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# Promoting Self-Regulated Learning Skills in Agent-based Learning Environments

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**Abstract:** We have developed computer environments that support learning by teaching, concept mapping, scaffolding, and the use of self regulated learning (SRL) skills by social interactions with virtual agents. More specifically, students teach a computer agent, Betty, and can monitor her progress by asking her questions and getting her to take quizzes. The system provides SRL support via dialog-embedded prompts. Our primary goals have been to support learning in complex science domains and facilitate development of self-regulated learning skills. Our analyses have identified actions such as "asking queries" and "tracing explanations" as key self-regulation strategies that promote learning.
**Keywords:** learning by teaching, intelligent pedagogical agents, self regulated learning

## Introduction

We have developed computer-based learning environments that use the learning by teaching paradigm to help middle school students develop higher-order cognitive skills when learning in science and math domains [4][5][10]. To teach, one must gain a good understanding of the domain knowledge and then structure the knowledge in a form that they can present to others [2]. Preparing to teach is a self-directed and open-ended activity where one explores, integrates, and structures knowledge first for oneself, and then for others. Biswas, Schwartz, & Bransford [3] have reported that students preparing to teach felt that the responsibility to teach encouraged them to gain deeper understanding of the materials. Effective teaching also requires reflection through the explicit monitoring of how well students understand and use concepts. Studies have shown that tutors and teachers often reflect on their interactions with students during and after the teaching process in order to better prepare for future learning sessions [8]. We look upon teaching as a metacognitive, reflective, and iterative process with three main phases: decision-making, performing actions, and monitoring.

We have designed a teachable agent (TA) system called Betty's Brain, where students teach a computer agent using a well-structured visual representation [10]. Using their agent's performance (which is a function of how well it is taught) as a motivation, students learn for themselves to remediate the agent's knowledge, and, in this process, they learn better on their own. An important property of our TA environment is that students can monitor how their agents answer questions, and they can correct them when the agent makes mistakes. Since the agent's mistakes are directly related to what they have been taught by the student, our *learning-by-teaching* environments are well-suited to helping students become more knowledgeable of and responsible for their own cognition and reasoning. As a result, the students are likely to develop skills on *how to learn* and how to *prepare for future learning* [6]. We have hypothesized that working with Teachable Agents helps students better understand domain knowledge, and engage in a variety of productive learning strategies that promote organizing and reasoning with this

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knowledge. Furthermore, the activities involved in the teaching process helps the students monitor their own learning as they teach their agent.

In previous work we found that learning-by-teaching with metacognitive support helped students learn about river ecosystems, and also better prepared them for future learning on related topics [4]. We have recently turned our attention to analyses of students' behaviors as they teach Betty and create their concept maps. Such analyses are important because they shed light on students' underlying learning processes, and what kind of strategies they are bringing to this task [12].

In this paper, we discuss methodologies for deriving and analyzing students' behavior sequences as they interact with the system. We hypothesize that these behaviors reflect students' use of monitoring strategies as they learn for themselves and teach their agent. The data, collected in the form of log files that recorded students' activities, came from a study where 5$^{th}$ grade students first learned about river ecosystems. This was followed by a transfer phase, where the same students learned and taught about the land-based nitrogen cycle. We will discuss our methods for extracting the student activity sequences from system log files, and the role that context plays in analyzing and interpreting students' behaviors and strategies.

## 1. Learning by Teaching: Betty's Brain

The Betty's Brain system is illustrated in Figure 1. The teaching process is implemented as three primary activities: (1) *teach* Betty using a concept map representation [11]; (2) *query* Betty and find out how she answers the query; and (3) *quiz* Betty to check her performance on predefined sets of questions that are assigned by a Mentor agent. Betty uses qualitative reasoning methods to reason through chains of links [3] to answer questions. When asked, she explains her reasoning using text and animation schemes. Betty also provides feedback that reflects the students' teaching behaviors. The goal is to get the students to adopt more metacognitive strategies in their learning tasks [9]. 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.

