NS = No Scaffolding; CS = Conceptual Scaffolding

Table 4 Total raw frequency of specific SRL processes used over time, by condition

SRL processes	Scaffolding condition									
	No scaffolding, n = 18					Conceptual scaffolding, n = 19				
	Time 1	Time 2	Time 3	Time 4	Overall	Time 1	Time 2	Time 3	Time 4	Overall
Planning										
Goal-setting	4	1	7	3	15	4	3	0	5	12
Planning	1	2	3	0	6	1	1	0	0	2
Prior knowledge activation	2	4	5	5	16	4	21	17	12	54
Recycling goals	3	3	1	2	9	18	14	23	5	60
Time & effort planning	0	2	3	5	10	0	0	1	2	3
Total	10	12	19	15	56	27	39	41	24	131
Mean (*SD*)	0.55 (1.24)	0.55 (1.24)	0.50 (0.78)	1.42 (0.86)	3.56 (3.24)	1.42 (2.46)	2.26 (2.81)	2.42 (2.75)	1.18 (1.16)	5.00 (5.41)
Monitoring										
Content evaluation	5	4	7	2	18	10	7	7	2	26
Feeling of knowing	7	14	22	7	50	13	14	23	19	69
Identifying adequacy	3	1	2	2	8	5	4	3	5	17
Judgment of learning	4	3	5	3	15	1	5	3	0	9
Monitoring progress to goals	5	3	2	5	15	3	8	6	5	22
Monitoring strategies	2	2	3	0	7	1	2	1	1	5
Self-questioning	6	0	1	0	7	3	3	3	4	13
Total	32	27	42	19	120	36	43	46	36	161
Mean (*SD*)	2.83 (4.44)	1.5 (4.44)	2.33 (3.48)	1.05 (1.58)	6.11 (8.73)	2.42 (2.83)	2.26 (2.81)	2.42 (2.75)	1.89 (2.13)	8.73 (5.41)
Strategies										
Coordinating sources	6	1	5	9	21	2	3	2	1	8
Drawing	3	2	0	0	21	0	1	0	1	2

Table 4 continued

SRL processes	Scaffolding condition									
	No scaffolding, n = 18					Conceptual scaffolding, n = 19				
	Time 1	Time 2	Time 3	Time 4	Overall	Time 1	Time 2	Time 3	Time 4	Overall
Finding location	0	6	1	2	5	4	6	7	2	19
Free searching	3	2	5	3	9	3	2	4	3	12
Goal directed search	0	3	0	1	13	1	5	6	3	15
Making inferences	2	1	0	2	4	4	4	5	1	14
Memorizing	6	0	2	7	5	2	0	3	5	10
Using mnemomics	1	0	0	0	15	0	0	0	0	0
Reading notes	2	3	4	5	1	1	1	7	2	11
Re-reading	4	17	12	8	14	3	16	12	18	49
Selecting new Sources	42	33	55	27	41	44	34	55	26	159
Summarizing	22	19	21	10	157	22	48	42	31	143
Taking notes	40	31	27	9	72	53	32	21	4	110
Total	131	118	132	83	464	139	152	164	97	552
Mean (*SD*)	6.55 (5.08)	7.27 (2.47)	7.55 (4.11)	4.67 (4.01)	29.27 (11.38)	7.30 (2.61)	8.16 (4.89)	9.00 (4.58)	5.24 (3.18)	27.10 (13.46)
Handling task difficulties										
Control of Context	3	7	8	6	24	3	5	7	11	26
Task Difficulty	1	1	1	0	3	0	0	0	0	0
Total	4	8	9	6	27	3	5	7	11	26
Mean (*SD*)	0.22 (1.24)	0.22 (0.54)	0.66 (1.13)	0.61 (1.28)	1.33 (2.70)	0.15 (.69)	0.26 (0.65)	0.42 (1.13)	0.68 (2.05)	2.21 (3.42)

significantly more planning processes throughout the learning task than participants in the NS condition. On average, participants in the CS condition planned six times during the 30 min learning task ($M_{CS} = 6.2$), while the participants in the NS condition only planned twice during the 30 minute learning task ($M_{NS} = 2.2$; see Fig. 1). Further examination of the frequency of the individual planning processes illuminates the specific planning processes that differentiate the two conditions (see Table 4). For example, participants in the CS condition, on average, recycled their goals in working memory and activated their prior knowledge more frequently throughout the 30-min learning task than participants in the NS condition.

