Adaptive scaffolding and self-regulated learning from hypermedia: A developmental study

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Abstract

In this study we examined the effectiveness of three scaffolding conditions on middle school, high school, and undergraduate students’ learning about the circulatory system using hypermedia as indicated by their posttest scores on four learning measures using pretest scores as a covariate. The learning measures included a matching and labeling task, an essay, and a flow diagram. One hundred and seventy-nine students (N = 179; middle school, n = 58; high school, n = 53; and undergraduate, n = 68) were randomly assigned to one of three scaffolding conditions (no scaffolding, fixed scaffolding, and adaptive scaffolding) and were trained to use a hypermedia environment to learn about the circulatory system. Students’ learning across scaffolding conditions and across developmental levels revealed that the adaptive scaffolding condition facilitated students’ learning about the topic on all learning measures significantly more than did the other scaffolding conditions. Students across the three developmental levels tended to learn the same amount of knowledge on all learning measures. There was no interaction between scaffolding condition and developmental level. We conclude by discussing implications of embedded scaffolds for hypermedia learning environments.
Adaptive scaffolding and self-regulated learning with hypermedia: A developmental study

As hypermedia becomes more widely used in schools, new questions arise about its potential impact on students’ learning. Hypermedia has the potential to increase students’ learning of challenging and complex educational topics such as the circulatory system (Shapiro & Niederhauser, 2004). However, the widespread use of hypermedia for learning raises new questions about its potential impact on students’ learning about complex and challenging topics (Dillon & Gabbard, 1998). In fact, research indicates that students of all ages experience certain difficulties in regulating their learning with hypermedia (Azevedo, Guthrie, & Seibert, in press). Research shows that allowing students to control the sequencing of instruction and time spent learning, to access multiple representations of information, and to make choices about non-linear multiple representations requires them to regulate their learning and may undermine the potential of hypermedia as powerful learning environments (e.g., Azevedo, Cromley, & Seibert, in press). Researchers have therefore attempted to facilitate students’ learning with hypermedia by using scaffolds, or instructional aids, designed to support students’ learning (e.g., Brush & Saye, 2001).

Scaffolds are tools, strategies, and guides that can support students in regulating their learning of complex topics with hypermedia. Although there are many descriptive studies of how scaffolds have been used in computer-based learning environments to support complex learning (e.g., Land & Greene, 2000), there is little empirical evidence that deals specifically with which types of scaffolds are effective in helping students of different ages regulate their learning with hypermedia. In the present study, we examine whether different scaffolding methods are effective in facilitating middle school, high school, and college students’ ability to regulate their learning about the circulatory system with a hypermedia environment.

Hypermedia environments give students access to a non-linear structure within which a wide range of information is represented as text, graphics, animation, audio, and video (Jacobson &
Kozma, 2000; Jacobson et al., 1996; Jonassen & Reeves, 1996; Lajoie, 2000). Learning in such an environment requires a learner to regulate his or her learning; that is, to make decisions about what to learn, how to learn it, how much to learn, how much time to spend on it, how to access other instructional materials, whether he or she understands the material, when to abandon and modify plans and strategies, and when to increase effort (Williams, 1996; Winne, 2001).

We have chosen Winne and Hadwin’s (1998, 2001) model of self-regulated learning as an appropriate theoretical framework for examining students’ learning complex topics with hypermedia. Their model allows researchers to examine the complex interplay between learner characteristics, elements of the hypermedia environment, and the mediating learning processes during learning with hypermedia. Specifically, students need to analyze the learning situation, set meaningful learning goals, determine which strategies to use, assess whether the strategies are effective in meeting the learning goal, evaluate their emerging understanding of the topic, and determine whether the learning strategy is effective for a given learning goal. They need to monitor their understanding and modify their plans, goals, strategies, and effort in relation to contextual conditions (e.g., cognitive, motivational, and task conditions). Further, depending on the learning task, they may need to reflect on the learning episode and modify their existing understanding of the topic (Winne, 2001; Winne & Hadwin, 1998). Because of these demands, and despite their potential for fostering learning, hypermedia environments may prove to be ineffective if learners do not regulate their learning. 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).

The Role of Scaffolding in Facilitating Students’ Learning with Hypermedia

Scaffolding involves providing assistance to students on an as-needed basis, fading the assistance as their competence increases (Hogan & Pressley, 1997). Scaffolding is an instructional...
process in which the teacher or tutor supports students cognitively, motivationally, and emotionally in learning while helping further develop their autonomy (Chi, deLeeuw, Chiu, & LaVancher, 1994; Meyer & Turner, 2002). During instructional scaffolding, the teacher or tutor supports the students’ self-regulation, as needed, in three ways: (a) helping students build competence through increased understanding, (b) engaging students in learning while supporting their socioemotional needs, and (c) helping students build and exercise autonomy as learners. These notions of classroom scaffolding have recently been used in hypermedia to foster students’ learning (e.g., Brush & Saye, 2001).