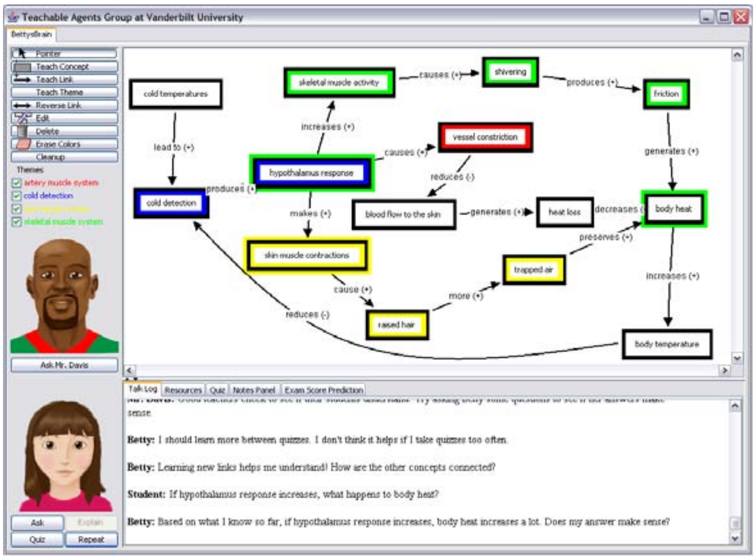


Figure 1: The Betty's Brain System

## 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 [6][7]. We have adopted 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

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strategies as new materials and strategies are learnt [1][13][15]. In conjunction with these higher level cognitive activities, social interactions and motivation also play an important role in the self-regulation process [14]. 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.

**Table 1.** Some Interactive Action Patterns and Betty's responses

| Regulation Goal | Pattern Description | Betty's Response | Mr. Davis' Response |
|---|---|---|---|
| Monitoring through Explanation | **Multiple requests for Betty to answer questions but no request for explanation** | Let's see, you have asked me a lot of questions, but you have not asked for my explanations lately. Please make me explain my answers so you will know if I really understand. | Without asking Betty to explain her answers, you may not know whether she really understands the chain of events that you have been trying to teach her. Click on the Explain button to see if she explains her answer correctly. |
| Self-Assessment | **Repeated quiz request with little updates to the map.** | Are you sure I understand what you taught me? Please ask me some questions to make sure I got it right. I won't take the quiz otherwise. Thanks for teaching me about rivers! | You have not taught Betty anything new. Please, spend some time teaching her new links and concepts and make sure she understands by asking her questions. Then she can take the quiz again. If you need help learning new things, check the resources. |
| Tracking Progress | **The most recent quiz score is significantly lower than the previous** | I would really like to do better. Please check the resources, teach me, and make sure I understand by asking me questions that are on the quiz. My explanation will help you find out why I am making mistakes in my answers. Also, be sure to check out the new tips from Mr. Davis. | Betty did well on the last quiz. What happened this time? Maybe you should try rereading some of the resources and asking Betty more questions so that you can make sure she understands the material. |
| Setting Learning Goals | **Betty is asked a question that she cannot answer for the second time** | I just don't know the relationships yet, maybe we should ask Mr. Davis what we need to learn. | I've seen this kind of difficultly with teaching some of my own students in the past. You should try looking for missing link connections or links that are in the wrong direction. |

Betty's persona in the SRL version incorporates metacognitive knowledge that she conveys to the students at appropriate times to help them develop and apply self regulation strategies [10]. We have identified a number of recurrent interactive action sequences, where metacognitive feedback might be useful for students. When the system detects such patterns, Betty provides suggestions on strategies the students may employ to improve their own understanding of the subject matter. Some of the triggering patterns related to goal setting, self assessment, and monitoring are illustrated in Table 1. Betty's responses combine motivational and self-regulation cues, whereas the Mentor, Mr. Davis' responses focus primarily on self regulation strategies. Mr. Davis' responses are also linked to the students' activity patterns.

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## 3. Experimental Design

Our participants were 56 students in two 5th grade science classrooms, taught by the same teacher. Students were assigned to one of three conditions using stratified random assignment based on standardized test scores. The students first created concept maps on river ecosystem concepts and causal relations during the main phase (seven 45-minute sessions). The system used in the different conditions varied on the type of scaffolding provided by the mentor agent and the Betty agent. After an eight-week delay, students participated in the transfer phase (five 45-minute sessions) in which they learned about a new domain, the land-based nitrogen cycle. All students used an identical system during the transfer phase. Students were also given a pre- and post-test before and after the main study intervention. The test contained both multiple choice questions as well as conceptual free response questions.

