How Metacognitive Feedback Affects Behavior in Learning and Transfer

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Abstract. We have developed learning environments that use learning by teaching with metacognitive support to help middle school students learn about complex science topics. We study the role of metacognitive feedback in learning by teaching environments by examining student behaviors and performance across a primary task and a transfer task, noting how the behavior patterns for the high and low performers change as they progress from the primary to the transfer task. In this paper, we examine the apparent behavior shifts that occur as students observe, practice, and then internalize self-regulation skills. Our results show the benefit of metacognitive feedback, and we discuss approaches for incorporating adaptive metacognitive feedback in future systems.

Keywords. learning-by-teaching; metacognitive support, learning behaviors.

Introduction

We have been using learning by teaching models to create learning environments for middle school students that promote the development of higher-order cognitive skills for problem solving in science and math domains [1][2][3]. The resulting teachable agents (TA's) are software programs where students teach a computer agent using well structured visual representations , and these interactions help shape their thinking [2][4].

Previous studies showed evidence that learning-by-teaching with metacognitive support helped students develop better learning and self-monitoring strategies, and this prepared them for future learning on related topics, even when this learning happened outside of the support provided by the TA environment [2]. In this paper, we perform systematic analyses to draw links between student learning and their observed behaviors during the learning task. The learning measure is defined by the students' performance on a preparation for future learning (PFL) task. We notice a shift in the behaviors exhibited by both high and low performers from the main to the transfer study. Others, such as Witherspoon et al. [5] have found that learners initially try a variety of strategies when learning a new domain, and as they gain a better perspective they begin to adopt more sophisticated planning strategies for learning in that domain. More generally, we believe a similar behavior shift from observation and cognitive acquisition to self-control and self-regulation occurs as students gain a deeper understanding of the reasoning mechanisms and the metacognitive feedback they receive in our TA environment [6]. The rest of the paper provides an overview of Betty's Brain, our learning by teaching system, the metacognitive support provided by the system, a description of our experimental study, and a summary of our findings and future work.

1. Learning by Teaching: Betty's Brain

The teaching process in Betty's Brain, illustrated in Figure 1, is implemented as three primary activities: (i) *teach*: students explicitly teach Betty using a concept map representation, (ii) *query*: students use a template to generate questions to see if Betty can answer questions based on what she has been taught, and (iii) *quiz*: students observe Betty's performance on a set of predefined questions. Betty uses qualitative reasoning methods to reason through chains of links [2], [7] to answer questions, and, if asked, explains her reasoning using text and animation schemes. Betty also provides feedback to get the students to adopt more metacognitive strategies in their learning tasks [8]. Students reflect on Betty's answers and her explanations, and revise their own knowledge as they make changes to the concept maps to teach Betty better. Details of the Betty's Brain system and experiments that we have conducted with this system are summarized in [2], [8]. Next we discuss the metacognitive support provided to students as they learn about river ecosystems.

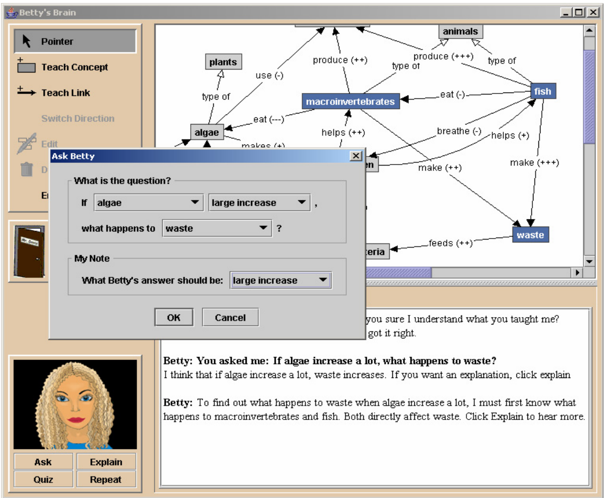

Figure 1: Betty's Brain System with Query Window

2. Metacognitive Support in Betty's Brain

Cognitive science researchers have established that metacognition and self-regulation are important components in developing effective learners in the classroom and beyond [9], [10], [11]. Pintrich differentiates between (i) *metacognitive knowledge* that includes knowledge of general strategies and when they apply, as well as knowledge of one's own abilities, and (ii) *metacognitive control* and *self regulatory processes* that learners use to monitor and regulate their cognition and learning [12]. We believe the TA environments when combined with adequate scaffolding and feedback can provide appropriate educational opportunities for students to develop both metacognitive knowledge and control, and thereby, improve their subsequent learning.