Recent research indicates that due to students’ inability to regulate their learning, use of hypermedia rarely leads to significant learning gains. This has been found across several complex topics and ages (e.g., Azevedo & Cromley, 2003, Greene & Land, 2000; Hannafin & Land, 1997; Jacobson & Archodidou, 2000; Wolf, Brush, & Saye, 2003). Studies indicate that students have difficulties in regulating aspects of their cognitive system, features of the hypermedia, and the mediating learning processes. For example, research has shown that students do not plan, set goals, monitor their understanding, use effective strategies, and reflect on their progress during learning with hypermedia (e.g., Azevedo, Cromley, Winters, Xu, & Iny, 2003). We argue that successful learning with these complex environments requires learners to self-regulate their learning.

**The Effectiveness of Different Scaffolding Conditions on Students’ Learning with Hypermedia**

In the absence of scaffolds, learning about complex topics with hypermedia is hindered for middle-school (Brinkerhoff & Glazewski, 2000; Oliver & Hannafin, 2000; Wolf et al., 2003) and college students (Greene & Land, 2000; Land & Greene, 2000). For example, a study by Azevedo, Guthrie, and Seibert (in press) examined whether undergraduate students could regulate their own learning when using a hypermedia environment to learn about the circulatory system. Students who showed significant learning gains from pretest to posttest, as measured by the shift in their mental
models of the circulatory system, 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 while some college students can learn with hypermedia environments, their ability to learn about complex systems is associated with the deployment of certain SRL mechanisms. Introducing scaffolds might facilitate the conceptual understanding of those who did not show learning gains. While published studies focus on middle school and college students, we were not able to locate empirical evidence about how high school students learn with hypermedia in the absence of scaffolds. Because of the poor learning results in the absence of scaffolds, researchers and designers have attempted to foster students’ learning with hypermedia by embedding fixed scaffolds in hypermedia environments.

Fixed scaffolds have shown mixed results in facilitating students’ learning of complex topics with hypermedia. Fixed scaffolds are static and are not adaptable to meet individual students’ learning needs. The majority of studies have found evidence that fixed scaffolds are effective in facilitating college and high school students’ learning about biology (e.g., Shapiro, 1999, 2000; Lin & Lehman, 1999). For example, a study conducted by Jacobson & Archodidou (2000) showed that embedded fixed scaffolds were effective in supporting high school students’ learning with hypermedia by demonstrating significant shifts in students’ mental model of evolutionary biology. In their study, eight high school students used a hypermedia system based on the main features of the knowledge mediator framework to learn neo-Darwinian evolutionary biology. Students using the experimental hypermedia system were found to change their evolutionary biology mental
models, and to continue to use expert-like models even one year after using the system. Other researchers have found the same positive results by using multiple fixed scaffolds with high school students to foster their learning of history (Brush & Saye, 2001; Saye & Brush, 2002). However, two studies found no significant effects: a study by McManus (2000) examining the effectiveness of advanced organizers as scaffolds for facilitating college students learning of computer literacy, and a study by Hartley (2001) using embedded fixed strategy instruction with high school students on computer networking.

The mixed results evidenced in the literature impede our ability to adequately assess the effectiveness of embedded fixed scaffolds in hypermedia environments. Specifically, while the use of single fixed scaffolds has been effective with college students for learning biology and the use of multiple fixed scaffolds has been effective with high school students for learning history, the results also indicate that fixed scaffolds do not foster learning in other domains, and that the effectiveness of fixed scaffolds with middle school students remain uninvestigated. We argue that fixed scaffolds are not always effective because they are not adaptable and therefore do not address students’ individual learning needs during learning nor do they support students’ regulatory behavior when using hypermedia. Although there are potential benefits of fixed scaffolds, researchers and designers have also attempted to foster students’ learning with hypermedia by using adaptive scaffolds.

Adaptive scaffolding, in contrast to fixed scaffolding, has been consistently shown to support students’ self-regulated learning, mostly because it adjusts to meet students’ learning needs. Adaptive scaffolding has been extensively examined in the context of human tutoring and classroom instruction and has repeatedly demonstrated that its effectiveness is based on a teacher’s or tutor’s ability to continuously diagnose the student’s emerging understanding and provide timely support during learning (e.g., Chi et al., 2001; Meyer & Turner, 2002). However, the effectiveness
of adaptive scaffolding for middle school, high school, and college students’ learning with hypermedia needs to be empirically established. Adaptive scaffolding requires a delicate balance, negotiating between providing support while continuing to foster a student’s own self-regulatory behavior during learning (e.g., planning, setting learning goals, and monitoring their emerging understanding).