Students utilized one of three versions of the system: a) a learning by teaching (LBT) version in which students taught Betty, b) a self-regulated learning by teaching (SRL) version in which students taught Betty and received metacognitive prompts from Betty, and c) an intelligent coaching system (ICS) version in which students created a map for themselves with guidance from the mentor agent. In the teaching conditions, LBT and SRL, students were asked to teach Betty by creating the visual concept map to help her pass a test so she could join the high school science club. In the SRL version Betty also generated spontaneous responses that were driven the interactive patterns described in Table 1. The ICS version was used as our control condition. Students constructed a concept map to answer three sets of quiz questions. Students in this condition had access to the same teach, query, and quiz functions, but these activities were not presented in terms of teaching Betty. Instead students were told to build their own maps and learn for themselves. When students submitted their maps for the quizzes, Mr. Davis, the mentor agent, provided corrective feedback in the form of hints on how to correct errors [10]. For the transfer phase, all students used a stripped down version of the LBT system in which all of the feedback provided by Betty or the mentor were removed.

## 4. Student Learning Performance

We hypothesized that the learning by teaching conditions (LBT and SRL) would perform better than the ICS condition. Furthermore, our hope was that the students in the SRL condition with metacognitive prompting would do the best of all. The students' pre- and post-test scores by condition are listed in Table 2. We ran a mixed factor repeated measures ANOVA and paired sample t-tests for each group. The results show that overall students did not show significant gains on the multiple choice questions ($F_{1,46} = 3.33$, $p = .074$), but there were significant gains in the free response question scores ($F_{1,46} = 67.84$, $p < .001$). The indication here is that students in the two conditions that taught, i.e., the SRL and LBT conditions seemed to learn more than the students in the ICS condition, but the students in the SRL condition did not perform better than the students in the LBT condition.

**Table 2.** Pre- and Post-Test Scores by Group

| | Multiple Choice | | | | | Free Response | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Group | Pre | Post | *t* | *p* | *d* | Pre | Post | *t* | *p* | *d* |
| ICS | 5.2 (2.0) | 5.6 (1.8) | .63 | .54 | .21 | 4.2 (1.8) | 6.8 (2.5) | 3.95 | .001 | 1.19 |
| LBT | 3.8 (1.5) | 4.9 (2.0) | 1.42 | .18 | .62 | 3.7 (1.6) | 8.9 (3.7) | 6.22 | < .001 | 1.82 |
| SRL | 4.3 (1.7) | 4.5 (1.9) | 1.13 | .28 | .11 | 4.1 (2.9) | 9.2 (4.3) | 4.55 | < .001 | 1.39 |

We scored the students' final main and transfer concept maps to identify correct inclusions of concepts and links based on the resources that were provided to the students.

We added the number of correct concepts and links, and then added them to produce a total map score. The results for the main phase are summarized in Table 3. In the main phase, the SRL condition generated maps with significantly more correct concepts than the ICS ($p < .001$) and LBT ($p < .005$) conditions. The SRL condition also had more correct links than the ICS ($p = .001$) and LBT conditions ($p = 0.096$). These results suggest that the SRL prompts improved the students' learning. However, the LBT students also generated more correct maps than did the ICS students, which suggests an overall benefit for learning by teaching.

**Table 3. Concept map scores: main and transfer phase**

| Map Scores | ICS | LBT | SRL | *p* |
|---|---|---|---|---|
| Main study totals | 22.5 (1.6) | 25.7 (1.5) | 32.4 (1.5) | < .001 |
| Transfer study totals | 22.65 (13.7) | 31.8(12.0) | 32.56 (9.9) | < .05 |

[a] SRL > ICS, $p < .05$;

Students' transfer map scores provide an indicator of whether interacting with a given version of the system (i.e., ICS, LBT, or SRL) better prepared students to learn in a new domain without scaffolds and prompts. Students in the SRL condition had the highest map scores after the transfer phase, and scored significantly higher than the ICS students ($p < .05$). Interestingly, the LBT students' scores were now comparable to the SRL students. However, LBT students did not differ significantly from the other two groups.

We also checked if the students' final map scores related to posttest performance, controlling for pretest performance (i.e., using pretest scores as control variable for each partial correlation). Table 4 summarizes the results. The multiple choice results were weakly correlated with the concept map scores, but the free response questions showed strong correlations, especially with the links. This is a clear indication that learning causal links, i.e., relationships between concepts in the domain was the key to understanding the concepts of interdependence and balance in the ecosystem.

**Table 4. Correlation of main phase map scores and post test performance**

| Map Score | Posttest Multiple Choice | Posttest Free Response |
|---|---|---|
| **Correct Concepts** | -.16 | .27[a] |
| **Correct Links** | .12 | .50[b] |
| **Total Score** | .02 | .46[b] |

[a]$p < .06$;. [b]$p < .001$.

