Can Scaffolds from Pedagogical Agents Influence Effective Completion of Sub-Goals during Learning with a Multi-Agent Hypermedia-Learning Environment?

Michelle Taub, Roger Azevedo, Nicholas Mudrick and Erika Clodfelter, North Carolina State University
François Bouchet, Sorbonne Universités
mtaub@ncsu.edu, razeved@ncsu.edu, nvmudric@ncsu.edu, eeclodfe@ncsu.edu, francois.bouchet@lip6.fr

Abstract: Research on Self-Regulated Learning (SRL) in hypermedia-learning environments revealed that students are unable to engage in effective use of SRL, which have important implications for designing hypermedia-learning environments. 60 undergraduate students interacted with MetaTutor, an intelligent, multi-agent hypermedia-learning environment, with the overall goal of learning about the human circulatory system. There are two experimental conditions; prompt and feedback and control. We investigated if there were significant differences on the performance on and use of sub goals among the different experimental conditions. Results indicated significant differences between experimental conditions, such that participants in the prompt and feedback condition had higher sub goal quiz scores, spent more time engaging in each sub goal, had larger page relevant ratios, and had lower irrelevant page ratios, compared to participants in the control condition. These results suggest the importance of scaffolding in promoting the effective use of SRL strategies while interacting with a hypermedia-learning environment.

Introduction

Self-Regulated Learning (SRL) research has investigated students' use of Cognitive, Affective, Metacognitive, and Motivational (CAMM) processes as they interact with hypermedia-learning environments (e.g., Azevedo et al., 2013, Kinnebrew et al., 2013; Lester et al., 2013). According to Winne and Hadwin's (1998) model, learning occurs through different cyclical phases, during each of which information processing occurs. Unfortunately, students typically do not regulate their learning and therefore several researchers have incorporated Pedagogical Agents (PAs) to model and scaffold self-regulatory processes in Computer-Based Learning Environments (CBLEs). Research has investigated how effective the agents are in fostering effective learning (Veletsianos & Russell, 2014). Such research has examined agent aesthetics (Mayer & DaPra, 2012) and agent presence (Park & Catrambone, 2007), with respect to learning; and the influence of PAs on learning and motivation (Baylor, 2009), but has not investigated how Pedagogical Agents can influence students' engagement in self-regulated learning processes and activities, such as goal-setting, taking quizzes, and visiting content, which is relevant to the current sub-goal being worked on.

This study investigated how students completed their sub-goals in order to complete the learning session with MetaTutor, a hypermedia-learning environment. More specifically, we investigated if there were significant differences in students' performance on sub-goal quizzes, time spent on sub-goals, and navigation to relevant and irrelevant pages to the particular sub-goal, among experimental conditions, which differ on the feedback provided form the PAs. We expected that: (1) participants in the prompt and feedback condition would obtain significantly higher sub-goal quiz scores than participants in the control condition; (2) participants in the prompt and feedback condition would spend significantly more time engaging in each of their sub goals than participants in the control condition; and (3) participants in the prompt and feedback condition would have significantly higher relevant page ratios and significantly lower irrelevant page ratios than participants in the control condition.

Methods

Participants

Sixty undergraduate students (60% female) from two large universities in North America participated in this study. Participant ages ranged from 18-38 years old; $M = 21.3$, $SD = 2.66$. They were compensated with $10 per hour for their participation, up to a total of $40.

Research Design

This study was conducted with an experimental design; participants were randomly assigned either to the prompt and feedback condition ($n = 29$) or control condition ($n = 31$). These conditions vary with respect to the role of the Pedagogical Agents (PAs) in the system. Briefly, in the prompt and feedback condition, students are provided with scaffolding from the PAs, who prompt students to engage in several cognitive (e.g., Taking Notes, Summarizing, and Prior Knowledge Activation) and metacognitive (e.g., Judgment of Learning, Feeling

of Knowing, and Content Evaluation) SRL strategies, and provide feedback on the use of these strategies. Thus, in this condition, participants were not expected to learn independently for they are provided with assistance from the PAs, who are there to guide them to engage in effective SRL, and furthermore to learn successfully about the human circulatory system. In the control condition, students were not provided with any prompts or scaffolds from the PAs. Students were, therefore, free to navigate the system as they choose to, and can engage in the SRL strategies, but will not be prompted to do so.