In contrast to the plethora of studies on the effectiveness of adaptive scaffolding in tutoring and classroom instruction (e.g., Meyer & Turner, 2002) and computer-based learning environments (e.g., Aleven & Koedinger, 2002), only a few studies have provided evidence that adaptive scaffolding in biology, statistics, and science leads to enhanced learning for middle school and college students with hypermedia (Azevedo, Cromley, & Seibert, in press; Kao & Lehman, 1997; Pedersen & Liu, 2002a, 2002b). Overall, the literature indicates that adaptive scaffolding is critical for students’ ability to regulate their learning and can therefore enhance the learning of complex science topics such as the circulatory system while using hypermedia. These studies consistently demonstrate the effectiveness of adaptive scaffolding in facilitating students’ learning. For example, Kao and Lehman (1997) found that college students assigned to an adaptive scaffolding condition embedded in a hypermedia environment outperformed those assigned to comparison groups on a test of basic statistics. Similarly, Pedersen and Liu (2002a, 2002b) conducted two studies in which middle school students who were assigned to a modeling scaffolding condition outperformed those assigned to either a didactic or a no scaffolding condition. Students in the modeling condition had access to an embedded expert scientist who would adapt to each student’s individual learning needs by showing them strategies that he would use while solving the problem, and by explaining the problem to the student, how he would solve it and how he would use other embedded scaffolds to solve it. Furthermore, this expert would model numerous strategies including self-questioning, making connections, identifying missing information, forming hypotheses, and taking notes.
A recent study by Azevedo, Cromley, and Seibert (in press) demonstrates the comparative effectiveness of adaptive scaffolding, fixed scaffolding, and no scaffolding on college students’ ability to regulate their learning of biology with hypermedia. Their findings revealed that the adaptive scaffolding condition facilitated the students’ shift in both their mental models of the circulatory system and declarative knowledge, as measured by matching and labeling tasks. Students in all three conditions gained declarative knowledge from pretest to posttest. Also, participants in the adaptive scaffolding condition regulated their learning by activating prior knowledge, monitoring their emerging understanding by using several strategies, and engaging in adaptive help-seeking. They also found that students’ in the no scaffolding and fixed scaffolding condition performed equally well on those same learning measures. Furthermore, their think-aloud data provided evidence that learners in both the fixed and no scaffolding conditions were less effective at regulating their learning and also exhibited greater variability in self-regulation of their learning during the knowledge construction activity.

In sum, the relatively few studies which have been conducted on the effectiveness of fixed scaffolding and 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. Furthermore, research in this area has focused exclusively on examining the effects of different scaffolding methods and has paid little attention to how students at different ages may benefit from these different types of scaffolds. In this study, we investigated whether providing different types of scaffolding during learning with a hypermedia environment could foster middle school, high school, and undergraduate students’ learning of a complex system.

Overview of Current Study and Hypotheses

In this study, we investigated the effectiveness of different scaffolding methods for facilitating college, high school, and middle school students’ ability to learn about the circulatory system with
hypermedia. In this paper we focus on three specific research questions: (a) Do different scaffolding conditions lead to significant learning? (b) Are there significant differences in middle school, high school, and college students’ posttest scores on each of the four learning measures? and (c) Is there an interaction between the three scaffolding conditions and the three developmental levels on each of the four learning measures?

We used Winne and colleagues’ (Winne, 2001; Winne & Hadwin, 1998) model of SRL and the existing empirical literature on scaffolding and learning with hypermedia (e.g., Azevedo, Guthrie, & Seibert, in press), and extended Azevedo, Cromley, and Seibert’s (in press) study by using the same three scaffolding conditions—adaptive scaffolding (AS), fixed scaffolding (FS), and no scaffolding (NS), and comparing how these scaffolding conditions facilitated middle school, high school, and college students’ learning on measures of the circulatory system with hypermedia.

In the *adaptive scaffolding* (AS) condition, students were provided with an overall learning goal. They had access to a human tutor who provided adaptive scaffolding by helping them enact various key mechanisms of SRL, such as planning their learning, monitoring their emerging understanding, using different strategies to learn about the circulatory system, handling task difficulties and demands, and assessing their emerging understanding. These SRL variables were used dynamically and adaptively by the tutor during learning. In the *fixed scaffolding* (FS) condition, the students were given the same overall learning goal and a list of ten domain-specific questions (created in consultation with a nurse practitioner). These were designed to scaffold their conceptual understanding of the circulatory system by providing a fixed list of sub-goals which an expert would use to learn about the system. In the *no scaffolding* (NS) condition, the students were given the same overall learning goal, but we wanted to determine whether students could learn about a complex science topic in the absence of any scaffolding.
With regard to the first research question, we hypothesized that the AS condition would lead to significantly higher posttest scores (after accounting for pretest scores) on all four learning measures. In contrast, we hypothesized that, in comparison to the AS condition, both the FS and NS conditions would lead to no significant student learning on the four measures measures, and that they would not differ from each other.

As for the second research question, and consistent with cross-aged studies (see Pintrich & Zusho, 2002 for a review), we hypothesized that the college students would lead to significantly higher posttest scores (after accounting for pretest scores) on all four learning measures than the high school students, who would learn significantly more than the middle school students, on each of the four learning measures.