In summary, our interpretation is that working with Betty, especially with metacognitive prompts, helped students develop metacognitive strategies that supported their abilities to learn subsequently. We probe further by examining patterns of how students interacted with the system.

## 5. Analysis of Students Activity Sequences

All student activities in the Betty's Brain system was captured in log files. Example activities include, adding, deleting, or changing a concept or link to the concept map, viewing resources, and asking queries. With each activity, we also recorded additional information related to the activity. Since the log files captured a lot of information, we developed a set of filter programs to remove irrelevant information from the raw log files, and to represent the relevant information in a compact format that was suitable for further analysis. For the purpose of this study, we abstracted student activities on the system into five primary groups: (i) Edit Map (EM) – this includes activities for building and changing the concept maps, students could add, delete, and modify concepts and links, (ii) Ask Query (AQ) – students ask Betty (the Mentor in the ICS condition) to answer one queries, (iii) Quiz Taken (QT) – students request Betty to take a quiz generated by the Mentor (for the ICS condition students take the quiz for themselves), and the Mentor grades the quiz answers, (iv) Resource Access (RA) – students can access the resource page and read

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about information related to the science topic, (v) Request Explanation (RE) – after asking a question, the student can ask Betty (or the Mentor in the ICS condition) to explain how the answer to a particular question was derived. Explanations often involve multiple steps to generate an answer.

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,QT,EM,AQ,RA,EM,AQ,QT,EM,RA,EM,QT,RA,EM,QT,EM,QT,EM,QT,RA,AQ

We correlated student learning as measured by their scores on the free response questions of the post test as well as their final concept map scores. The goal of this study is two-fold: (1) to see if students' behavior patterns match self-regulated learning strategies that have been reported in the literature (e.g., [13][14]) and (2) to see how these behavior patterns varied between the different conditions.

Table 6 lists the mean and standard error of the frequency of student activities by condition over all of their main study sessions. The activities corresponding to the shaded rows showed significant differences between the conditions. The SRL and LBT conditions were significantly different from the ICS group in the frequency of their map editing activities, but there were no significant differences between the SRL and LBT conditions. For queries, SRL was significantly different from the ICS and LBT conditions, but there was no difference between the LBT and ICS conditions. However, when we looked at the proportion of repeated queries (i.e., one query immediately followed by another), the SRL group had a larger proportion than the LBT group and the LBT group had a larger proportion than the ICS group, and all of these differences were statistically significant. When it came to quizzes, the LBT group got Betty to take the quiz more often than the SRL and ICS groups, and the SRL group used the explanation feature significantly more than the other two conditions.

We correlated these frequency measures to students post test free response scores and their total map scores. These results are summarized in Table 7. Students who spent a greater portion of their time editing their maps or going through repeated sequences of quiz and editing behaviors scored lower on their post tests and had lower map scores. On the other hand, students who asked a greater proportion of queries and followed them up with a request for explanations did well in their post tests and generated higher quality concept maps in the main phase of the study. The use of queries and explanations implies an effort by the students to monitor their own learning by generating queries and checking if the answers make sense. Asking for and looking through explanations is a more detailed form of monitoring because it involves trying to understand and check on the correctness of chains of causal reasoning. In contrast, spending a large proportion of effort in creating and editing the concept map without reading resources and checking for correctness clearly demonstrates a suboptimal trial and error (or guess and check) approach to learning. The positive and negative correlations to post test and concept map scores bear this out.

Though these results are only correlational and not causal, they do indicate that the two learning by teaching conditions, and in particular the SRL condition was more likely to demonstrate behaviors that could be linked to self regulation learning strategies.

**Table 6: Comparison of the frequency of student activities by condition. Results of an ANCOVA controlling for pre-test free response**