MetaTutor: A Multi-Agent Hypermedia-Learning Environment

MetaTutor is an intelligent, multi-agent hypermedia-learning environment that provides learners with an overall goal of learning everything they can about the human circulatory system (Azevedo et al., 2013). In this environment, there are 48-pages of text and diagrams, which students can navigate to as they complete their sub goals. The sub goals, which students can set for learning are: (1) Path of Blood Flow, (2) Heartbeat, (3) Heart Components, (4) Blood Vessels, (5) Blood Components, (6) Purposes of the Circulatory System, and (7) Malfunctions of the Circulatory System. Each student sets two sub-goals, and can choose to add more during the learning session. The experimental session lasted for two days. On day one, the session lasted thirty minutes, and involved the student completing several demographic self-report questionnaires, and the pre-test, which included 30 multiple-choice questions on the human circulatory system. On day two, students returned to the lab, where they were instructed to use the MetaTutor system and its hypermedia content for 90-minutes, followed by the completion of a post-test (which also included 30 multiple-choice question test on the circulatory system). During the 90-minute session, Gavin the Guide (one of the four PAs embedded in the environment) administered the AEQ self-report emotions questionnaire (e.g., Pekrun et al., 2011), in order to assess how the student was currently feeling at that point during the session. Gavin administered this measure every 14 minutes, for a total of six times throughout the learning session. There are seven sub goals, which students can set at the beginning of the learning session.

There are four Pedagogical Agents (PAs) embedded within the system, who represent the different facets of SRL. *Gavin the Guide* introduces the learner to the session, and administers the pre-test, post-test, demographic questionnaires and emotion questionnaires throughout the session. *Pam the Planner* assists in planning, and helps students set sub goals to work through during the session. *Sam the Strategizer* assists in the use of learning strategies, and encourages students to create summaries on the content. *Mary the Monitor* focuses on monitoring strategies, and administers the sub goal quiz when a student has completed working on his or her current sub goal.

