External Regulating Agents' Adaptive Content and Process Scaffolding: The Key to Fostering Mental Model Development during Hypermedia Learning

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Abstract

We examined the effectiveness of different scaffolding interventions in facilitating adolescents' shift to more sophisticated mental models as indicated by both performance and process data. Ninety-three (*N* = 93) adolescents were randomly assigned to one of three scaffolding conditions (adaptive content and process scaffolding [ACPS], adaptive process scaffolding [APS], and no scaffolding [NS]) and were trained to use a hypermedia environment to learn about the circulatory system. Pretest, posttest, and verbal protocol data were collected. The performance data revealed that the students in the ACPS condition gained significantly more conceptual knowledge, as examined using a structural equation model, than did those in the other two comparison conditions. The verbal protocol data revealed that students in the ACPS condition used a significantly higher proportion of planning processes than students in the NS condition, and a significantly higher proportion of monitoring processes than students in the APS and NS condition. By contrast, students in the NS condition used a significantly higher proportion of handling task difficulty processes than students in the ACPS and APS condition.

Keywords: self-regulated learning; mental models; science; metacognition; learning strategies; hypermedia

Objectives of the Study

Computer-based learning environments (CBLEs) are effective to the extent that they can adapt to the needs of individual learners by systematically and dynamically providing scaffolding of key learning processes (Anderson et al., 1995; Lajoie & Azevedo, 2006). These environments' ability to provide adaptive, individualized instruction is derived from an understanding of how learner characteristics, system features, and the mediating learning processes interact during learning in particular contexts. A critical aspect of providing individualized instruction is scaffolding, or instructional support in the form of guides, strategies, and tools which are used during learning to support a level of understanding that would be impossible to attain if students learned on their own (Chi et al., 1996; 2001; Collins et al., 1989; Graesser, McNamara, & VanLehn, 2005). Despite our ability to provide adaptive scaffolding to students who are learning about well-structured tasks with traditional CBLEs such as intelligent tutoring systems (ITS; e.g., Anderson et al., 2005), providing adaptive scaffolding for students learning about conceptually-challenging domains remains a challenge for non-linear hypermedia instruction (e.g., Azevedo, 2005; Hmelo-Silver & Azevedo, 2006). We argue that harnessing the full power of hypermedia learning environments will require empirical research aimed at understanding what kinds of scaffolds are effective in facilitating individualized instruction and when these scaffolds are best deployed (see Azevedo, 2005).

In this study, we examined the effectiveness of different human scaffolding conditions in both facilitating adolescents' learning about the circulatory system with a hypermedia environment, and facilitating adolescents' ability to regulate their learning with hypermedia. We also investigated *why* and *how* different types of scaffolding were differentially effective. We created three scaffolding conditions based on Winne and colleagues' (Winne, 2001) information-processing model of self-regulated learning (SRL), research on scaffolding (e.g., Azevedo & Hadwin, 2005; Chi et al.;, 1996, 2001; Graesser et al., 1995, 2005; Pea, 2004; Wood et al., 1976) and research on learning with hypermedia (Azevedo et al., 2005, in press). The empirical results from our human tutoring studies can be used to inform the design of adaptive hypermedia learning environments.

In this paper we focused on three research questions—1) *Does a confirmatory factor analysis of our four measures of circulatory system knowledge meet common fit criteria?* 2) *What is the influence of the pretest, developmental level, and condition on participant posttest scores, as examined using structural equation modeling*? 3) *How are different scaffolding conditions and developmental levels related to students' use of self-regulatory processes during learning with hypermedia?*

Method

Participants. Ninety-three (N=93) adolescent students (mean age = 13.7 years, 55% girls) from both a middle and high-school located in the mid-Atlantic received community service credit for their participation in this study. The students had limited exposure to the circulatory system in their science classes.

Human Tutors. All three tutors had completed a bachelor's degree; when we collected data, two of the tutors were enrolled in a doctoral program, and one was enrolled in a Master's program, all in Human Development. Their mean age was 33 (range = 29–39); there were 1 male and 2 female tutors. All tutors had completed a 6-hour tutor training, including viewing videotapes, analyzing coded transcriptions of tutoring sessions, and reading our previously published studies. Two hours of that training were specific to the condition (ACPS or APS) assigned to the tutor. Each tutor had also been responsible for collecting data from 50-150 participants in our previous studies (e.g., Azevedo et al., 2005). Therefore, they were familiar with the experimental protocol, including all sections of the hypermedia environment, collecting think-aloud protocols, administering the pre- and posttest measures, and all other experimental materials and procedures.