| Map Quality | ICS | LBT | SRL | *F* | *MSE* | *p* |
|---|---|---|---|---|---|---|
| **Single Activities** | | | | | | |
| *Edit Map (EM)* | .66 (.02) | .48 (.02) | .41 (.02) | 24.49 | .26 | < .001 |
| *Resources (RA)* | .11 (.02) | .13 (.02) | .09 (.02) | 1.74 | .01 | .19 |
| *Queries (AQ)* | .07 (.02) | .12 (.01) | .22 (.01) | 26.56 | .09 | < .001 |
| *Quizzes (QT)* | .10 (.02) | .20 (.02) | .12 (.02) | 11.55 | .05 | < .001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Explanation (EX)* | .04 (.02) | .04 (.02) | .13 (.02) | 8.17 | .04 | .001 |
| **Query Sequences (AQ)** | | | | | | |
| *Edit Map (AQ, EM)* | .45 (.05) | 40 (.05 | .25 (.05) | 4.86 | .19 | .012 |
| *Resources (AQ, RA)* | .04 (.02) | .08 (.02) | .06 (.02) | 2.05 | .01 | .14 |
| *Queries (AQ, AQ)* | .15 (.03) | .18 (.03) | .33 (.02) | 14.54 | .16 | < .001 |
| *Quizzes (AQ, QT)* | .08 (.04) | .13 (.04) | .16 (.04) | 1.09 | .03 | .35 |
| *Explanation (AQ, EX)* | .14 (.04) | .17 (.04) | .18 (.04) | 0.21 | .21 | .81 |
| **Quiz Sequences (QT)** | | | | | | |
| *Edit Map (QT, EM)* | .70 (.05) | .48 (.05) | .34 (.05) | 12.41 | .54 | < .001 |
| ***Resources (QT, RA)*** | .15 (.03) | .21 (.03) | .07 (.03) | 5.69 | .08 | .006 |
| ***Queries (QT, AQ)*** | .07 (.03) | .07 (.03) | .40 (.03) | 38.86 | .61 | < .001 |
| ***Quizzes (QT, QT)*** | .04 (.03) | .20 (.03) | .15 (.03) | 7.73 | .10 | .001 |
| ***Explanation (QT, EX)*** | .02 (.01) | .03 (.01) | .02 (.01) | .31 | .00 | .73 |

**Table 7: How student activities related to post-test free response score and final map quality scores**

| Behaviors | Posttest Free Response | Total Map Score |
|---|---|---|
| **Single Activities** | | |
| ***Edit Map (EM)*** | -.33[a] | -.52[c] |
| ***Resources (RA)*** | .23 | .06 |
| ***Queries (AQ)*** | .02 | .49[c] |
| ***Quizzes (QT)*** | .21 | .04 |
| ***Explanation (EX)*** | .26[a] | .37[b] |
| **Query Sequences** | | |
| ***Edit Map (AQ, EM)*** | -.10 | -.26 |
| ***Resources (AQ, RA)*** | .22 | .25 |
| ***Queries (AQ, AQ)*** | .04 | .23 |
| ***Quizzes (AQ, QT)*** | -.04 | .12 |
| ***Explanation (AQ, EX)*** | .32[a] | .35[a] |
| **Quiz Sequences** | | |
| ***Edit Map (QT, EM)*** | -.23 | -.54[c] |
| ***Resources (QT, RA)*** | .12 | .11 |
| ***Queries (QT, QA)*** | -.01 | .47[c] |
| ***Quizzes (QT, QT)*** | .52[c] | .31[a] |
| ***Explanation (QT, EX)*** | -.26 | -.02 |

[a]$p < .05$. [b]$p < .01$. [c]$p < .001$.

## 6. Discussion and Conclusions

The Betty's Brain system leverages the benefits of learning by teaching and concept mapping to facilitate students' science learning. We have hypothesized that working with Betty is helpful because it supports students' engagement and promotes educationally productive cognitive and metacognitive processes. The results reported here and prior research, appear to support this hypothesis. Students who utilized learning by teaching versions of our system (i.e., the LBT and SRL versions) constructed better concept maps that captured causal relationships between entities in a river ecosystem than were students who used the non-teaching ICS version of the system. Moreover, students' performance was strongest when we explicitly supported their use of self-regulated learning strategies by having Betty model and prompt for such behaviors. Not only did these students do well in the main phase of our study when the prompts were present, they also continued to outperform other groups in the transfer phase when the prompts were removed. Furthermore, the students' ability to create better concept maps correlated well with post test free response questions.

Although assessments of learning outcomes were in agreement with our hypotheses, it was also critical to explore students' actual behaviors during the teaching and learning process. Did students in the LBT and SRL conditions perform well because they were engaged in productive cognitive and metacognitive behaviors? Our preliminary correlation analysis demonstrates that student in the LBT and SRL conditions did demonstrate more sophisticated monitoring behaviors. On the other hand, the ICS students seemed to use more trial and error approaches.

In the future, we will adopt a more novel method for examining students' behavior sequences by generating hidden Markov Models (HMMs) from their activity sequences [9]. This approach will allow us to go beyond frequency counts and proportions of individual behaviors, and instead examine how particular behaviors are interrelated in more global patterns. This analysis also gives a better sense of the context in which specific actions occur. For example, students might access the text resources for a variety of purposes, such as to learn new information or to double-check their answer to a quiz question.

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