We adopt a self-regulated learning (SRL) framework that describes a set of comprehensive skills that start with setting goals for learning new materials and applying them to problem solving tasks, deliberating about strategies to enable this learning, monitoring one's learning progress, and then revising one's knowledge, beliefs, and strategies as new materials and strategies are learnt. In conjunction with these higher level cognitive activities, social interactions and motivation also play an important role in the self-regulation process [11]. We believe that two interacting factors of our TA implementations are particularly supportive of self regulation. The first is the visual *shared representation* that the students use to teach their agents. The second factor, *shared responsibility*, targets the positive effects of social interactions to learning. This manifests in the form of a joint effort where the student has the responsibility for teaching the TA (the TA knows no more and no less than what the student teaches it), whereas the TA has the responsibility for answering questions and taking tests.

Betty's persona in the SRL version incorporates metacognitive knowledge that she conveys to the students at appropriate times to help the student develop and apply monitoring and self regulation strategies [8]. For example, when the student is building the concept map, Betty 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. The idea of these spontaneous prompts is to get the student to reflect on what they are teaching, and perhaps, like a good teacher check on their tutee's learning progress. These interactions are directed to help Betty's student-teacher understand the importance of monitoring and being aware of one's own abilities. On other cues, the Mentor (and sometimes Betty herself) provides suggestions on cognitive strategies the students may employ to improve their own learning and understanding of the subject matter under consideration.

3. Experimental Design

To study the effect of metacognitive and self-regulation strategies on learning behaviors, we designed three version of the TA system. We refer to the system used in the control condition as the intelligent tutoring system (ITS) because this directed learning environment contains some aspects of traditional ITS's [13]. In this condition, the students were taught instead of teaching someone else. Mr. Davis, the Mentor agent, asked the students to construct a concept map to answer three sets of quiz questions. When students submitted their maps for a quiz, Mr. Davis provided corrective feedback that was based on errors in the quiz answers [2]. System 2 was a Learning by Teaching (LBT) environment, where students were asked to teach Betty by creating a concept map. The students were told that Betty needed help to pass a test so she could join the high school science club. Students using the LBT system could query Betty to see how well she was learning, and they could ask Betty to take quizzes at any time during the teaching process. After Betty took a quiz, Mr. Davis graded the quiz, and provided Betty and her student-teacher with corrective feedback. The text of the feedback was identical to what was provided in the ITS system. System 3 was a learning-by-teaching system with Self Regulated Learning (SRL). Students in this condition also taught Betty but the primary differences between the LBT and SRL systems were in Betty's behavior and interactions with the student, as well as the feedback that the Mentor provided after Betty took a quiz. Betty's persona in the SRL version incorporated metacognitive knowledge, which she communicated to the students to help them develop and apply monitoring and self regulation strategies to aid their own learning [8]. The PFL study used a version of the system similar to the LBT version, in that it did not incorporate metacognitive feedback.

4. Experimental Study and Results

The study was conducted in two 5th grade science classrooms in a Metro Nashville school. 53 students from the two classrooms were divided into three equal groups using a stratified sampling method based on standard achievement scores in mathematics and language. The three groups, ITS, LBT, and SRL, worked for seven 45 minute sessions over a period of two weeks to create their concept maps on aquatic ecosystems. A PFL study was conducted approximately 8 weeks after the main study where students focused on creating concept maps for the land-based nitrogen cycle. Students were administered pre and post-tests before and after the main study.