Tutoring Scripts. We developed standardized scripts for both tutoring conditions. For the APS condition, the script was designed to be relatively domain-independent, whereas the script for the ACPS condition necessarily included content relevant to the human circulatory system.

The script for the **APS condition** was as follows:

1. Student selects a paragraph to read, and reads it out loud.
2. If the student stops reading after Step 1 and enacts an effective SRL strategy, take no action. If the student does not enact any SRL strategy, prompt the student with, "*Can you think of anything that you could do to help you learn this?*"

2a. If the student then enacts an effective SRL strategy, take no action. If the student does not enact any SRL strategy, prompt the student with, either "Do you think that strategy will help you learn?" ([TIMUS] if the student had previously used a strategy) or "Do you think [name of strategy; e.g., summarizing] would help you learn this?"

3. If the student does not stop reading after Step 1, interrupt and prompt the student with, "You have read a lot, can you think of anything that you could do to help you learn this?"

3a. If the student then enacts an effective SRL strategy, take no action. If the student does not enact any SRL strategy, prompt the student with, either "Do you think that strategy will help you learn?" (scaffolding monitoring of strategy if the student had previously used a strategy) or "Do you think [name of strategy; e.g., coordinating informational sources] would help you learn this?".

4. At time prompts, prompt student to Monitor Progress towards Goal (e.g., "You have 20 minutes left, do you feel like you've met your learning goal?")
5. Then prompt student to activate prior knowledge (e.g., "Can you tell me back in your own words what you just learned").
6. Repeat from Step 1.

The script for the **ACPS condition** was as follows:

1. Student selects a paragraph to read, but before student reads

1a. Prompt student to activate prior knowledge (e.g., "Tell me what you already know about [topic of paragraph]"). Regardless of students' responses, prompt with "Let's read on and see what the paragraph says."

2. If the student stops reading after Step 1a and enacts an effective SRL strategy, take no action. If the student does not enact any SRL strategy, prompt the student to use a specific effective strategy, for example, "I want you to summarize what you just read"
3. If the strategy in Step 2 was enacted correctly, give positive feedback. If the strategy was enacted incorrectly,

4a. Give negative feedback (optional), or

4b. Prompt the student to use a fix-up strategy, such as re-reading or

4c. Tutor gives a correct explanation, and tells student to correct his/her summary, drawing, etc.

5. Ask student to continue reading, following Steps 1-4.
6. At time prompts, prompt student to Monitor Progress towards Goal (e.g., "You have 20 minutes left, do you feel like you understand [topic]?")
7. Prompt student to select next passage to be read, ensuring that at least 5 minutes are spent in each of the three main articles. Give feedback about the relevance of the passage the student selected.

7a. If the passage is relevant, tell student so (TIIAI)

7b. If the passage is irrelevant, tell student so (TICE), and suggest a more relevant passage (TIIAI)

8. Repeat from Step 1.

Paper and Pencil Measures. Paper-and-pencil materials consisted of a consent form, a participant questionnaire, a pretest, and a posttest. All of the paper-and-pencil materials have been used by Azevedo and colleagues (see Azevedo et al., 2005). The measures consisted of a consent form, a participant questionnaire, a pretest, and a posttest. 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 task), (2) a color picture of the heart on which students were asked to label 14 components (labeling task), (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"* (mental model essay), and (4) a flow diagram in which the students were asked to identify the correct order of blood flow (flow task). The posttest was identical to the pretest. These measures were posited to be valid indicators of the latent factor circulatory system conceptual knowledge, both at pretest and at posttest. Our first research question, below, tested a measurement model to assess whether this model fit our data.

Hypermedia Learning Environment. Participants learned about the circulatory system by using a commercially-based hypermedia environment which included several important sections including the circulatory system, blood, and heart, and contained multiple informational sources—text, static diagrams, photographs, and a digitized animation depicting the functioning of the circulatory system. Together these three articles comprised 16,900 words, 18 sections, 107 hyperlinks, and 35 illustrations.

Experimental Procedure. The authors tested the participants individually in all conditions. Participants were randomly assigned to one of three scaffolding conditions: ACPS (n = 31), APS (n = 31), and NS (n = 31). 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, participants were trained on how to use the hypermedia environment to learn about the circulatory system. Fourth, the experimenter provided instructions for the learning task. The following instructions were read and presented to the participants in writing.

