Case Studies in Learning by Teaching
Behavioral Differences in Directed versus Guided Learning

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Abstract

Our studies with Betty's Brain, a learning by teaching environment, have shown that the system is effective in helping fifth grade students gain a good understanding of river ecosystem concepts. The use of self-regulation strategies demonstrated that the learning gains transferred to new domains where students worked without the self-regulation system. This paper analyzes the log files of the student activities to determine which activities in the learning environment contribute to the students developing metacognitive strategies that contribute to their preparation for future learning.

Keywords: learning by teaching; self-regulation strategies; teachable agents; behavior log analysis.

Introduction

An important challenge for computer-based learning environments is to demonstrate that they develop students' abilities to learn, even after they leave the computer environment (Anderson et al., 1995). The cognitive science and education literature have established that understanding and transfer are greatly aided by constructivist, exploratory, and anchored learning environments (Bransford et al., 2000). Relevant social interactions can add motivation and also enhance effective learning (Soller, 2001).

We have adopted the learning by teaching paradigm (Palincsar et al., 1984) as the basis for designing learning environments. Researchers (Bargh et al., 1980; Biswas et al., 2001) have shown that people learn more when they teach others as opposed to when they prepare to take tests themselves. Teaching involves a number of constructivist activities. Teachers prepare and organize their knowledge in anticipation of the needs of their students. They provide explanations and demonstrations during teaching and reflect on the questions and feedback they receive from the students. Effective teaching also requires the explicit monitoring of students during and after the teaching process. This helps teachers to evaluate their own understanding and the methods they have used to convey this understanding to students (Artzt et al., 1999).

We have implemented a software agent, Betty's Brain, that students can teach using concept maps (Novak, 1996). Once taught, *Betty* uses qualitative reasoning methods (Forbus, 1984) to answer questions. Students reflect on Betty's answers, revise their own knowledge, and make corresponding changes to the concept map to teach Betty better. Details of the Betty's Brain system, and experiments that we have conducted with this system are presented elsewhere (Biswas et al., 2004a, 2004b; Davis et al., 2003; Leelawong et al., 2002). Our experiments in fifth grade science classrooms showed that learning by teaching with self-regulated learning (SRL) (Zimmerman, 1989) led to better transfer than situations where the students were taught by a pedagogical agent (Johnson et al., 2000).

The encouraging results from the Betty's Brain experiments prompted us to take a more detailed look at how students used the different versions of the system, especially the feedback they got from Betty and the mentor. This called for more in-depth analysis of student activities and behaviors that can be attributed to the self-regulation strategies. In this paper, we perform a case analysis of the log files of student activities during the main and transfer studies. The next section briefly outlines the teachable agent system and the experimental study we conducted in the fifth grade science classrooms.

Betty's Brain

The main interface to the Betty's Brain system is shown in Figure 1. This interface implements three primary components of teaching: (i) *teach* Betty using a concept map, (ii) *query* Betty to see how much she has understood, and (iii) *quiz* Betty to see how well prepared she is to take the test, which will gain her admittance to the Science club. These components model the primary constructivist activities involved in various phases of the teaching process: *preparation*, *teaching*, and *monitoring* (Colton et al., 1993).

Students teach Betty about entities in river ecosystems, e.g., fish, algae, macroinvertebrates, waste, and bacteria, and the relations between these entities, e.g., fish consume dissolved oxygen, algae replenish it, waste is consumed by bacteria to produce nutrients, and nutrients help algae grow. Betty is equipped to reason about the knowledge that she has been taught to answer questions like *"if macroinvertebrates increase what happens to bacteria?"* She uses qualitative reasoning methods (Leelawong et al., 2001) to make inferences through chains of links. She determines that on the one hand macroinvertebrates create more waste and waste feeds bacteria, but on the other hand, macroinvertebrates also consume algae and dissolved oxygen, and, therefore, there is less oxygen for bacteria to breathe, and this inhibits their growth.

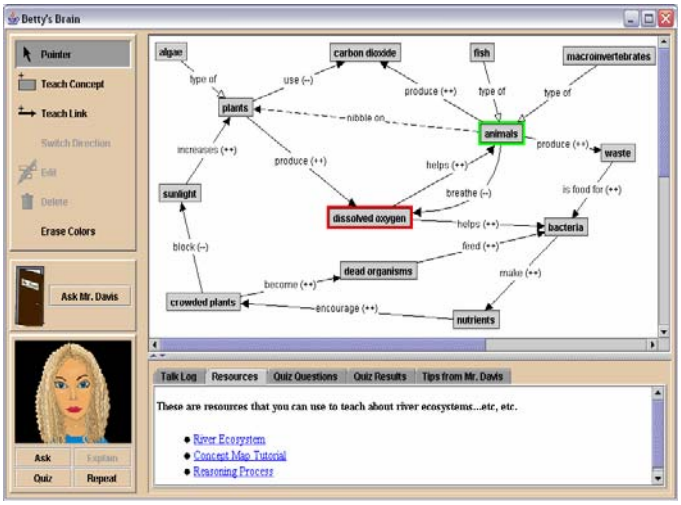

Figure 1: Betty's Brain Interface

Betty presents her answers and explanations for her derivations using text, speech, and animation. Students query Betty or get her to take quizzes to see how much she has learnt. Indirectly, this helps them reflect on how much they themselves know. Since students using the system are novices in domain knowledge and teaching practices, we provide online resources that contain all the relevant material that students need to teach Betty. The students and Betty also have access to a mentor agent, Mr. Davis, who can answer a variety of questions when asked. The feedback provided along with the students' motivation to help Betty, results in their revising and adding to the concept maps to help Betty improve her performance on the quizzes.