4.1. Analysis of Students' Behaviors

Student activity sequences in each session of the main study were extracted from the system log files. The sequences contained six primary activities: (i) Edit Map (EM), (ii) Ask Query (AQ), (iii) Request Quiz (RQ), (iv) Resource Access (RA), (v) Request Explanation (RE), and (vi) Continue Explanation (CE). Actions where the students were adding, modifying, or deleting concepts and links in their concept map were classified as EM activities. The RQ and RA activity labels are self explanatory. Students in the LBT and SRL groups could ask Betty queries (AQ), and then check Betty's reasoning by asking for explanations (RE). Betty's explanations often involved multiple steps that mirrored the multiple steps used by the reasoning process to generate an answer. Betty provided an initial response to a request for an explanation (RE), and then followed it up with more details if the student clicked on the "Continue Explanation" (CE) button. The ITS group also had access to the query and explanation features for debugging their concept maps. Explanations were provided by the Mentor agent. An example activity sequence for a student working on the LBT system in one of the seven sessions appears below:

RA,EM,AQ,EM,AQ,RQ,EM,AQ,RA,EM,AQ,RQ,EM,RA,EM,RQ,RA,EM,RQ,EM,RQ,EM,RQ,RA,AQ

In previous work [8][14] we used intuition and empirical observations to link behavior sequences to manifestations of metacognitive control and self regulation [11][12]. A primary finding in the earlier studies was that students who frequently exhibited the *Quiz-Edit-Quiz* behavior (defined as RQ_EM_RQ or EM_RQ_EM) were more likely to have concept maps with low scores. The pattern appeared to reflect trial and error (edit map, see if it worked using the quiz, then repeat to fix problems). On the other hand, students who asked queries to check on the changes they had made to their concept map (EM_AQ) and requested explanations after asking queries (EM_AQ_RE) were more likely to produce high scoring concept maps. Preliminary analysis showed that students in the SRL condition used the EM_AQ and EM_AQ_RE patterns more frequently than the other groups, and the ITS group used the EM_RQ_EM pattern more often than the LBT and SRL groups. We concluded that the metacognitive support helped the SRL students learn good monitoring behavior. Furthermore, the SRL group also produced better concept maps than the ITS and LBT groups.

In this paper we compare behavior sequences that correspond to high and low learning performance in the main and PFL studies. Our findings, like [5], show a definite shift in self regulatory behavior as students gain a better understanding of the domain and learn self regulation strategies by observation and practice. We speculate whether this implies a progression from cognitive acquisition to full self-regulation as outlined in [6].

4.2. Identifying Behavior Patterns Indicative of High and Low Performance

We use correlational analysis to identify activity patterns in the main and PFL study that are indicative of high and low performance. Correlations are computed between the frequency of pattern use by the students and their learning performance. A normalization factor (i.e., the number of occurrences of the first activity in the sequence) is applied to the frequency computation. We define students' learning performance by the quality of their concept map at the end of the transfer (PFL) study. Concept map quality is computed as the sum of the correct concepts and correct links in the student's concept map. Concepts and links are defined to be correct if they appear in the expert map[1] or if they are graded to be relevant by two coders because they demonstrated a correct understanding of the domain (even if they were not necessary to answer the quiz questions).

Correlational analysis provides a preliminary method for linking behavior patterns to levels of learning performance. In future work we will develop methods that more definitely establish causal relation between observed behaviors and student learning.

We first identify behaviors in the main study that are indicative of high and low PFL performance. For the correlation computations, we restricted the number of considered activity patterns in the main study to lengths of two and three.[2] The mean correlation value for these patterns with the transfer map was 0.087 (SD = 0.146). The activities with large positive correlations were associated with high performance, and the activities with large negative correlations were associated with low performance. A cutoff criterion of M ± 2.SD was used to select the highest and lowest performance patterns. Table 1 lists the activity patterns with correlation values above the high cutoff of 0.379 and below the low cut off of -0.205.

Table 1. Activity patterns with high and low correlation values with transfer study concept map score

High correlation		**Low correlation**	
Activity Pattern	Correlation Value	Activity Pattern	Correlation Value
AQ_RA_EM	0.460	RQ_EM	-0.310
EM_AQ_RA	0.419	RQ_EM_RQ	-0.280
AQ_RA	0.414	EM_RQ_EM	-0.214
		AQ_ EM	-0.207

The three activity patterns that correlated well with high performance included two activities: (i) RA, resource access, for seeking more information about the domain, and (ii) AQ, asking queries to check on answers generated by the concept map. These students used the AQ_RA_EM and EM_AQ_RA activity patterns to check the correctness of their concept maps by asking queries and then looking up the resources to see if the answers were correct. AQ_RA_EM would imply that the students then went on to make changes in their concept maps, and EM_AQ_RA would imply that students used resources to check on the changes they had just made to their concept maps.). We should clarify that the online resources were organized like a textbook with hyperlink structures and keyword search features. Students had to read relevant portions of the text and infer the relations between entities in their construction of the concept map.

