Effect of Metacognitive Support on Student Behaviors in Learning by Teaching Environments

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Abstract. We have developed environments that use teaching as a metacognitive, reflective, and iterative process to help middle school students learn about complex processes. We demonstrate that metacognition and self-regulation are crucial in developing effective learners and preparing them for future learning tasks. As evidence, we discuss the impact of metacognitive support on students' learning performance and behavior patterns that promote better learning through self-monitoring.

Keywords. Metacognition, teachable agents, behavioral analysis.

1. Introduction

Using the learning-by-teaching paradigm, we have developed a computer system where students teach a software agent named Betty. Self-regulated learning (SRL) strategies are incorporated into Betty's persona [2]. For example, as the student teaches Betty using a concept map she occasionally responds by demonstrating reasoning through chains of events. She may query the user, and sometimes remark (right or wrong) that the answer she is deriving does not seem to make sense. This paper describes an experiment conducted in 5th grade classrooms to demonstrate the effectiveness of the TA system with metacognitive support. Specifically, we focus on the students' ability to learn and use metacognitive strategies like monitoring and debugging.

2. Experimental Study

The study was conducted in two 5th grade science classrooms in a Metro Nashville school. 54 students were divided into three groups using a stratified sampling method based on standard achievement scores in mathematics and language. Group 1 used a system where the student was taught by a computer-based pedagogical agent that emulated an *intelligent tutoring system (ITS)* [3]. This system represented our control condition to establish the differences between learning by teaching and learning by being taught. The pedagogical agent in the system, Mr. Davis, asked the students to construct a concept map to answer three sets of quiz questions. When students submitted their maps for a quiz he provided corrective feedback that was based on errors in the quiz answers [1]. Group 2 used a basic *Learning by Teaching System (LBT)*, where students taught Betty by creating a concept map, but Betty did not demonstrate any metacognitive behaviors. The students could query Betty to see how she reasoned with what she was taught and ask her to take the quizzes. Mr. Davis graded Betty's answers, and provided the same corrective feedback as in the ITS version of the system. Group 3, the *Self Regulated Learning System (SRL),* represented our experimental condition. Like the LBT system, students taught Betty, but Betty's persona incorporated SRL behaviors. The three groups worked for seven 45-minute sessions over a period of two weeks to create their concept maps on aquatic ecosystems.

A *Preparation for Future Learning (PFL)* task was conducted approximately 12 weeks after the main study. Students taught Betty about the land-based nitrogen cycle which was a new topic they had not discussed in class. All students used a baseline system that included resource materials on the nitrogen cycle. The Mentor provided no directed feedback, and Betty did not provide metacognitive support.

3. Results and analysis

We analyzed students' understanding by evaluating the concept maps they had generated at the end of the main and PFL studies where concept map quality was determined by the number of correct concepts and links. More importantly, we analyzed students' behaviors by examining differences in behavior patterns between groups.

We found that overall the SRL group produced better concept maps than the ITS and LBT groups in both studies though not all of the differences were statistically significant. This can be attributed to a number of factors as discussed in previous studies with Betty's Brain [1][2]. Analysis of the behavioral data led us to believe that the ITS group relied mostly on the Mentor's directed feedback to debug their maps so they could pass the quiz and were therefore less prepared to learn a new domain in the PFL study. The other two groups spent more effort in developing a better understanding of the domain so they could better teach Betty. They looked beyond concepts in the quiz questions and the corrective feedback from the Mentor [2].

In order to further investigate the effect of metacognitive feedback, we analyzed the differences in behavior between groups. Student behaviors in each session of the main and PFL studies were extracted as sequences of activities from the system log files. The sequences were defined in terms of six primary activities: Edit Map (EM), Ask Query (AQ), Request Quiz (RQ), Resource Access (RA), Request Explanation (RE), and Continue Explanation (CE).

For each group we generated transition diagrams which show the probability of transitioning from one activity to another, allowing us to identify activity sequences that are characteristic of a group's overall behavior. The transition diagrams demonstrated that the EM and EM–RQ sequences dominated for the ITS group in the main study. For the LBT and SRL groups there were more EM–AQ transitions, and the SRL group is the only one that used the AQ–RE–CE sequence of activities substantially. This shows that the SRL students put in effort to debug their concept maps, before they got Betty to take the quiz. The repeated use of AQ, RE, and CE is a clear indication of their monitoring their own learning processes and that the metacognitive support of the SRL system had a positive effect on desired learning behaviors.

In order to verify the value of these activity sequence patterns, we correlated them with concept map quality in both the main and PFL study. Table 1 shows that students who exhibited the EM–RQ behavior pattern more often were the students who produced lower quality concept maps ($p < 0.01$). On the other hand, students who exhibited the EM-AQ, AQ–RE, and AQ–RE–CE patterns more produced better concept maps ($p < 0.05$). The correlations held true for the PFL study maps.

Table 1: Correlation between Behavior Patterns and Concept Map Quality

Main Study Pattern	**Main Concept Map Pearson Correlation**	**PFL Concept Map Pearson Correlation**
EM-AQ	0.48 [b]	0.22 [b]
EM-RQ	–0.36 [a]	–0.16 [b]
AQ-RE	0.29 [a]	0.38[a]
AQ-RE-CE	0.2 [b]	0.29 [a]

[a]: significant at 0.05 level; [b]: significant at 0.01 level.

In the transition diagrams for the transfer study interesting similarities in behaviors between all three groups occurred, which we will not discuss in detail here.

4. Conclusions

The results of this study provide two important pointers: (i) metacognitive support does aid in more effective learning of domain content, and (ii) metacognitive and monitoring strategies do transfer and can be very effective in helping students prepare for future learning even when they are in environments where the learning scaffolds have been removed. In terms of improving self-monitoring and metacognitive skills, the students with SRL feedback support were more likely to develop good strategies for learning in new domains. Future work will focus on domains that include dynamic processes where students learn using scientific inquiry and the learning by teaching paradigm. We hypothesize that our approach of helping students to develop cognitive strategies and better self-monitoring skills will help them develop methods for creating and refining hypotheses through observation and experiments, testing those hypotheses, and then applying them to complex problem solving tasks.

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