As for the third research question, we did not posit a hypothesis given the lack of empirical evidence about scaffolding conditions and age.

Method

Participants

Participants were 179 students including 58 seventh-grade (M age = 12.3 years; 22 boys and 36 girls) middle school students, 53 tenth-grade high school students (M age = 15.5 years; 25 boys and 28 girls), and 68 undergraduate students (non-biology majors; M age = 21.8, M GPA = 3.2; 10 males and 58 females). Most participants demonstrated average or little knowledge of biology and the circulatory system on the pretest (see below).

Research Design

This study combined a between-subjects factorial design (179 students, at three developmental levels, randomly assigned within developmental level to one of three scaffolding conditions—Adaptive Scaffolding [AS], Fixed Scaffolding [FS], and No Scaffolding [NS]) with a think-aloud protocol methodology (Ericsson & Simon, 1993). Among the middle-school students,
there were 20 participants in the AS condition and 19 each in the FS and NS conditions. For the high-school students, there were 18 participants each in the AS and FS conditions and 17 in the NS condition. For the undergraduates, there were 21 participants in the AS condition, 24 in the FS condition, and 23 in the NS condition.

Measures

The paper-and-pencil materials consisted of a consent form, a participant questionnaire, a pretest, and a posttest. All of the paper-and-pencil materials, except for the consent form and questionnaire, were constructed in consultation with a nurse practitioner and a science teacher (the third author). Prior to taking part, participants either read and signed a consent form or were asked to have their parents/guardians sign the consent form. The participant questionnaire solicited information concerning age, sex, current GPA (for the undergraduates), number and title of biology classes completed, any other science classes related to the circulatory system, 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 13 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 14 components (labeling), (3) another 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.” (essay), and (4) an outline of the human body on which the students were asked to list in order eight structures (a list of terms was provided) related to the circulatory system to represent the flow of blood through the body (blood-flow diagram). The posttest was identical to the pretest.
Hypermedia Environment

During the experimental phase the participants used Microsoft Encarta’s Reference Suite™ (2003) 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 DVD-based 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 informational sources—text, static diagrams, photographs, and a digitized animation depicting the functioning of the circulatory system. Together these three articles comprise 16,900 words, 18 sections, 107 hyperlinks, and 35 illustrations. During learning, participants were allowed to use all of the features incorporated in Encarta such as the search functions, hyperlinks, and multiple sources of information, and were allowed to navigate freely within the environment. For example, a student who had set a goal to learn more about systemic circulation could find the relevant section of Encarta by either using the “find” function anywhere in Encarta, or if he or she was already in the circulatory system section, they could either use the “find in this article” search function or link to it from the table of contents.

Procedure

Participants within each developmental level were randomly assigned to one of three groups: AS, FS, and NS. At least one of the authors tested each participant. 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 20 minutes to complete it. Participants wrote their answers on the pretest and did not have access to any instructional materials. Third, the experimenter provided instructions for the learning task. The following instructions were read and presented to the participants in writing.
No Scaffolding (NS) Condition. For the NS condition the instructions were: “You are being presented with a hypermedia encyclopedia, which contains textual information, static diagrams, and a digitized video clip of the circulatory system. We are trying to learn more about how students use hypermedia environments to learn about the circulatory system. Your task is to learn all you can about the circulatory system in 40 minutes. Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body. We ask you to ‘think aloud’ continuously while you use the hypermedia environment to learn about the circulatory system. I’ll be here in case anything goes wrong with the computer and the equipment. Please remember that it is very important to say everything that you are thinking while you are working on this task.”

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

Adaptive Scaffolding (AS) Condition. The instructions for the AS condition were identical to those for the NS condition, however, learners had access to a tutor (the third author) who would help them learn about the circulatory system during the learning session by providing adaptive scaffolding: that is, assist the learner to plan their learning, monitor their emerging understanding, use different strategies to learn, and handle task difficulties and demands, while they covered the same overall goal as the participants in the NS condition. The tutor was instructed not to provide extensive praise nor did she provide any additional content knowledge not contained in the sections the students used in the hypermedia environment during the learning episode.

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. In all three conditions, an experimenter remained nearby but simply reminded participants to keep verbalizing when they were silent for more then three seconds (e.g., “say what you are thinking”). All participants were reminded of the global learning goal (“Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body”) as part of their instructions for learning about the circulatory system. All participants had access to the instructions (which included the learning goal) during the learning session. Participants in the FS condition also had access to the 10 sub-goals, while participants in the AS condition had access to the tutor. All participants were given 40 minutes to use the hypermedia environment to learn about the circulatory system. There was no significant difference between conditions in the time spent using the hypermedia environment to learn about the circulatory system (AS $M = 40.0$ min, $SD = 0.10$; FS $M = 39.9$ min, $SD = .13$; NS $M = 39.9$ min, $SD = 0.12$). 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 20 minutes to complete the posttest. All participants independently completed the posttest in 20 minutes without their notes or any other instructional materials by writing their answers on the sheets provided by the experimenter.

