The Role of Prompting and Feedback in Facilitating Students’ Learning about Science with MetaTutor

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Abstract
An experiment was conducted to test the efficacy of a new intelligent hypermedia system, MetaTutor, which is intended to prompt and scaffold the use of self-regulated learning (SRL) processes during learning about a human body system. Sixty-eight (N=68) undergraduate students learned about the human circulatory system under one of three conditions: prompt and feedback (PF), prompt-only (PO), and control (C) condition. The PF condition received timely prompts from animated pedagogical agents to engage in planning processes, monitoring processes, and learning strategies and also received immediate directive feedback from the agents concerning the deployment of the processes. The PO condition received the same timely prompts, but did not receive any feedback following the deployment of the processes. Finally, the control condition learned without any assistance from the agents during the learning session. All participants had two hours to learn using a 41-page hypermedia environment which included texts describing and static diagrams depicting various topics concerning the human circulatory system. Results indicate that the PF condition had significantly higher learning efficiency scores, when compared to the control condition. There were no significant differences between the PF and PO conditions. These results are discussed in the context of development of a fully-adaptive hypermedia learning system intended to scaffold self-regulated learning.

Objectives and Theoretical Framework
When learning about complex science topics such as the human circulatory system, research indicates that individuals can gain deep conceptual understanding through effective use of self-regulated learning (SRL). The successful use of cognitive and metacognitive SR processes involves setting meaningful goals for one’s learning, planning a course of action for attaining these goals, deploying a diverse set of effective learning strategies in pursuit of the goals, continuously monitoring one’s own understanding of the material and the appropriateness of the current information, and making adaptations to one’s goals, strategies, and navigational patterns, based on the results of such monitoring processes and their resulting judgments (Azevedo, 2005; Azevedo & Witherspoon, 2009; Opfermann, Azevedo, & Leutner, in press; Pintrich, 2000; Winne, 2001; Winne & Hadwin, 2008; Zimmerman, 2001; Zimmerman & Schunk, in press). Although learners should attempt to follow these guidelines when attempting difficult topics, exploration of typical learning has demonstrated that few learners, in fact, engage in effective self-regulated learning. We assume that, while motivation and affect play a role in determining learners’ willingness to self-regulate, a lack of self-regulatory skills is the main obstacle to adequate regulation and therefore deficient learning gains and conceptual understanding (Azevedo & Jacobson, 2008; Shapiro, 2008; Schwartz et al., 2009; White, Frederiksen, & Collins, 2009). Therefore, our current research is directed toward scaffolding learners’ use of self-regulation using artificial pedagogical agents (PAs) during learning with MetaTutor, a multi-agent adaptive hypermedia learning environments that models, scaffolds, and fosters learners’ use of cognitive and metacognitive SRL processes during learning about human biology.

Learners attempting to self-regulate often face limitations in their own metacognitive skills, which, when compounded with lack of domain knowledge, can result in cognitive overload in open-ended learning environments like hypermedia (Azevedo, Johnson, Chauncey, & Graesser, in press; Leelawong & Biswas, 2008; McQuiggan, Robinson, & Lester, 2010). One method of relieving the cognitive burden placed on learners in this situation is to provide assistance in the form of adaptive scaffolding. Previous experiments conducted by Azevedo and colleagues (e.g., Azevedo, Cromley, Winters, Moos, & Greene, 2005; Azevedo, Moos, Greene, Winters, & Cromley, 2008) established that adaptive scaffolding
provided by a human tutor leads to greater deployment of sophisticated planning processes, metacognitive monitoring processes, and learning strategies as well as larger shifts in mental models of the domain. The purpose of the current work is to determine if adaptive scaffolding, provided by pedagogical agents (PAs) within an adaptive, intelligent hypermedia learning environment, would also be capable of producing the same or better learning outcomes and increased use of effective self-regulated learning processes.

This experiment used a mixed-methodology design that combined product and process data to examine the effect of various types of SRL prompting and scaffolding delivered by pedagogical agents (PAs) in an adaptive intelligent hypermedia learning environment. Three learning conditions were used to determine the efficacy of scaffolding SRL through pedagogical agents: 1) prompting with feedback condition (PF), 2) prompting only condition (PO), and 3) no prompting condition (NP). Participants were randomly assigned to one of the three conditions and asked to learn about the human circulatory system using a hypermedia learning environment, MetaTutor, during a two-day experiment. This experiment included the collection of concurrent think-aloud protocols, eye-tracking data, human-agent dialogue, learning outcome measures, log-file data, metacognitive judgments during learning, embedded quizzes, and facial recognition data for affect classification. Due to the complexity of the data analyses, we only report on a few of the log-file variables and the learning outcomes data (presented here as learning efficiency).