Three of the four patterns that showed strong correlations with low performance, i.e., EM_RQ_EM, RQ_EM_RQ, and RQ_EM were linked to the suboptimal *Quiz-Edit-Quiz* strategy that we have discussed before [2][8]. AQ in the fourth pattern AQ_EM may be a good activity, however, the fact that students went on to edit their concept maps instead of performing

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[1] The expert map was used by the mentor agent, Mr. Davis, to grade the students' concept maps and provide feedback. However, the students did not have access to the expert map.

[2] A maximum length of 3 was chosen to reduce computation time. In future work, we will look at longer behavior patterns.

monitoring activities, such as RA (resource access) or RE (request explanation), led us to believe that these students were not using the AQ feature in a very useful way.

In previous studies, we had conjectured and demonstrated qualitatively that significant use of activity patterns that included the query and explanation mechanisms (AQ, RE, CE) was indicative of high performance. The pattern AQ_RE is the 4th highest ranked activity pattern (correlation value = 0.35) was a little below the high cutoff level. The high rank for the AQ_RE activity pattern is encouraging, but from this analysis one may conclude that the students who perform well in the PFL study use a balanced strategy of initiating their monitoring processes by asking queries and then following them up by asking for explanations (to check on the reasoning mechanisms) or reading the resources further (to check on the correctness of the answer).

4.3. Behavior Patterns by Group

We were also interested in knowing if the different Betty's Brain conditions influenced the students' behavior patterns. Like before, we hypothesized that the metacognitive support for the SRL group in the main study would result in these students using activity patterns linked to high performance more frequently than the ITS and LBT groups. On the other hand, the ITS group would show more frequent use of the low performance activity patterns (see [2], [8]). We used an ANOVA to check for significant differences behaviors between the groups (see Table 2). The ANOVA was followed by post-hoc analysis using Tukey's HSD to establish pairwise differences between groups [15]. This table is not included for the sake of brevity. Pairwise differences at the $p < 0.05$ level are marked in bold, and those significant at the $p < 0.1$ level are marked in italics.

Table 2. ANOVA results – behavior differences

Behavior	F(2, 51)	Sig
AQ_RA_EM	*2.554*	*0.088*
EM_AQ_RA	**16.925**	**< 0.001[a,b]**
AQ_RA	**3.490**	**0.038**
AQ_EM	1.829	0.171
EM_RQ_EM	**8.345**	**0.001[c]**
RQ_EM_RQ	**8.656**	**0.001[c]**
RQ_EM	**7.111**	**0.002[c]**

a – SRL students performed behavior significantly more than ITS students ($p<0.05$)
b – LBT students performed behavior significantly more than ITS students ($p<0.05$)
c – SRL students performed behavior significantly less than ITS students ($p<0.05$)

The results show significant differences between the SRL and ITS groups for three of the behaviors (one high performing behavior: EM_AQ_RA, and two low performing: RQ_EM_RQ and EM_RQ_EM). The only significant difference between ITS and LBT is the EM_AQ_RA pattern. If one relaxes the significance level to $p < 0.1$, five patterns (bold + italicized) show significant differences between the SRL and ITS groups, five of the behavior patterns are different between the ITS and LBT groups, and there is one behavior difference between the SRL and LBT groups (EM_AQ_RA). This analysis seems to support the fact that the SRL group with metacognitive support used more high performing behavior patterns to support learning than the other two groups and the ITS group used more of the low performing behavior patterns than the other two groups. The LBT group was in between. Table 5 shows the main study concept map scores for each group. It is clear that the SRL students produced better concept maps (correct concepts + links) than the ITS and LBT groups. The differences in concept map scores are statistically significant.

4.4. PFL Behaviors and PFL performance

Next, we examined activity patterns in the PFL task linked to high and low performance. The mean correlation value for these patterns with the transfer study map was 0.061 (SD = 0.199). Using M ± 2SD as the cutoff, we defined the behaviors indicative of high and low performance.