Monitoring and handling task difficulties

The main effects and interactions for SRL processes related to monitoring and handling task difficulties were not significant ($p > .05$; see Fig. 1).

Question 3: to what extent do different scaffolding conditions affect the fluctuation of motivation during learning with hypermedia?

The participants' responses to four motivation questions on the pre-task portion of the OMQ, their responses to the same four motivation questions at the three regular intervals during the 30 min learning task (Time 1: 8 min, Time 2: 16 min, and Time 3: 24 min), and their responses to the same four motivation questions on the post-task portion of the OMQ were used for this research question. Separate repeated measures ANOVAs with motivation at different time episodes (Pre-task motivation, Time 1 motivation, Time 2 motivation, Time 3 motivation, and Post-task motivation) as a within-subjects factor, and scaffolding conditions (No Scaffolding [NS] and Conceptual Scaffolding [CS]) as a between-subjects factor were used. Four separate analyses were conducted for each of the four motivation questions: Interest, Task difficulty, Effort, and Usefulness.

Interest

The sphericity assumption was not met so the Huynh-Feldt correction was applied. The main effect of time on interest was significant, $F(2.32, 92.71) = 3.676$, $p < .05$, $\eta^2 = .08$, the main effect of condition was not significant ($p > .05$), and the interaction between time on interest and condition was not significant ($p > .05$). A pairwise comparison of interest at different times indicated that participants across both conditions reported significantly higher levels of interest as they progressed through the task ($p < .05$; see Fig. 2). See Table 5 for means and standard deviations of the participants' reported interest over time, by condition.

Task difficulty

The sphericity assumption was met for this analysis. The main effect of time on task difficulty was not significant ($p > .05$), the main effect of conditions was significant, $F(1, 40) = 4.348$, $p < .05$, $\eta^2 = .10$, and the interaction between time on task difficulty and condition was not significant ($p > .05$). The result indicated that participants in the CS condition reported the task as being significantly easier than participants in the NS

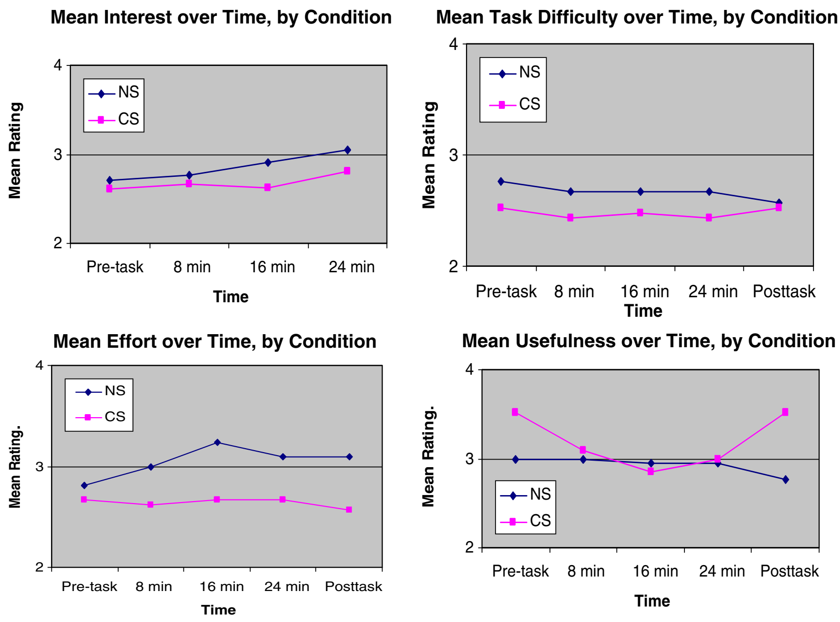

Fig. 2 Mean self-report rating of motivation over time, by condition. *Note*: NS = No Scaffolding; CS = Conceptual Scaffolding

condition (see Fig. 2). See Table 5 for means and standard deviations of the participants' perceived task difficulty over time, by condition.

Effort

The sphericity assumption was met for this analysis. The main effect of time on effort was not significant ($p > .05$), the main effect of conditions was significant, $F(1, 40) = 4.067$, $p < .05$, $\eta^2 = .09$, and the interaction between time on effort and condition was not significant ($p > .05$). The result indicated that participants in the CS condition reported putting forth significantly less effort throughout the learning task than participants in the NS condition (see Fig. 2). See Table 5 for means and standard deviations of the participants' reported effort over time, by condition.