No Scaffolding (NS) Condition. In this 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."*

In the *Adaptive Content and Process Scaffolding (ACPS)* condition, the students were provided with an overall learning goal (the same as for NS, above: "*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.")* and had access to a tutor who provided two types of adaptive scaffolding during learning: 1) *content scaffolding*—i.e., scaffolding students' learning by assessing their emerging understanding of the circulatory system to ensure that they met their overall learning goal, 2) and *process scaffolding*—i.e., scaffolding students' learning by assisting them in enacting various self-regulatory process, such as helping them plan their learning by activating their prior knowledge, monitoring their emerging understanding, using different strategies to learn about the circulatory system, handling task difficulties and demands, and assessing their emerging understanding. Similar to published human tutoring studies that considered naturalistic tutoring (e.g., Chi et al., 1996, 2001; Graesser et al., 2001), both this type of adaptive scaffolding and the one described next were used dynamically and adaptively by the tutor during learning to ensure that the learner reached the overall learning goal.

In the *Adaptive Process Scaffolding (APS) condition*, the students were given the same overall learning goal and also had access to a tutor. This condition was identical to the ACPS condition, except that the tutor provided only *process scaffolding* (see ACPS above). The students were never provided content scaffolding in this condition.

Following the instructions, a practice task was administered to familiarize all participants with the think-aloud procedure while they used the hypermedia environment to learn about the circulatory system. In all three conditions, an experimenter sat next to the participant and reminded the participant to keep verbalizing when they were silent for more then three seconds (e.g., "*say what you are thinking*"). All participants were reminded of the global learning goal ("*Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body"*) as part of their instructions for learning about the circulatory system. Participants had access to the instructions (which included the learning goal) during the entire learning session. Participants in the ACPS and APS conditions had access to the tutor. All participants were given 40 minutes to use the hypermedia environment to learn about the circulatory system. 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 without their notes or any other instructional materials by writing their answers on the sheets provided by one of the experimenters.

Coding and Scoring of Product and Process Data . The coding of the participants' answers to the matching, labeling, and blood flow tasks, mental model essays, the segmentation of the participants' verbalizations while they engaged in the learning tasks, along with the coding scheme we used to analyze the participants' regulatory behavior are described in detail in Azevedo and colleagues (2005, p. 393-397). A trained graduate student used the coding scheme and coded all of the transcriptions by assigning each coded segment with one of the 33 SRL variables. Inter-rater agreement established for the mental models was .96 (agreement on 179/186 mental model essays), and participants' and tutors' coded verbalizations was .98 (agreement on 1,956 out of 1,984 segments). Inconsistencies were resolved through discussion among the co-authors.

Results

1) Does a confirmatory factor analysis of our four measures of circulatory system knowledge meet common fit criteria?

Before moving to our structural model and a test of the first of our two main research questions, it was necessary to assess the measurement model using confirmatory factory analyses (CFA; Kline, 2004). In this case, the CFA involved both continuous (matching, labeling, flow) and categorical (mental model) indicators both at pretest and posttest. This type of CFA was performed using Mplus version 4.1 (Muthén & Muthén, 2006a) with the default estimator for models with continuous and categorical indicators: the robust weighted least squares estimator (WLSMV; Muthén & Muthén, 2006b). This estimation procedure uses simple linear regressions to model the continuous factor indicators and probit regressions for the categorical indicator (Muthén & Muthén, 2006b). The initial measurement model consisted of the four pretest measures as indicators of the latent pretest conceptual knowledge factor, and the four posttest measures as indicators of the latent posttest conceptual knowledge factor. The Lagrange Multiplier Test showed that the measurement model fit could be significantly improved through covarying the errors of the mental model pretest and posttest indicators. We added this covariance to the model given that we could theoretically support it. Both mental model essay measures utilized writing skills, as opposed to the other indicators which involved only matching or writing single words (labeling). With this added covariance, the chi-square test of model fit was non-significant, indicating good fit [χ^2 (8, N = 93) = 9.289, p = .318]. In addition, the Comparative Fit Index (CFI) value was .983, and the Root Mean Square Error of Approximation (RMSEA) value was .042, both indicative of good fit (Kline, 2005). With this evidence, we retained our measurement model as a reasonable fit to the data. Satisfied with the measurement model, we then imposed a structural model with covariates upon the data, also called a MIMIC (Multiple-Indicator, Multiple-Cause) model, to address our second research question.

2) What is the influence of the pretest, developmental level, and condition on participant posttest scores, as examined using structural equation modeling?