A comparison of Tables 1 and 3 shows a definite shift in the high performing activity patterns. In the main study, there was significant use of RA and AQ t as well of AQ_RE. On the other hand, the top four patterns in Table 3, revolve around the use of EM and AQ. At first glance, one may wonder if this implies a shift to the suboptimal *Quiz-Edit-Quiz* strategy by the high performing group. On further reflection we realized that the high performing students had gained a good understanding of the reasoning process through self-monitoring by asking queries and explanations in the main study, and they could now directly apply this to the new concept maps without using the scaffolds provided in the system (AQ, RE, and CE). It is also reassuring to see that RA_EM_RQ remained a significant activity pattern, which implies the students were still demonstrating information seeking strategies in the new domain by accessing the resources before editing their maps. EM_RQ_RE is an unusual pattern, but we ignored it because its frequency of use was very low compared to the other patterns in the table. In the transfer study, there were few intermediate questions, so students had to do a lot more reasoning on their own to generate the right maps.

Table 3. PFL activity patterns with high and low correlation values with transfer study concept map score

High correlation		**Low correlation**	
Activity Pattern	Correlation Value	Activity Pattern	Correlation Value
RQ_EM_RQ	0.584	RQ_AQ_EM	-0.477
RQ	0.575	EM_AQ	-0.369
EM_RQ	0.547	EM_AQ_EM	-0.366
EM_RQ_EM	0.530	AQ	-0.348
EM_RQ_RE	0.481	RA_EM_AQ	-0.347
RA_EM_RQ	0.480	RQ_AQ	-0.347

We believe that the observed shift demonstrates a progression from relying on self-other monitoring in the LBT and SRL groups to self-reliance and self-monitoring (cf. to [6]). Preliminary analysis of students' query usage by session shows that the shift in behavior occurs as a continuum over time in the main study and not as two discrete points from the main to PFL study (Fig. 2). This shift is particularly noticeable for the SRL condition. A more detailed causal analysis across time is required to establish the nature of the shift, but the correlational analysis provides a plausible reason for the decrease in query use from the main to the PFL study.

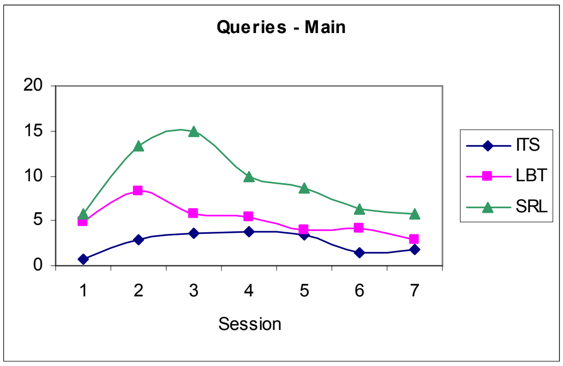

Figure 2. Queries asked across sessions in the main study

There is also an observed shift in the activity patterns used in the main and transfer studies for the low performers. These students had difficulties understanding the reasoning mechanisms in the main study, so they resorted to suboptimal strategies to build their concept maps. In the transfer study, AQ was used frequently in the low performing activity patterns, implying an attempt to gain a better understanding of the reasoning mechanisms using monitoring processes. However, unlike the high performing behaviors in the main study, the transfer study activity patterns do not combine AQ with information seeking (RA) or monitoring (RE and CE) activities. The high performing activity patterns from the main study EM_AQ_RA and AQ_RA_EM still show positive correlations of 0.252 and 0.188, respectively, in the transfer study, which implies a stronger association with the high performing behaviors. This implies that at best, this positive shift for the low performers was still in the early phases of learning and practicing metacognitive strategies, as opposed to demonstrating internalization (understanding) and self-reliant behavior like the high performers.