**Coding and Scoring**

In this section we describe the coding of the students’ mental models, and the students’ answers for the matching task, labeling of the heart diagram, blood-flow diagram, and inter-rater agreement.

**Mental models.** Our analyses focused on the participants’ posttest mental models (after accounting for pretest mental models) based on the different scaffolding conditions. One goal of our research was to capture the initial and final mental model that each participant had of the circulatory
system. This analysis depicted the status of each student’s mental model prior to and after learning, as an indication of representational change that occurred with deep understanding. In our case, the status of the mental model refers to the correctness and completeness in regard to the local features of each component, the relationships between and among the local features of each component, and the relationships among the local features of different components.

We followed Chi and colleagues’ (Chi et al., 1994; Chi, 2000) 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. Similarly, a student’s final mental model of how the circulatory system works was derived from their statements from the essay section of the posttest. We expanded Chi’s original (Chi et al., 1994; Chi, 2000) six general types of mental models and strategically embedded six more, resulting in 12 models which represent the progression from no understanding to the most accurate 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 consulting nurse practitioner and the science educator (the third author). A complete description of the necessary features for each mental model is provided in Table 2.

The second and third authors scored the students’ pretest and posttest mental models by assigning the numerical value associated with the mental models described in Table 2. For example, a student who simply stated that blood circulates would be given mental model of 2. A student who wrote that the heart pumps the blood through blood vessels to carry oxygen to the body would be given a mental model of 5. The 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 agreement below).

Matching task, labeling of the heart diagram, and blood-flow diagram. The second and third authors 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 0-13). Similarly, the second and third authors scored the heart diagram by giving each student either a 1 (for each correctly labeled component of the heart) or a 0 (for each incorrect label) (range 0-14). The second and third authors also scored the blood-flow diagram by giving each student a 1 (for correct placement of a provided term) or a 0 (for incorrect placement of a provided term) (range 0-8). The correct progression of the provided terms for the flow is: 1) right atrium, 2) right ventricle, 3) arteries/capillaries/veins or lungs, 4) lungs or arteries/capillaries/veins, 5) left atrium, 6) left ventricle, 7) arteries/capillaries/veins or body, and 8) body or arteries/capillaries/veins. The scores for each student’s pretest and posttest on the matching task, heart diagram, and flow diagram were tabulated separately and used in subsequent analyses.

Inter-rater agreement. Inter-rater agreement was established by training the second and third authors to use the description of the mental models developed by Azevedo, Cromley, and Seibert (in press) and Azevedo, Guthrie, and Seibert (in press) (see Table 2). They independently coded all 358 selected protocols (pretest and posttest essays of the circulatory system from each participant) using the 12 mental models of the circulatory system previously described and presented in Table 2. There was agreement on 342 out of a total of 358 student descriptions, yielding an inter-rater agreement of .96. All disagreements were then resolved by discussion. Inter-rater reliability was also established for the matching and labeling tasks, and blood-flow diagram. For each of these tasks, there was agreement on 358 out of 358 student responses, yielding an inter-rater agreement of 1.00 for each task.
Results

We used a 3 (scaffolding condition: NS, FS, AS) X 3 (developmental level: middle school, high school, undergraduate) ANCOVA on the posttest scores for mental models (essay), matching and labeling tasks, and the blood-flow diagram, using the corresponding pretest scores as the covariate. Among the middle-school students, there were 20 participants in the AS condition and 19 in both the FS and NS conditions. For the high-school students, there were 18 participants in both the AS and FS conditions and 17 in the NS condition. For the undergraduates, there were 21 participants in AS condition, 24 in the FS condition, and 23 in the NS condition. Before conducting each analysis, we ensured homogeneity of regression slopes and significance of the covariate for all dependent variables.

**Mental Models.** A 3 X 3 ANCOVA on the mental models posttest scores, using the mental models pretest score as a covariate, showed a significant main effect for scaffolding condition ($F[2, 165] = 5.72, \text{MSE} = 6.14, p < .05, \eta^2 = .07$) but no significant main effect for developmental level ($F[2, 165] = 2.32, \text{MSE} = 6.14, p > .05, \eta^2 = .03$). There was no significant interaction of scaffolding condition and developmental level, ($F[4, 165] = 1.14, \text{MSE} = 6.14, p > .05, \eta^2 = .03$). Given the absence of an interaction, the main effect for scaffolding condition was further analyzed using Fisher’s LSD procedure on the marginal means, with $\alpha = .05$. Mean adjusted posttest scores for the AS condition were significantly greater than those for the NS and FS conditions, which did not differ significantly from each other. The mean adjusted posttest scores and their standard deviations are presented in Table 3.