Method and Data Sources
Participants
Participants were 69 undergraduate students (70% females) from a large public university in Southeastern United States. The mean age of the participants was 23 and their mean GPA was 2.84. All participants were paid $10 per hour, up to $40 for completion of the 2-day, 4-hour experiment.

Materials and MetaTutor
The materials used in the experiment consisted of several computerized elements. The pretest and posttest each comprised 25 multiple-choice items with four foils for each question. Items on the pretest and posttest included text-based items (which could be answered by directly referring one sentence within the content) and inferential items (which required integrating information from at least two sentences within the content). Two equivalent forms of the test were created using a total of 50 items and the forms used for pretest and posttest were counterbalanced across participants. The learning environment used by all participants, MetaTutor, is an adaptive hypermedia learning environment including 41 pages of text and static diagrams, organized by a table of contents displayed in the left pane of the environment (See Figure 1). The version of MetaTutor used in this experiment comprises material on the human circulatory system. Along with the table of contents, the environment includes a timer indicating time remaining, an SRL palette which learners may use to instantiate an interaction with the pedagogical agent, and an overall learning goal (which is the same for all participants) and sub-goals (which are created by all participants at the beginning of the learning session). Additionally, four distinct pedagogical agents (Gavin, Pam, Mary, and Sam) are displayed in the upper right-hand corner of the environment, which provide varying degrees of prompting and feedback throughout the learning session designed to scaffold students’ SRL skills and content understanding (see Azevedo, Johnson, Chauncey, & Burkett, 2010 for details).

Learning Conditions
We designed and tested three versions of the MetaTutor environment that covered the human circulatory system. In the Prompt and Feedback (PF) version, participants were prompted (by PAs) to use specific self-regulatory processes, and given immediate feedback about their use of those processes. In the Prompt only (PO) version, participants received the same prompts as the ones provided to those in the PF version. However, the agents in the PO version did not provide feedback. The timing of the prompts used in both the PF version and the PO version was adaptive to the individual learner and was determined using various factors of learner interaction, including time on page, time on current sub-goal, number of pages visited, relevancy of the current page for the current sub-goal, etc. In the No Prompt (NP) version of MetaTutor, participants did not receive prompts or feedback. All three versions (PF, PO, NP) provided an SRL palette which allowed participants to self-select any SRL processes they would like to use during the learning session.

Experimental Procedure
On day one of the experiment, participants completed a demographics questionnaire and the pretest on the human circulatory system. Learners were given up to 20 minutes to complete the pretest.

On day two, the learners engaged in the learning session and completed the posttest on the human circulatory system. Before beginning the learning session, the Tobii T60 (Tobii T60, 2009) eye-tracker was calibrated to each participant individually. All participants were then instructed in the think-aloud procedure and shown a short video demonstrating thinking aloud. Next, each participant was shown another short video explaining and demonstrating the various functionalities of MetaTutor and providing the learners with their overall learning goal (See Figure 1 for learning goal). This introductory video also
Results

In this section we present some of the log-file data and the learning outcomes data. The results are presented in Table 1.

Learning Time with the Science Content

Learning time was calculated by summing the amount of time spent viewing the instructional content. Interactions with the agents, in which the instructional content was not visible, were not included in learning time. An ANOVA indicated a significant difference among the groups in learning time, $F(2,66) = 40.71, p < .001$. LSD post-hoc analyses indicated that the Control group had a longer total learning time ($M = 87.94, SD = 12.42$) when compared to both the PO condition ($M = 68.31, SD = 11.18$) and the PF condition ($M = 56.84, SD = 11.82$), $p < .001$. Additionally, the PO condition had a significantly longer learning time compared to the PF condition, $p < .01$.

Number of Pages Visited. An ANOVA indicated a significant difference among the groups in the mean number of pages visited (out of 41 possible) during the learning session, $F(2,66) = 22.17, p < .001$. LSD post-hoc analyses revealed that the Control group visited significantly more pages ($M = 38.87, SD = 3.84$) than both the PO condition ($M = 33.26, SD = 8.39; p < .05$) and the PF condition ($M = 23.56, SD = 10.07; p < .001$). Additionally, the PO condition visited significantly more pages than the PF condition, $p < .001$. Subsequent revisits to the same page were not counted in total.

Amount of Time on Pages and Diagrams

The results indicate that students did not differ significantly in the amount of time spent on each page (See Table 1). On average, students spent anywhere from 60 seconds to 90 seconds on each page ($p > .05$). By contrast, an ANOVA revealed a significant difference among groups in the mean time spent viewing individual diagrams within the environment, $F(2,66) = 3.02, p = .052$. LSD Post-hoc analyses revealed that mean diagram view time was greater for the PF condition ($M = 1.05$ min, $SD = 0.99$) compared to the Control condition ($M = 0.54$ min, $SD = 0.46$), $p = .016$. The PO condition did not differ significantly from the remaining two conditions ($M = 0.75$ min, $SD = 0.51$).