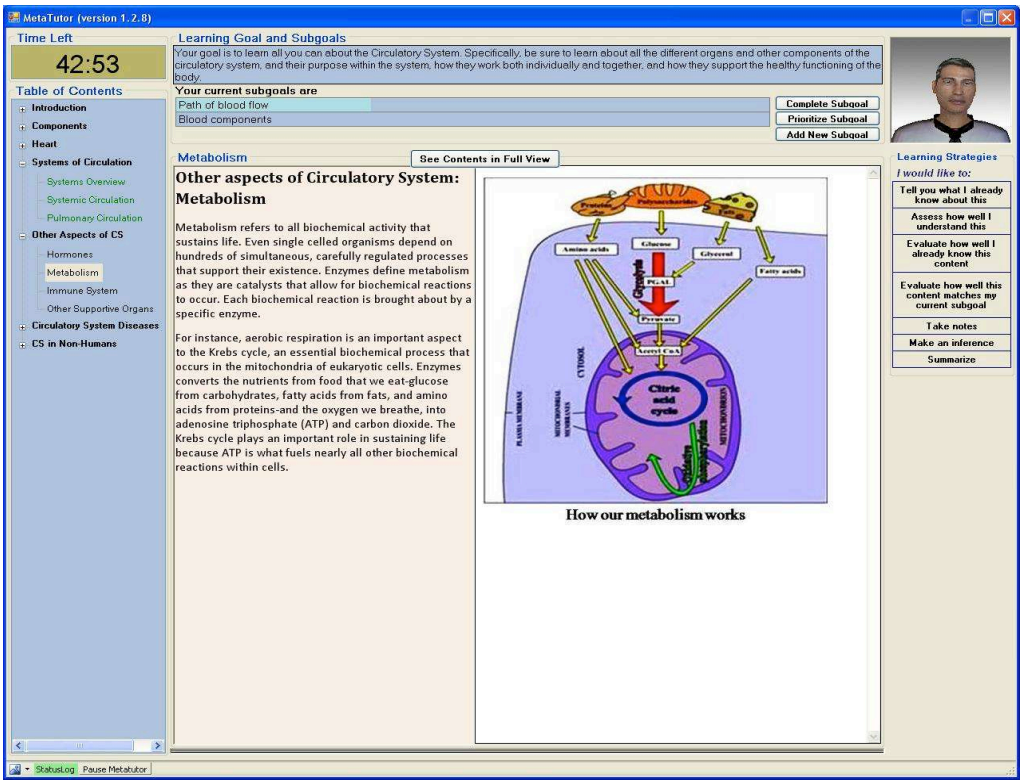

Figure 1. Screenshot of the MetaTutor interface

The MetaTutor interface consists of multiple parts. See Figure 1 for an image of the MetaTutor interface. On the top left corner, there is a clock, which displays the time remaining in the session. Just below the timer, there is a table of contents, which displays the title of each page, and so students can choose which page to navigate to. On the bottom, there is a text box, where students can type in information, and can respond to the questions, which respond to the metacognitive SRL strategy questions. On the right hand side, there is the SRL palette, which lists the cognitive and metacognitive SRL processes, such as taking notes, content evaluation, and judgment of learning, which students can click on, if they choose to engage in one. The Pedagogical Agent is located in the top right corner. One agent is displayed at a time, and is displayed according to the scaffold and activity the student is engaging in. On the top of the interface, the student's overall learning goal, to learn everything about the human circulatory system, is listed, with a list of the sub goals set, which are placed underneath it. There is a status bar for each sub goal, which indicates how far along the student is in completing the sub goal; and students can click to complete the current sub goal if he or she feels it is complete.

Experimental Procedure

During learning with MetaTutor, we collected multi-channel data, which provides a wide array of product and process data related to cognitive and metacognitive SRL processes and learning activities. As students learn, we collected: (1) log-file data, which include time-stamped information, at the millisecond level, of every mouse click and keyboard entry the student makes into the system, which includes when the student engages in an SRL strategy, and when a PA intervenes; (2) eye-tracking (Tobii T60) data, which measures students' gaze behavior and fixations as he or she navigates through the system; (3) physiological data, which measured students' arousal based on electro-dermal activity to events (e.g., agent feedback) during learning; (4) video recordings, which captured the students' facial recording and allows for us to detect their emotional states during learning; and (5) video and audio recordings of the learners' concurrent think-aloud protocols and interactions with the system. For this study, we only analyzed data from the log-files.

Coding and Scoring

Several variables were extracted from the multi-channel data. However, in this study we only report on a subset of the variables extracted from the log-files. For example, mean sub-goal quiz scores and time spent engaging in the current sub goal were obtained from the log-files. Quiz scores ranged from 0-9; $M = 6.16$, $SD = 2.33$, and mean time spent on each sub-goal was calculated in seconds. A graduate student, with the assistance of two undergraduate students read through the printed log-files and identified the sub-goals participants set (e.g., Path of Blood Flow), how long students spent engaging in each sub goal, and which pages students navigated to as he or she completed the sub goal.

Sub-goals were coded into two groups, based on level of difficulty. Group 1 consisted of the less difficult sub goals: Path of Blood Flow, Heart Components, Blood Vessels, and Blood Components; and Group 2 consisted of the more difficult sub goals: Heartbeat, Purposes of the Circulatory System, and Malfunctions of the Circulatory System. Sub-goals were categorized into these categories based on the number if pages associated with the sub-goals, such that sub-goals with more relevant pages were deemed less difficult, and categorized into Group 1, whereas sub-goals with fewer relevant pages were deemed more difficult, and were categorized into Group 2. In order to determine page relevancy ratios, each page number was marked as relevant or irrelevant, based on an excel sheet containing information regarding each sub-goal, including which pages of content and which diagrams are relevant to each of the seven sub-goals, and so we were able to mark the pages relevant to each sub goal. Total numbers of relevant and irrelevant pages were calculated, which were then calculated as ratios using the following formulas; $|Total\ Relevant\ Pages\ Viewed\ :\ Total\ Pages\ Viewed|$ and $|Total\ Irrelevant\ Pages\ Viewed\ :\ Total\ Pages\ Viewed|$ for relevant page ratio and irrelevant page ratio, respectively. Participants set at least two sub goals each, and so although we had 60 participants, we obtained 183 data points, which represented the total amount of sub goals that were set among all 60 participants.

Results

In order to address the posited research questions, we ran several *t*-tests, in order to test for significant differences between the experimental conditions on their performance and use of the seven MetaTutor sub goals.

Research Question 1: Are there Significant Differences between Conditions on Sub Goal Quiz Scores?

An independent samples *t*-test was used to determine if there was a significant difference between experimental groups on their scores on Sub Goal quizzes. We extracted quiz scores from the log-files, which captured time-stamped information during the learning session.