**Matching task.** A 3 X 3 ANCOVA on the matching task posttest scores, using the matching task pretest score as a covariate, showed a significant main effect for scaffolding condition ($F[2, 165] = 6.54, \text{MSE} = 308.18, p < .05, \eta^2 = .07$) and a significant main effect for developmental level ($F[2, 165] = 9.56, \text{MSE} = 308.18, p < .05, \eta^2 = .10$). However, there was no significant interaction
of scaffolding condition and developmental level, \(F[4, 165] = 1.21, MSE = 308.18, p > .05, \eta^2 = .03\). Given the absence of an interaction, main effects were further analyzed using Fisher’s LSD procedure on the marginal means, with \(\alpha = .05\). Based on the results for scaffolding condition, mean adjusted posttest scores for the AS condition were significantly greater than those for the NS and FS conditions. Scores for the NS condition were significantly greater than those for the FS condition. For developmental level, mean adjusted posttest scores for the undergraduate and high school students were significantly greater than those for the middle school students. Scores for the undergraduate and high school students were statistically indistinguishable. The mean adjusted posttest scores and their standard deviations are presented in Table 3.

Labeling task. A 3 x 3 ANCOVA on the labeling task posttest scores, using the labeling task pretest score as a covariate, showed a significant main effect for scaffolding condition \(F[2, 165] = 29.59, MSE = 454.56, p < .05, \eta^2 = .26\) and a significant main effect for developmental level \(F[2, 165] = 12.02, MSE = 454.56, p < .05, \eta^2 = .13\). However, there was no significant interaction of scaffolding condition and developmental level, \(F[4, 165] = .22, MSE = 454.56, p > .05, \eta^2 = .01\). Given the absence of an interaction, main effects were further analyzed using Fisher’s LSD procedure on the marginal means, with \(\alpha = .05\). Based on the results for scaffolding condition, mean adjusted posttest scores for the AS condition were significantly greater than those for the NS and FS conditions. Scores for the NS condition were significantly greater than those for the FS condition. For developmental level, mean adjusted posttest scores for the undergraduate students were significantly greater than those for the high school and middle school students. Scores for the high school and middle school students were statistically indistinguishable. The mean adjusted posttest scores and their standard deviations are presented in Table 3.

Flow diagram. A 3 x 3 ANCOVA on the flow diagram posttest scores, using the flow diagram pretest score as a covariate, showed a significant main effect for scaffolding condition \(F[2,
165] = 9.88, \( MSE = 4.46, p < .05, \eta^2 = .11 \), and a significant main effect for developmental level \( (F[2, 165] = 4.23, MSE = 4.46, p < .05, \eta^2 = .05) \). However, there was no significant interaction of scaffolding condition and developmental level, \( (F[4, 165] = .73, MSE = 4.46, p > .05, \eta^2 = .02) \).

Given the absence of an interaction, main effects were further analyzed using Fisher’s LSD procedure on the marginal means, with \( \alpha = .05 \). Based on the results for scaffolding condition, mean adjusted posttest scores for the AS condition were significantly greater than those for the NS and FS conditions. Scores for the NS condition were significantly greater than those for the FS condition. For developmental level, pairwise comparisons indicated that the mean adjusted posttest scores were statistically indistinguishable. The mean adjusted posttest scores and their standard deviations are presented in Table 3.

Discussion

Our results suggest that hypermedia can be used to enhance the ability of students of different ages to learn about complex topics, provided that they are provided with adaptive scaffolding designed to regulate their learning. We have empirically demonstrated the effectiveness of adaptive scaffolding in facilitating middle school, high school, and undergraduate students’ learning as indicated by their posttest scores on four learning measures. Adaptive scaffolding led to significant increases in students’ learning of the circulatory system and was more effective than providing students with no scaffolding, which led to more learning than providing students with fixed scaffolding. As for developmental levels, undergraduate, high school, and middle school students learned about the same amount of knowledge of the circulatory system. The levels of variability in their performance on all four learning measures obscured any development differences in learning. Also, we failed to find an interaction between scaffolding conditions and developmental levels, indicating that regardless of students’ ages, the three scaffolding conditions followed the same patterns of differential effects on all students’ learning about the circulatory system.
With regard to the first research question, the results provided partial support for the hypothesis that students in the AS condition learned more than did the FS and NS students when using a hypermedia environment to learn about the circulatory system. The learning for all AS participants on all of the four learning measures was significantly greater than those in the other two scaffolding conditions. We also provide contradictory evidence that runs counter to our hypothesis that both the FS and NS conditions would lead to significant learning on all four measures, and that they would not differ from each other. In fact, our results indicate that the NS condition led to significant learning compared to the FS condition on three of the four learning measures. We did find consistent results on three of the four learning outcomes that students who received AS learned more than the students in the NS condition, who in turn learned more than the students in the FS condition. This finding is partially consistent with recent studies conducted by Azevedo and colleagues (e.g., Azevedo & Cromley, 2003; Azevedo et al., in press), who found that AS leads to superior learning compared to the other two scaffolding conditions. We hypothesize that students in the adaptive scaffolding condition learned significantly more on these tasks (i.e., matching, labeling, and flow diagram) because the tutor often scaffolded their learning by encouraging them to use effective strategies such as drawing their own picture of heart, labeling the components of the heart, taking notes, and coordinating multiple information sources (although it is possible that this may reflect a practice effect). Our findings add another dimension to the largely qualitative literature on students’ usage of embedded hypermedia scaffolds (e.g., Wolfe et al., 2003). We conclude that providing students with adaptive scaffolding during learning can facilitate their ability to learn with hypermedia by addressing students’ individual learning needs during learning.