The structural model with covariates is shown in Figure 1.

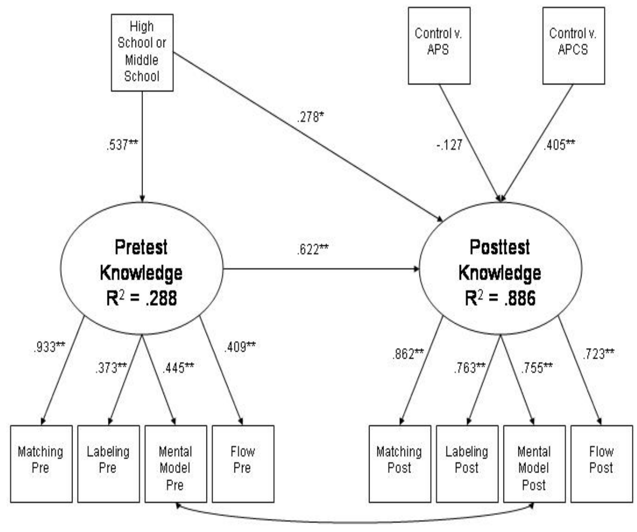

Figure 1: Structural Model with Covariates (MIMIC model)

The covariance between the latent variables for pretest and posttest was changed to a causal relation and dummy-coded covariates were inserted to test the influence of developmental level upon the pretest and the posttest as well as condition upon the posttest. There were no statistically significant interactions between covariates, thus these predictors were not included in the final structural model. The fit of this structural model could not be compared to the measurement model using a chi-square difference statistic due to the necessity of using the WLSMV estimator (Muthén & Muthén, 2006b). However, this model also had a non-significant chi-square value [$\chi 2$ (18, N = 93) = 23.586, p = .169] as well as a CFI of .954 and a RMSEA of .058, all indicators of good fit (Kline, 2005). As such, we retained the structural model as a reasonable fit to the data. Standardized path coefficients can be found in Figure 1, showing statistically significant factor loadings for each indicator for each latent variable. The pretest latent factor had a statistically significant relation with the posttest latent factor, meaning that all other causal arrows predicting posttest are considered to be effects above and beyond both each other and pretest. In essence, this model can be thought of as akin to a 2 by 3 (developmental level and condition) analysis of covariance with a latent covariate (pretest) and dependent variable. Developmental level had a statistically significant relation with both the pretest and the posttest, indicating that high-schoolers had a higher average score than middle-schoolers on both latent factors. Developmental level explained 29 percent of the variance in the latent pretest factor. The non-significant causal arrow from "control v. APS" to posttest indicates that these two conditions did not differ in their mean scores on the latent posttest after adjusting for latent pretest and developmental level. However, the arrow for "control v. ACPS" is statistically significant and shows that the ACPS condition had a higher adjusted mean than the control condition. Analyses comparing the ACPS and APS conditions showed a statistically significant difference as well, with the ACPS adjusted mean higher than that of the APS condition. Effect sizes for these statistically significant causal relations are shown in Table 1. Pretest, developmental level, and condition combined to explain 89% of the variance in the latent posttest conceptual knowledge variable. The variance extracted for the pretest factor was .34 and for the posttest factor was .60. Given that we were using latent factors rather than summed scores, we assessed reliability with Coefficient *H*, a maximal reliability measure. Coefficient *H* indicates the degree to which the factor is described by the information found within its measured indicators (see Hancock & Mueller, 2001), and was .88 for the pretest factor and .87 for the posttest factor.

Table 1: Effect Sizes for Statistically Significant Paths in the Structural Model

Independent Variable	*Dependent Variable*	*Effect Size*
Developmental Level	Pretest	.381
Developmental Level	Posttest	.147
Pretest	Posttest	.162
Control v. ACPS	Posttest	.222
APS v. ACPS[a]	Posttest	.315

[a] Path not shown due to dummy-coding

3) How are different scaffolding conditions and developmental levels related to students' use of self-regulatory processes during learning with hypermedia?

A series of 3 x 2 ANOVAs were run to determine whether there were significant differences in the proportion of SRL processes students used during learning with hypermedia, by condition and developmental level. We examined how students regulated their learning of the circulatory system by calculating the proportion of variables related to the five main self-regulated learning categories of *planning, monitoring, strategy use, handling task difficult and demands*, and *interest*. As such, we conducted five 3 x 2 ANOVAs for each of the five SRL categories, with condition (ACPS, APS, and NS) and developmental level (High school and Middle School) as between-subjects factors and SRL category proportion as the within subjects factor.