Usefulness

The sphericity assumption was met for this analysis. The main effects and interactions for usefulness were not significant ($p > .05$; see Fig. 2). See Table 5 for means and standard deviations of the participants' perceived task usefulness over time, by condition.

Discussion

This study provides empirically based analyses that offer theoretical and methodological implications. From a theoretical standpoint, this study builds on existing models of SRL in

Table 5 Mean and (standard deviation) of motivation variables over time, by condition

SRL processes	Scaffolding condition									
	No scaffolding, n = 21					Conceptual scaffolding, n = 21				
	Pre-task	8 min	16 min	24 min	Post-task	Pre-task	8 min	16 min	24 min	Post-task
Interest	2.71 (0.85)	2.76 (0.83)	2.90 (0.83)	3.05 (0.86)	X	2.62 (0.59)	2.67 (0.57)	2.62 (0.60)	2.81 (0.67)	X
Task difficulty	2.76 (0.54)	2.67 (0.45)	2.67 (0.48)	2.67 (0.48)	2.57 (0.60)	2.52 (0.60)	2.43 (0.61)	2.47 (0.51)	2.43 (0.67)	2.52 (0.60)
Effort	2.81 (0.68)	3.00 (0.83)	3.23 (0.76)	3.10 (0.77)	3.10 (0.62)	2.67 (0.91)	2.61 (0.80)	2.67 (0.73)	2.67 (0.85)	2.57 (0.75)
Usefulness	3.00 (0.44)	3.00 (0.59)	2.95 (0.59)	2.95 (0.74)	2.75 (0.89)	3.52 (0.70)	3.10 (0.44)	2.86 (0.36)	3.00 (0.48)	3.54 (0.44)

X = Self-report data was not collected at this time interval learning with hypermedia (e.g., Azevedo et al. 2004a, 2005) by examining the fluctuation of SRL processes during learning. While assumptions underlying the SRL theory assume that self-regulation is a dynamic process that is mediated by various factors (Pintrich 2000; Winne 2001; Winne and Hadwin 1998; Zimmerman 2000, 2001), previous research has not extensively examined the dynamic nature of different SRL processes (i.e., planning, strategy use, monitoring, and handling task difficulties) *during* learning. Results from this study provide empirical evidence that SRL is a dynamic process.

Specifically, the frequency with which the participants used strategies changed at different points during the 30-min learning task. Examining the individual raw frequencies of strategies indicates that participants' selection of new information sources in the hypermedia environment may explain why their strategy use fluctuated over the 30 min learning task. Participants from both conditions, on average, selected new informational sources frequently during Time 1 (0–8 min) and Time 3 (16–24 min), slightly less frequently at Time 2 (8–16 min), but substantially less frequently towards the end of the 30-min learning task (Time 4). The participants' prior knowledge of the domain and learning context may explain the fluctuation of this particular strategy. Most participants in this study had minimal prior knowledge of the circulatory system (as evidenced by their pre-test), and had not previously used this particular hypermedia environment. Thus, in the beginning of the 30-min learning task (i.e., Time 1), participants may have initially wanted to explore the novel learning environment, especially because they were asked to learn about a topic in which they had very little prior knowledge. Consequently, these participants may have been more apt to select new informational sources quite frequently during the beginning of the learning task.

Once they became more familiar with the environment, and began the initial construction of knowledge, these participants may have focused on particular pieces of information within specific locations of the hypermedia environment. As such, they may have decreased their selection of new informational sources at Time 2. Then, once they had built a foundation of knowledge towards the middle of the 30-min learning task, they may have once again explored the environment based on this new knowledge base (i.e., increased selection of new informational sources at Time 3). Towards the end of the learning task, however, these participants most likely had explored the entire environment, which may explain why they substantially decreased their selection of new informational sources at Time 4. Though this hypermedia environment is nonlinear and contains a substantial body of information, it is still not completely open-ended. The participants may simply have navigated through most, if not all, of the hypermedia environment towards the end of the learning task.