The aforementioned outcome is consistent with previous research which shows that adaptive scaffolding that deals with specific learning needs is optimal for facilitating learning. We hypothesize that the key in adaptive scaffolding is the tutor’s ability to regulate each student’s
learning by deploying several key processes and mechanisms such as planning, monitoring, enactment of effective strategies, and handling task difficulties and demands. Such outcomes have been reported for a variety of domains and tasks such as biology, statistics, and science (e.g., Azevedo, Cromley, & Seibert, in press; Kao & Lehman, 1997; Pedersen & Liu, 2002a, 200b). More importantly, this finding contributes to the literature by demonstrating that adaptive scaffolding provided by a tutor during learning with hypermedia and aimed at facilitating the ability of students at different ages to regulate the complex SRL processes and mechanisms, can lead to a significant amount of learning. An implication of these findings is that an empirical approach to understanding how learners regulate their learning when using hypermedia should guide the design of embedded adaptive scaffolds in hypermedia environments (Azevedo, 2002; Hannafin, Hill, & Land, 1999; Reiser, 2002; Saye & Brush, 2002).

With regard to the second research question, the results provide partial support for the hypothesis that the college students would learn significantly more on all four learning measures than the high school students, who would learn significantly more than the middle school students, on each of the four learning measures. Despite the extensive literature on developmental differences in students’ self-regulated learning (Pintrich & Zusho, 2002), we saw different results for each of the learning outcomes. This occurred despite the appearance of developmental differences on the posttest scores (see Table 3), our results indicate that there are no significant differences across developmental levels and that all students learned the same amount of knowledge of the circulatory system. Despite the expected and generally accepted age-graded developmental trajectory that older students are more capable of regulating their learning than are younger students.

We hypothesize that the lack of evidence regarding developmental differences raises several issues related to students’ SRL in general and learning with hypermedia. First, despite the age differences, the students had low prior knowledge of the domain. As novices with limited cognitive
resources, they were not capable of deploying certain self-regulatory mechanisms to facilitate their learning (Pintrich & Zusho, 2002; Winne, 2001, Winne & Hadwin, 1998). Second, our results reflect the distinction made by Pintrich and Zusho (2002) regarding one’s competence to use the strategies versus actual performance or use of the strategies, and indicate that older students may or may not know various cognitive and metacognitive strategies or more importantly may not use them even if they have knowledge of them. In addition, this may also be attributed to the fact that they were asked to learn complex material in a new context—with a hypermedia environment. This finding fits with the task-expertise developmental perspective in that novice learners (regardless of age) may show less benefit from regulating their learning than will more experienced or knowledgeable students (Pintrich & Zusho, 2002).

With respect to the third research question, our study adds to the literature by providing evidence that students at three developmental levels do not differentially benefit from different scaffolding conditions to use hypermedia to learn about a complex and challenging science topic. Our results contribute to the literature by providing empirical evidence that there are no developmental differences for students with the same amount of prior knowledge in benefiting differentially from several types of scaffolding during learning with hypermedia. To date, research on the role of scaffolding and learning with hypermedia has focused exclusively on same-aged students. For example, studies have considered middle school (e.g., Pedersen & Liu, 2002a), high school (e.g., Jacobson & Archidodou, 2000), or undergraduate students (e.g., Azevedo, Cromley, & Seibert, in press). While this literature has provided mixed results in terms of how students at different ages benefit from different types of scaffolds when learning with hypermedia, our study is the first to systematically manipulate different scaffolding conditions across three developmental levels. More empirical research is needed to investigate how different scaffolding conditions affect
different aged-students with different levels of prior knowledge learning and levels of expertise while learning about complex and challenging topics with hypermedia.

Limitations

Even though the experimenter was present in every condition, the results for the adaptive condition might be due to the presence of the human tutor. In addition, a practice effect might have contributed to the significant learning of adaptive scaffolding students. More research is also needed to determine how different scaffolding methods can enhance students’ ability to regulate their learning. More specifically, the effects of different scaffolding methods should be designed to examine their ability to impede or facilitate certain aspects of self-regulated learning. Further, the role of tutors as external regulating agents who are able to provide different types of adaptive scaffolding needs to be investigated to examine how the mediating learning processes between tutor and learner influence students learning with hypermedia.