Like before, we were interested in seeing if the three different treatments in the main study[3] influenced the transfer study activity patterns. Table 4 lists the results of the ANOVA followed by Tukey's HSD for post hoc analysis of significant pair-wise differences. Only one activity pattern, RQ, showed post hoc differences between pairs of groups at the $p < 0.05$ level. As we have discussed earlier, the high performing students had a good understanding of the reasoning mechanisms, and they did not need to use the AQ and RE features to monitor and debug their concept maps. It is quite likely that a number of these students were from the SRL group (based on the results in Table 2 and 5). Therefore, their observed behaviors mainly involve reading resources, editing the map, and taking the quiz to see if their generated map is correct. Though their monitoring behaviors are not directly observed, their overall strategies were successful in producing higher quality maps. Again, detailed causal and temporal (i.e., student progression over time) analysis of this data has to be performed to gain a better understanding of the effect of the different conditions on learning performance.

Table 4. ANOVA results – behavior differences in Transfer study by condition

Behavior	F(2, 51)	Sig
RQ_EM_RQ	0.680	.512
RQ	**4.149**	**.022**[a,b]
EM_RQ	*2.613*	*.084*

[3] All three groups used the same barebones LBT system in the transfer study. Students were told if their quiz answers were right or wrong. They did not receive directed or metacognitive feedback.

EM_RQ_EM	0.873	.425
EM_RQ_RE	1.359	.267
RA_EM_RQ	1.715	.192
RQ_AQ_EM	0.767	.470
EM_AQ	0.739	.483
EM_AQ_EM	**3.330**	**.045**
AQ	1.305	.281
RA_EM_AQ	1.396	.258
RQ_AQ	0.811	.451

a – SRL performed behavior significantly more than ITS ($p<0.05$)
b – LBT performed behavior significantly more than ITS ($p<0.05$)

We reiterate that overall the SRL group showed significantly better performance in the main and transfer study concept map generation. The LBT performance was in between the SRL and ITS performance. Table 5 summarizes these as concept map scores at the end of the main and transfer studies. In the main study, the better scores may be attributed to the explicit metacognitive feedback provided to the SRL students. For the transfer study, this seems to reinforce our hypothesis that students in the SRL group (and possibly the LBT group) internalized the reasoning mechanism and monitoring strategies, and, therefore, produced better concept maps even though our log files did not capture these behaviors.

Table 5. Concept map quality: main study

Group	Main Concept Map Score mean (sd)	PFL Concept Map Score mean (sd)
ITS	22.83 (5.3)	22.65 (13.7)
SRL	31.58 (6.6)[a, b]	32.56 (9.9)[a]
LBT	25.65 (6.5)[a]	31.81 (12.0)[c]

a – significantly greater than ITS ($p < 0.05$)
b – significantly greater than LBT ($p < 0.05$)
c – significantly greater than ITS ($p < 0.10$)

5. Conclusions

The results of this study provide evidence that metacognitive support promotes more effective learning of domain content. For the high performers, a clear shift in behaviors was observed from the main to the PFL study. These students used a balanced strategy that combined information seeking and self-monitoring in the main study. They demonstrated better understanding and self-reliance; therefore, there was less use of the scaffolds provided for monitoring in the PFL study. The information seeking behavior to learn new domain content was a dominant activity pattern across both studies. A shift was also observed for low-performing students, from the classic suboptimal *Quiz-Edit-Quiz* strategy to more use of the query mechanism (monitoring), but the strategies they used did not progress enough to where they combined monitoring with effective information seeking behavior (RA) to learn the new domain, or to use the explanation mechanism (RE) to monitor their own performance when building their concept maps. More of the low performers came from the ITS and LBT groups, which did not receive metacognitive feedback during the learning phase.

We believe a more in-depth analysis of both student behaviors and additional performance metrics or assessments will more clearly reveal the underlying differences and the cause for these differences. Also, examining how these behaviors form and evolve over time may lead to a better understanding of the differences between groups and learners.

Lastly, this work has important implications toward the development of more intelligent learning environments. If the goal of these environments is to make students better prepared for future learning (PFL) on their own, it is important to design these environments so that they facilitate the shift from observations to emulation to internalization and self-reliance. One way to achieve this is to build in *adaptive metacognition* (e.g., [16]) into these learning environments. We hope more detailed causal analysis of the performance and behavior data will provide us with the information needed to start designing these environments.

Acknowledgments

This work has been supported by a Dept. of ED IES grant #R305H060089 and NSF REESE Award #0633856.

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