In addition to their decreased selection of new informational sources, participants also took fewer notes towards the end of the task. Based on cognitive overload theory (Gerjets and Scheiter 2003; Kester et al. 2005; Mayer and Moreno 2003), students may take more notes in the beginning of a learning task in which they are presented with multiple representations. Novel information from multiple sources of information may present cognitive overload (Gerjets and Scheiter 2003; Kester et al. 2005), and taking notes is a strategy to offload information from multiple sources. Process data from this study indicated that participants from both conditions relied quite heavily on this particular strategy. However, as the participants progressed through the 30-min learning task and built a knowledge base of the circulatory system, information that was novel in the beginning of the learning may have become more familiar towards the end of the 30 min. Thus, towards the end of the learning task, participants may not need to offload by taking notes because some information in the hypermedia environment is no longer novel. However, it should be noted that the relationship between the use of specific strategies, such as taking notes and selecting new informational sources, and the development of knowledge is purely hypothetical. Future research is needed that examines how the use of specific strategies changes as students develop knowledge during learning with hypermedia. Though tracing knowledge development during learning poses methodological challenges, it is a promising direction for future research that is examining how students learn with hypermedia. Furthermore, previous research examining the dynamics of SRL during learning (e.g., Hadwin et al. 2004) has been primarily cognitive in nature, and has not tapped into students' motivation during learning with hypermedia. Results from this study suggest that participants reported that their interest increased as they progressed through the learning task. As such, this study suggests that some cognitive *and* motivational processes may fluctuate during learning with hypermedia.

In addition to potentially expanding our theoretical understanding of cognitive and motivational processes involved in learning with hypermedia, this study also has methodological implications for future research. Previous SRL research has used think-aloud protocol to provide rich data on students' use of SRL processes during learning with hypermedia (e.g., Azevedo et al. 2005), and motivation research has typically used self-report questionnaires to capture students' motivation (e.g., Boekaerts 2002). However, these two measurement protocols have been used independently in previous research. This study highlights the potential of developing a methodology that uses both self-report measures and think-aloud protocols in capturing the various processes involved in learning with hypermedia. Future research should consider integrating both of these measures to further our understanding of the complexities of learning with hypermedia.

In addition to the theoretical and methodological contributions, this study also extends previous research that has examined the impact of conceptual scaffolds on how students learn with hypermedia (Hannafin et al. 1999). While previous research has examined how conceptual scaffolds affect learning with hypermedia, the results from this line of research has been mixed. Some research suggests that providing students with conceptual scaffolds may foster learning (Shapiro 1999, 2000), while other research has found that conceptual scaffolds may actually interfere with learning (Azevedo et al. 2004a). This study indicated that the provision of conceptual scaffolds, in the form of guiding questions, during learning with hypermedia is positively associated with students' learning of challenging science topics. While students from both conditions significantly increased their declarative knowledge of the circulatory system, significantly more students from the CS condition had a higher mental model of the circulatory system on the post-test than students from the NS condition. As highlighted by McDaniel and Donnelly (1996), research that has examined the relation between asking students higher-ordered questions, such as the questions provided in the CS condition, and learning has typically focused on factual, or declarative, knowledge. Thus, this study contributes to our understanding of the relation between providing students with higher-ordered questions and their conceptual knowledge development with hypermedia.

In addition, the results also indicated that provision of conceptual scaffolds was associated with the learning process. Specifically, participants who received conceptual scaffolds during learning used, on average, more planning processes during the 30 min learning task than students who did not receive conceptual scaffolding. Examining the individual raw frequencies of two specific planning processes, activation of prior knowledge and recycling goals in working memory, may explain why there was a statistically significant difference between the two conditions with regard to the SRL category of planning. On average, students in the CS condition recycled goals in working memory and activated prior knowledge more frequently than students in the NS condition. The nature of the conceptual scaffolds used in this study may explain these findings. The conceptual scaffolds used in this study were five guiding questions that the participants were asked to answer during learning, and these questions were designed so that each one fostered an increasingly complex understanding of the circulatory system. In order to answer each increasingly complex question, students needed to recall what they had learned for the previous question. Consistent with the literature from elaborative interrogation (e.g., Martin and Pressley 1991), effective higher-ordered questions allow students to anchor newly acquired knowledge in prior knowledge.

Furthermore, students may need external guidance when using an open-ended environment to learn about a challenging topic in which they have very little prior knowledge. The questions provided in the CS condition offered the participants with external guides, and the frequency in which participants from this condition recycled goals in working memory (i.e., re-read the guiding question) suggests that they were often relying on the questions to guide their interaction with hypermedia (see Table 4 for the frequency of recycling goals in working memory, by condition). Though it may be intuitive that providing guiding questions during learning should foster knowledge development, this study provides process data, which helps explain *why* this type of conceptual scaffold facilitates knowledge development.