Implications of Adaptive Scaffolding for Fostering Students’ Learning with Hypermedia

Our results have implications for the design of hypermedia environments designed to foster students' learning of complex topics. To this end, we could incorporate certain tutor scaffolding moves to emulate the role of the tutor in this study. Our results present a major challenge to existing technologies since it would be extremely difficult to facilitate students’ learning of complex topics if the computer was to provide adaptive scaffolding by dynamically modifying its scaffolding methods and supporting the students’ self-regulated learning (Hadwin & Winne, 2001).

The hypermedia system could be designed to assess each student’s learning by having the student take the pretest and use their scores to calibrate the students’ initial understanding of the complex topic. Similar to the human tutor, the system would have to continuously assess the students’ evolving mental model of their learning through embedded testing. After each major section of the content, the system could test the students’ knowledge and modify its content based
on his/her current understanding. These adjustments would need to be made based on the student’s progress vis-à-vis the overall learning goal which could be embedded as a fixed scaffold within a hypermedia environment.

Similar to Hadwin and Winne’s (2001) CoNoteS2 environment, the system would progress from a research tool designed to test different scaffolding conditions and collect traces of students’ self-regulatory behaviors to one that is fully adaptive and therefore able to provide students with adaptive scaffolding that meets their learning needs during learning. For example, the system could be designed to deploy several key SRL mechanisms such as assisting students’ planning activities by providing a list of sub-goals similar to those presented to students in the FS condition. However, the only difference would be in the dynamic interplay between the system’s ability to assess student emerging understanding of the topic, their progress towards the overall learning goals, and their ability to deploy key SRL mechanisms. System complexity would evolve as it provided adaptive scaffolding in terms of allowing a student to regulate their own learning and “knowing” when to provide different levels of scaffolding aimed at supporting different SRL processes necessary to foster students’ learning of the topic. For example, both the learner and hypermedia system would need to plan their learning, monitoring the students’ cognitive system and other aspects of the learning environment (e.g., appropriate content of the topic relate to the students’ current learning goal), using effective strategies (e.g., summarization, hypothesizing), handling task difficulties and demands, and generating interest in the topic (see Azevedo, Cromley, & Seibert, in press). In sum, our empirical results challenge current views on the design of hypermedia environments designed to foster complex learning by providing students with adaptive scaffolding. This study further points to a new way of using empirical evidence to design and use hypermedia learning environments to improve education which focuses on the use of computers as MetaCognitive tools designed to detect, trace, monitor, and foster the learners’ self-regulated learning (Azevedo, 2002).
References


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Table 1

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

1. Name the components of blood.

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

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

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

5. List the support structures of the heart.

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

7. Describe the flow of electricity through the heart.

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

9. Describe the movement of blood through the circulatory system, naming all the organs involved.

   You may use paper and pencil to assist if necessary.

10. Identify at least 3 major functions of the circulatory system.
Table 2

*Necessary Features for Each Type of Mental Model (from Azevedo, Cromley, & Seibert, in press)*

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
   - describes “purpose” – oxygen/nutrient transport
   - mentions one of the following: electrical system, transport functions of blood, details of blood cells

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

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

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

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

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

12. **Double Loop - Advanced**
    - blood circulates
    - heart as pump
    - vessels (arteries/veins) transport
    - describe “purpose” - oxygen/nutrient transport
    - describes loop: heart - body - heart - lungs - heart
    - structural details described: names vessels, describes flow through valves
    - mentions one of the following: electrical system, transport functions of blood, details of blood cell
### Table 3

*Means (and Standard Errors) for Adjusted Posttest Scores Across Scaffolding Conditions and Developmental Levels*

<table>
<thead>
<tr>
<th>Measures</th>
<th>Scaffolding Conditions</th>
<th>Developmental Levels</th>
<th>Scaffolding Conditions</th>
<th>Developmental Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Scaffolding</td>
<td>Fixed Scaffolding</td>
<td>Adaptive Scaffolding</td>
<td>Middle School</td>
</tr>
<tr>
<td></td>
<td>( n = 61 )</td>
<td>( n = 59 )</td>
<td>( n = 59 )</td>
<td>( n = 58 )</td>
</tr>
<tr>
<td>Essay (Mental Model)</td>
<td>7.04 (.32)</td>
<td>6.23 (.33)</td>
<td>8.73 (.32)</td>
<td>6.02 (.33)</td>
</tr>
<tr>
<td>Matching</td>
<td>68.04 (2.34)</td>
<td>60.86 (2.38)</td>
<td>77.13 (2.39)</td>
<td>60.17 (2.33)</td>
</tr>
<tr>
<td>Labeling</td>
<td>38.64 (2.88)</td>
<td>20.76 (3.22)</td>
<td>53.96 (2.94)</td>
<td>27.67 (2.96)</td>
</tr>
<tr>
<td>Flow</td>
<td>3.67 (.28)</td>
<td>2.55 (.28)</td>
<td>4.76 (.29)</td>
<td>3.38 (.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High School ( n = 53 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70.96 (2.59)</td>
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<td></td>
<td></td>
<td>74.90 (2.18)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Undergraduate ( n = 68 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48.98 (2.61)</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>4.13 (.26)</td>
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