Planning. A 3 X 2 ANOVA showed a significant main effect of condition (F [2, 87] = 13.70, $p < .01$, $\eta^2 = .24$), a significant main effect of development level (F [1, 87] = 5.07, $p < .05$, $\eta^2 = .06$), and a non-significant interaction between condition and development level ($p > .05$). A post-hoc LSD test on condition indicates the participants in the ACPS condition used, on average, a significantly higher proportion of planning processes ($M = .15$) than participants in the NS condition ($M = .08$; $p < .01$). Additionally, participants in the APS also used, on average, a statistically significantly higher proportion of planning processes ($M = .17$) than students in the NS condition ($M = .08$; $p < .01$), but participants in the ACPS and APS condition did not significantly differ ($p > .05$). Lastly, a follow-up independent t-test indicates that middle school students used, on average, a significantly higher proportion of planning processes ($M = .15$) than high school students ($M = .12$), $t(91) = 2.023$, $p < .05$.

Monitoring. A 3 X 2 ANOVA showed a significant main effect of condition (F [2, 87] = 18.28, $p < .01$, $\eta^2 = .30$), a non-significant main effect of development level ($p > .05$), and a non-significant interaction between condition and development level ($p > .05$). A post-hoc LSD test on condition indicates the participants in the ACPS condition used, on average, a higher proportion of monitoring processes ($M = .37$) than participants in the APS condition ($M = .25$; $p < .01$) and participants in the NS condition ($M = .22$; $p < .01$). Participants in the APS and NS condition did not significantly differ ($p > .05$).

Strategies. A 3 X 2 ANOVA showed a non-significant main effect of condition ($p > .05$), a non-significant main effect of development level ($p > .05$), and a non-significant interaction between condition and development level ($p > .05$).

Task difficulty and demands. A 3 X 2 ANOVA showed a significant main effect of condition (F [2, 87] = 15.30, $p < .01$, $\eta^2 = .26$), a non-significant main effect of development level ($p > .05$), and a non-significant interaction between condition and development level ($p > .05$). A post-hoc LSD test on condition indicates the participants in the NS condition used, on average, a significantly higher proportion of task difficulty and demands processes ($M = .28$) than participants in the ACPS condition ($M = .12$; $p < .01$) and participants in the APS condition ($M = .17$; $p < .01$). Participants in the APS and ACPS condition did not significantly differ ($p > .05$).

Scientific Importance of this Study

Our results show that young students' learning of a challenging science topic with hypermedia can be facilitated if they are provided with adaptive content and process scaffolding designed to regulate their learning. We have demonstrated the effectiveness of adaptive content and process scaffolding (ACPS) in facilitating students' conceptual learning of the circulatory system. In contrast, providing students with either adaptive process scaffolding without content, or no scaffolding, was associated with less substantial conceptual knowledge gains. Verbal protocols provided evidence that students in the ACPS condition used significantly higher proportion of planning and monitoring processes when using a hypermedia environment to learning about the circulatory system. We conclude that the tutors' role in providing both content and process scaffolding is a key to facilitating students' self-regulated learning with hypermedia.

Our study contributes to an emerging field that merges cognitive and learning sciences, and educational technology and science learning research by addressing issues related to learning about challenging science topics (Hmelo-Silver & Azevedo, 2006) and recent criticisms that research on learning with hypermedia is atheoretical and lacks empirical evidence (Azevedo, 2005). Our study also contributes to an emerging body of evidence which illustrates the critical role of SRL in students' learning with hypermedia (e.g., Azevedo et al., 2005), and extends recent research regarding the role of adaptive scaffolding in facilitating students' learning with hypermedia. Furthermore, our data contributes to Azevedo and colleagues emerging model of SRL in learning with hypermedia and contributes to the SRL literature (e.g., Winne, 2001) by using verbal protocols to analyze how learners in different adaptive scaffolding conditions deployed SRL skills during learning with hypermedia. These two sources of data allow us to examine the critical role of tutors as external regulatory agents whose scaffolding methods facilitate students' self-regulated learning (e.g., Chi et al., 2001; Graesser et al, 2001). Lastly, our process data can be applied to inform the design of hypermedia environments as Metacognitive tools (Azevedo, 2005) to foster learners' self-regulated learning of challenging science topics by providing adaptive scaffolding (e.g., Graesser et al., 2005; White & Frederiksen, 2005).

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