Future directions

Future research should consider additional lines of inquiry to provide a more comprehensive understanding of how scaffolds affect learning with hypermedia. While this study focused on the treatment fidelity of scaffolds on participants' use of SRL processes and motivation, the quality of the participants' responses to the provided questions was not analyzed. As such, the extent to which these participants actually answered the questions and the quality of their responses is presently unclear. Analyzing responses to these questions will advance our understanding of the complexities in learning with hypermedia in the presence of conceptual scaffolds.

Second, in order to measure the fluctuation of SRL processes and their motivation during learning, time intervals were used throughout the 30-min learning task. There is limited empirical research that has actually collected process data on SRL and motivation during learning with hypermedia, and thus this study was, in part, an exploratory step in identifying the fluctuation of SRL processes and motivation during learning. Using time intervals allowed for the data points to be consistent across all participants. However, future research could use different data collection techniques to address the fluctuation of SRL processes and motivation. For example, assessing SRL processes and motivation at intervals tied to specified content in a hypermedia environment is an alternative method of measurement for future studies.

Lastly, this study used motivational constructs from the OMQ (Boekaerts 2002). Though it has been suggested that these constructs are related to students' direction, vigor, and persistence of behavior, they fall across a number of different dimensions in other frameworks. For example, in Pintrich's SRL framework, processes related to motivation fall into a number of different phases. While interest, as identified in this study, is a planning activity related to motivation, the evaluation of the task's difficulty, as identified in this study, falls into the reaction and reflection phase. Currently, there is limited empirical research, which has examined the role of these processes in the different phases of learning and, furthermore, more theoretical work is needed that considers how these various processes are related to each other (Winne 2005).

Limitations

While this study offers theoretical and methodological contributions to research examining the impact of conceptual scaffolds on cognitive and motivational processes during learning, there are some limitations that need to be addressed. First, the results may be constrained by the particular developmental group, context, and/or task in this study. That is, the relationship between conceptual scaffolds, motivation, and cognitive processes may be mediated by the particular developmental group (undergraduates), context (learning with hypermedia), and/or task (learning about the circulatory system). In order to tease apart any mediating influences of these variables, this line of research would benefit from future research examining the impact of conceptual scaffolds on how different developmental groups learn various domains in similar open-ended CBLEs. Second, the impact of conceptual scaffolds on motivation was constrained to four motivation questions from the OMQ (Boekaerts 2002). Other theoretically driven concepts of motivation, such as self-efficacy (Bandura 1994), have been shown to be strongly related to the process of learning in different domains (e.g., Pajares 1996) and in various contexts (Pintrich 2000). Future research would benefit from examining the relationship between conceptual scaffolds and theoretically driven motivation constructs such as self-efficacy. Third, the modest test–retest scores for the OMQ, as reported by Boekaerts (2002), raise some concern about the reliability of this measure. Though the context-sensitivity nature of the constructs in the OMQ may understandably minimize the test–retest scores, future research should further examine the reliability of this measure.

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Appendix

Appendix A Classes, descriptions and examples of variables used to code participants' use of self-regulatory processes (based on Azevedo et al. 2005)

Variable	Description[a]	Student example
Planning		
Goals	Consist either of operations that are possible, postponed, or intended, or of states that are expected to be obtained. Goals can be identified because they have no reference to already-existing states	''I'm looking for something that's going to discuss how things move through the system''
Planning	A plan involves coordinating the selection of operators. Its execution involves making behavior conditional on the state of the problem and a hierarchy of goals and sub-goals	''First I'll look around to see the structure of environment and then I'll go to specific sections of the circulatory system''
Prior knowledge activation	Searching memory for relevant prior knowledge either before beginning performance of a task or during task performance	''It's hard for me to understand, but I vaguely remember learning about the role of blood in high school''
Recycle goal in working memory	Restating the goal (e.g., question or parts of a question) in working memory	''…what are the most important things the circulatory system does…''
Time and effort planning	Attempts to intentionally control behavior	''I'm skipping over that section since 45 min is too short to get into all the details''
Monitoring		
Content evaluation	Monitoring content relative to goals	''I'm reading through the info but it's not specific enough for what I'm looking for''
Feeling of knowing	Learner is aware of having read something in the past and having some understanding of it, but not being able to recall it on demand	''… let me read this again since I'm starting to get it…''
Identify adequacy of information	Assessing the usefulness and/or adequacy of the content (reading, watching, etc.)	''…structures of the heart…here we go…''
Judgment of learning	Learner becomes aware that they don't know or understand everything they read	''I don't know this stuff, it's difficult for me''
Monitor progress toward goals	Assessing whether previously set goal has been met.	''Those were our goals, we accomplished them''
Monitor use of strategies	Participant comments on how useful a strategy was	''Yeah, drawing it really helped me understand how blood flow throughout the heart''
Self-questioning	Posing a question and re-reading to improve understanding of the content	[Learner spends time reading text] and then states ''what do I know from this?'' and reviews the same content
Strategy use		
Coordinating informational sources	Coordinating multiple representations, e.g., drawing and notes.	''I'm going to put that [text] with the diagram''