Results from the *t*-test revealed that there were significant differences between sub goal quiz scores among experimental groups; $t(40.688) = 2.693$, $p = .01$, $\eta^2 = 0.11$. More specifically, students in the prompt and feedback condition obtained higher mean sub goal quiz scores ($M = 6.94$, $SD = 1.20$) than students in the control condition ($M = 5.43$, $SD = 2.87$). This result indicates that participants who were provided with prompts and feedback during the learning session performed greater and achieved higher mean sub-goal quiz scores than participants in the control condition, suggesting that scaffolds from the Pedagogical Agents were effective in influencing how students performed on sub-goal quizzes.

Research Question 2: What Are the Effects of Prompts and Feedback on Time Spent on Sub Goals?

To address this research question, we performed an Independent Samples *t*-test, with time spent on sub goals as our independent variable. We calculated the time spent per sub goal by scanning through the log-files and calculating duration by obtaining the time started and time completed for each sub goal the participant worked on. We obtained data from 60 participants, however each participant completed at least two sub goals (range = 2 to 7; Mean number of sub-goals per participant = 3.05. $SD = 1.28$), and so we obtained 183 time data points.

Results from the Independent Samples *t*-test revealed a significant difference on time spent per sub goal among experimental conditions; $t(181) = -2.246$, $p = .03$, $\eta^2 = 0.03$. Specifically, participants in the prompt and feedback condition spent significantly more time working on each of their sub goals ($M = 37.54$ minutes, $SD = 26.54$ minutes) than participants in the control condition ($M = 28.55$ minutes, $SD = 27.05$ minutes). This finding indicates that when participants interacted with the Pedagogical Agents during learning, they spent significantly more time working on the sub goals that they set, which suggests that these participants made more valuable use of their learning time, compared to students who did not interact with the Pedagogical Agents during learning.

Research Question 3: Are there Significant Differences between Condition and Relevant Pages?

In order to test this research question, we performed two Independent Samples *t*-tests, with relevant page ratio and irrelevant page ratio as the independent variable for each test. The page numbers, which participants navigated to were obtained from the log files, and were then assessed as being relevant or irrelevant to the current sub goal. The page ratio was then calculated by dividing the total relevant pages/total pages and the total irrelevant pages/total pages for the relevant ratio and irrelevant ratio, respectively.

Results from these analyses indicated two sets of significant results. We found a significant difference in the ratio of relevant pages visited among experimental conditions; $t(181) = -5.442$, $p = .00$, $\eta^2 = 0.14$. Participants in the prompt and feedback condition had significantly greater relevant page visited ratios ($M = .62$, $SD = .26$) than participants in the control condition ($M = .40$, $SD = .31$). Furthermore, we found a significant difference in the ratio of irrelevant pages visited among experimental conditions; $t(174.838) = 2.853$, $p = .01$z, $\eta^2 = 0.04$. Participants in the prompt and feedback condition had significantly lower irrelevant page visited ratios ($M = .35$, $SD = .24$) than participants in the control condition ($M = .47$, $SD = .32$). These results indicate that if students interacted with the Pedagogical Agents during learning, this allowed for them to spend more time reading pages, which are relevant to the current sub-goal, and reading less pages that are irrelevant to the current sub goal. This suggests that students contributed effectively to completing their sub-goals, in terms of visits to relevant pages and less visits to irrelevant pages.

Discussion and Educational Implications

The results obtained from these analyses revealed the importance of providing prompts, scaffolds, and feedback to students as they learn with multi-agent, adaptive hypermedia-learning environments. In addition, these results have important implications for Self-Regulated Learning because they inform us of the usefulness of setting sub-goals, and of including Pedagogical Agents in hypermedia-based learning systems, in order to provide prompts and feedback to students to ensure effective SRL

Moreover, it is important to consider the educational implications from these results. First, the role of the teacher is crucial in the classroom because teachers can provide the appropriate scaffolds and feedback to his or her students to ensure that each student understands the content, and can apply these constructs to every day life. If teachers were able to collect multi-channel data on each student, this would allow for the teacher to gather reliable data, as opposed to making inferences, about each student's progress during learning. In addition, teachers can use methods, such as having students set sub-goals, in order for them to grasp an optimal understanding of the topic they are learning. Future work can, therefore, implement using multi-channel data in the classrooms, which would allow for accurate measures of student performance, and thus promote optimal learning in the classroom. The agents can be adaptive based on students' pre-test scores, sub-goal quiz scores, page quiz scores, use of SRL strategies (e.g., Taking Notes, Judgment of Learning, and Content Evaluation), emotional states, and think-aloud data, which they can assess and provide the appropriate prompts and feedback,

based on performance on all of these aspects. If we were to design adaptive multi-agent hypermedia systems, this would allow for us to cater to individual students' learning needs, and will promote optimal self-regulated learning when interacting with CBLEs.