Number of Sub-Goals Generated during Learning

An ANOVA indicated a significant difference among the groups in the number of sub-goals generated during the learning session, $F(2,66) = 8.74, p < .001$. LSD post-hoc analyses revealed that the PO condition ($M = 4.13, SD = 1.29$) and the Control condition ($M = 4.70, SD = 1.72$) both attempted significantly more sub-goals than the PF condition ($M = 3.04, SD = 0.98$), $p < .01$. There was not a significant difference between the PO condition and the Control condition.

An ANOVA indicated a significant difference among the groups in the mean time spent on each individual sub-goal during the learning session, $F(2,66) = 10.31, p < .001$. LSD post-hoc analyses revealed that the PF condition ($M = 41.39, SD = 18.62$) spent significantly longer on each sub-goal compared to both the PO condition ($M = 27.77, SD = 9.96$) and the Control condition ($M = 23.30, SD = 12.18$), $p < .01$.

Learning Efficiency

Each participant received one point for each correct answer selected on the pretest and posttest. From this value, a learning efficiency score was calculated by dividing the raw posttest score by the number of minutes the participant was actually learning (time on task). Time on task was defined as the sum of all of the time spent viewing domain-related content (text and/or diagram). During certain periods of the learning session, the learning content was hidden from view due to interactions with the agent. To account for differential learning time, the time each participant spent viewing the learning content was factored in to the learning efficiency score (Faw & Waller, 1976; Simons, 1983).
An analysis of variance (ANOVA) on the learning efficiency scores indicated a significant effect of learning condition on learners learning efficiency ($F [2,66] = 6.64, p < .01$). Post-hoc comparisons revealed that the Prompt and Feedback (PF) condition significantly outperformed the No Prompt (NP) condition ($d = 0.84$). Marginal differences were demonstrated for each of the remaining two comparisons ($p > .05$). See Table 1 for descriptive statistics.

### Scientific Significance and Contributions of the Study

Our results show that college students’ learning about a challenging science topic with hypermedia can be facilitated if they are provided with adaptive prompting and feedback scaffolding designed to regulate their learning. More importantly, we have demonstrated that PAs are effective in facilitating students’ SRL processes by providing timely prompting and feedback. Their effectiveness stems from the system’s ability to determine optimal times during a learning session (e.g., prompting learners to activate their prior knowledge at the beginning of each generated sub-goal; prompting students to assess whether the current text and diagram are relevant for the current sub-goal). We have demonstrated the effectiveness of prompting and feedback by showing that students in this condition (i.e., PF condition) read less science materials and navigated through fewer hypermedia pages during the learning task. They also tended to spend more time on each page and they also spend more time inspecting each diagram presented in MetaTutor. Those in the PF condition also set fewer sub-goals but they spend more time on each sub-goal. Overall, the data support existing theoretical frameworks and models of SRL (Pintrich, 2000; Winne & Hadwin, 2008; Zimmerman, 2006) related to the use of computers as MetaCognitive tools (Azevedo, 2005, 2009; Azevedo & Greene, in press; Azevedo et al., in press a,b).

Subsequent analyses of the verbal protocols, metacognitive judgments, emotions data, and log-file data will allow us to extend current models of SRL and build more sophisticated intelligent multi-agent technology-learning environments designed to detect, trace, model, and foster students’ SRL.

Our study contributes to an emerging field that merges educational, cognitive, and learning sciences, and educational technology research by addressing issues related to learning about complex science topics with multi-agent environments (Azevedo et al., 2010; Jacobson, 2008; Leelawong & Biswas, 2008; McQuiggan et al., 2010). 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, 2009; Azevedo et al., in press), and extends recent research regarding the role of intelligent, adaptive scaffolding in facilitating students’ learning with hypermedia. Converging temporally-aligned, multi-level data will allow us to examine the critical role of PAs as external regulatory agents whose scaffolding methods facilitate students’ self-regulated learning (e.g., Azevedo et al., in press a; Chi et al., 2001; Graesser et al, 2001). Lastly, both our product and process data can be applied to inform the design of intelligent multi-agent hypermedia environments as Metacognitive tools (Azevedo, 2005, 2009; Azevedo et al., in press a) to foster learners’ self-regulated learning of challenging science topics by providing adaptive scaffolding (e.g., Jacobson, 2008; Graesser, McNamara, & VanLehn, 2005; White & Frederiksen, 2005).

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