Appendix A continued

Variable	Description[a]	Student example
Draw	Making a drawing or diagram to assist in learning	''…I'm trying to imitate the diagram as best as possible''
Find location in environment	Statement about where in environment learner had been reading.	''That's where we were.''
Free search	Searching the hypermedia environment without specifying a specific plan or goal	''I'm going to the top of the page to see what is there''
Goal-directed search	Searching the hypermedia environment after specifying a specific plan or goal	Learner types in blood circulation in the search feature
Memorization	Learner tries to memorize text, diagram, etc.	''I'm going to try to memorize this picture''
Review notes	Reviewing learner's notes.	''Carry blood away. Arteries–away.''
Re-reading	Re-reading or revisiting a section of the hypermedia environment	''I'm reading this again.''
Selecting a new informational source	The selection and use of various cognitive strategies for memory, learning, reasoning, problem solving, and thinking. May include selecting a new representation, coordinating multiple representations, etc.	[Learner reads about location valves] then switches to watching the video to see their location
Summarization	Summarizing what was just read, inspected, or heard in the hypermedia environment	''This says that white blood cells are involved in destroying foreign bodies''
Using inferences	Making inferences based on what was read, seen, or heard in the hypermedia environment	…[Learner sees the diagram of the heart] and states ''so the blood….through the …then goes from the atrium to the ventricle… and then…''
Using mnemonic devices	Using a verbal or visual memory technique to remember content	''Arteries—A for away''
Taking notes	Copying text from the hypermedia environment	''I'm going to write that under heart''
Handling task difficulty and demands		
Control of context	Using features of the hypermedia environment to enhance the reading and viewing of information	[Learner double-clicks on the heart diagram to get a close-up of the structures]
Task difficulty	Learner indicates one of the following: (1) the task is either easy or difficult, (2) the questions are either simple or difficult, (3) using the hypermedia environment is more difficult than using a book	''This is harder than reading a book''

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

Appendix B Example of Coded transcript

Condition A/SRL/MOT/ UG13 "KA"
4/07/05

heart into the aorta, the body's largest artery Oh, the aorta is the largest artery, I remember that FoK
Smaller arteries that branch off the aorta distribute blood to various parts of the body. Smaller
arteries that branch off the aorta distribute blood to various parts of the body So, let's see, I am
going to write that down here..smaller arteries, so obviously they are arteries off an artery, TN TEP
branch off aorta, largest artery 8 minutes to distribute blood to various parts of the body. All
right, I need to quickly hurry because I also want to look at the picture, as well as click on Plan
whatever I haven't clicked on yet, I also want to click blood vessels, or blood, or we will see
Muscle tissue known as myocardium or cardiac muscle wraps around a scaffolding of tough
connective tissue. [un]. . *A tough, double-layered sac.. The heart's duties are much broader.* I
don't know, not really reading at all here..all right, cardiac cycle, all right I think control of heart CE
rate, I don't think I need to know all of that. I am going to click on this picture *The human heart* CoC
is a hollow, pear-shaped organ about the size of a fist. The heart is made of muscle that
rhythmically contracts, or beats, pumping blood throughout the body. Oxygen-poor blood from
the body enters the heart from two large blood vessels, the inferior vena cava and the superior
vena cava, and collects in the right atrium. Okay, so it starts here..in the superior and goes to, CoIS MUS
look in my notes, that would even better..inferior..right atrium, and then comes down into the CoIS
right atrium, and then into the left ventricle, okay, left ventricle, no, I am wrong, right ventricle, FoK
and then pulmonary artery…in the lungs..not in the picture, [un] figure out, pulmonary veins, left CoIS
atrium, I guess it comes here, up here, left atrium, left ventricle..aorta..that seems kind of weird I JoL
better read this. *When the ventricle becomes full* okay, hold on, five minutes, all right, let's see TEP
The human heart is a hollow, pear-shaped organ about the size of a fist. The heart is made of
muscle that rhythmically contracts, or beats, pumping blood throughout the body. Oxygen-poor
blood from.. When the atrium fills...oops, survey.

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