Overall, results from this study indicated that there is support for incorporating Pedagogical Agents in hypermedia-learning environments, as well as having students set sub-goals to work on as they navigate through the system. The PAs can be an important asset to include in Computer-Based Learning Environments because they have been shown to be effective in providing prompts, scaffolds, and feedback, which have assisted learners in obtaining higher mean sub-goal quiz scores, spending more valuable time accomplishing sub-goals, visiting more pages, which were relevant to their sub-goals, and visiting fewer pages, which were irrelevant to their sub-goals, compared to students who were not provided with this assistance from the PAs. Therefore, the PAs were effective in fostering and promoting effective completion of sub-goals, and thus effective self-regulated learning. It is advantageous, therefore, to maintain two experimental conditions in our set-up, in order to compare and determine how students interact with the PAs the most effectively. In addition, the results confirmed that setting sub-goals can be a useful tool for learning, and that when students are scaffolded appropriately, they can make effective use in completing the sub-goals they set.

References

Azevedo, R., Harley, J., Trevors, G., Duffy, M., Feyzi-Behnagh, R., Bouchet, F., & Landis, R. (2013) Using trace data to examine the complex roles of cognitive, metacognitive, and emotional self-regulatory processes during learning with multi-agent systems. In R. Azevedo & V. Aleven (Eds.), *International handbook of metacognition and learning technologies* (pp. 427-449). Amsterdam, The Netherlands: Springer.

Baylor, A. L. (2009). Promoting motivation with virtual agentes and avatars: Role of visual presence and appearance. *Philosophical Transactions, 364*, 3559-3565. doi: 10.1098/rstb.2009.0148

Kinnebrew, J., Biswas, G., Sulcer, B., & Taylor, R. (2013). Investigating self-regulated learning in teachable agent environments. In R. Azevedo & V. Aleven (Eds.), *International Handbook of Metacognition and Learning Technologies* (pp. 451-470). Amsterdam, The Netherlands: Springer.

Lester, J.C., Mott, B.W., Robinson, J.L., & Rowe, J.P. (2013). Supporting self-regulated science learning in narrative-centered learning environments. In R. Azevedo & V. Aleven (Eds.), *International Handbook of Metacognition and Learning Technologies* (pp. 471-483). Amsterdam, The Netherlands: Springer.

Mayer, R. E., & DaPra, C. S. (2012). An embodiment effect in computer-based learning with animated pedagogical agents. *Journal of Experimental Psychology, Applied, 18*(3), 239-252. doi: 10.1037/a0028616

Park, S., & Catrambone, R. (2007). Social facilitation effects of virtual humans. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 49*(6), 1054-1060. doi: 10.1518/001872007X249910.

Pekrun, R., Goetz, T., Frenzel, A., Barchfeld, P., & Perry, R. (2011). Measuring emotions in students' learning and performance: The Achievement Emotions Questionnaire (AEQ). *Contemporary Educational Psychology, 36*, 36-48.

Veletsianos, G., & Russell, S. R. (2014). Pedagogical agents. In J. M. Spencer, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of Research on Educational Communications and Technology* (pp. 759-769). New York, NY: Springer.

Winne, P. H., & Hadwin, A.F. (1998). Studying as self-regulated learning. In D.J. Hacker, J. Dunlosky, & A. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 277-304). Hillsdale, NJ: Erlbaum.

Winne, P. H., & Hadwin, A. F. (2013). nStudy: tracing and supporting self-regulated learning in the Internet. In R. Azevedo & V. Aleven (Eds), *International Handbook of Metacognition and Learning Technologies* (pp. 293-308). Amsterdam, The Netherlands: Springer.

Acknowledgements

The research presented in this chapter has been supported by funding from the National Science Foundation (DRL 1008282), the Institute of Educational Sciences (R305A120186), the Social Sciences and Humanities Research Council of Canada (430–2011–0170 and 890–2012–0138), the Canadian Foundation for Innovation, and the Canada Research Chairs program awarded to the second author.