Our experimental study included 54 students in a 5th grade science classroom in Southeastern USA. The experiment compared three different versions of the system: (i) Intelligent Tutoring Systems (ITS), (ii) Learning by Teaching (LBT), and (iii) LBT with Self Regulated Learning (SRL). The students were divided equally into the three groups using a stratified random sampling method. All three groups had access to identical resources on river ecosystems, the same quiz questions, and similar access to the query feature and the mentor agent, Mr. Davis.

The ITS group was taught by the mentor agent, Mr. Davis. He asked students to construct a concept map to answer three sets of quiz questions that were designed to meet science curriculum guidelines. When students submitted their maps for a quiz, Mr. Davis provided directed feedback to help them correct errors in the quiz.

The LBT and SRL groups were told to teach Betty and help her pass a test so she could become a member of the school Science club. In the LBT system, students could query Betty and ask her to take a quiz. Mr. Davis' feedback to Betty after she took the quiz, was the same as in the ITS system.

The SRL groups Betty persona was redesigned to incorporate self-regulation learning strategies like monitoring, assessing, goal setting, seeking assistance, and reflecting on feedback. Betty's behavior illustrated the self-regulation strategies in four ways. First, like a good student, Betty reflected on what she was taught, and sometimes generated spontaneous responses. For example, when Betty had been taught a causal path with multiple links, she would say, "*O.k. I think I know how this works. …*" and go on to reason with the path and explain her reasoning. Second, to get students to monitor Betty's and their own learning, she would encourage them to ask her questions. Betty refused to take the quiz for the first time till she had been taught a few causal links, and been asked a causal query for which she could generate an answer. Third, if her student-teacher did not periodically ask her questions, Betty would refuse to take the quiz stating: "*I do not feel prepared to take a quiz. I don't understand enough about causal relationships in the river. Please ask me some causal questions to see if I understand. Mr. Davis can help you learn more about being a good teacher.*" Last, unlike the other two groups, the SRL students were not offered direct feedback on how to correct their concept maps by the mentor. Mr. Davis provided more general feedback about reasoning through chains of events to derive answers to questions.

Our experimental results showed that students in all three groups learnt the same amount in the main study that included five 45 minute sessions with their respective systems (Biswas et al., 2004b). Figure 2 shows the average quiz performance by group at the end of every session (maximum score = 15). All three groups showed improved performance with time. On the average, the ITS and LBT groups had higher quiz scores than the SRL group, but the differences were not statistically significant. It is interesting to note that the SRL group started slowly, but performed better from session 3 on.

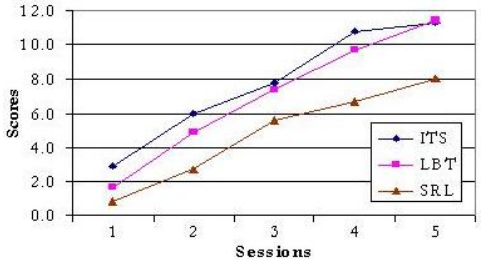

Figure 2: Average Quiz scores at the end of each session (max score = 15)

Three weeks after the main test we conducted a *preparation for future learning transfer test*, where students were asked to construct a concept map and answer questions about the land-based nitrogen cycle. The nitrogen cycle was not taught in class so they had to learn from resources provided during the transfer task. All three groups used a version of the system where the mentor agent graded the quiz answers, but provided no additional help.

Table 1 summarizes the results of the preparation for future learning test. The SRL and LBT groups had significantly more valid links than the ITS group, and the LBT groups had significantly more valid concepts than the ITS group. Even though the SRL group had more expert links than the ITS and LBT groups and more expert concepts than the ITS group, these differences were not statistically significant. Overall, the learning by teaching groups outperformed the ITS group,

but the effects of teaching self-regulation strategies on the students' abilities to learn a new domain are not clear from these results. The SRL group did better than the LBT group in terms of expert and valid links, and the LBT group had more valid concepts than the SRL group, but none of these results are statistically significant.

Table 1: Results of the Transfer Study

Student Map Included:	SRL Mean (sd)	LBT Mean (sd)	ITS Mean (sd)
Expert Concepts	4.6 (.7)	4.6 (.4)	3.5 (.4)
Expert Links	0.6 (.3)	0.3 (.2)	0.3 (.1)
Valid Concepts	7.7 (3.0)	8.3[a] (3.2)	5.3 (3.0)
Valid Links	6.4[a] (1.0)	6.1[a] (1.0)	3.3 (.7)

[a] Significantly greater than ITS, $p < .05$

To get a better understanding of these results, we have performed a more detailed analysis of the students' activities that was logged by the Betty's Brain system.

Analysis of Log Data

Student activities recorded were classified into the following categories: (i) editing the concept map (i.e., teaching Betty), (ii) reading resources to learn more about river ecosystems, (iii) asking queries of Betty, (iv) asking Betty to explain her answer to a query, (v) asking Betty to take a quiz, and (vi) asking the mentor agent for help on a specific topic. Each of these activities is directly associated with buttons on the system interface (see Fig. 1). For each category, more specific information was also recorded. For example, if a student created a new concept, the name of the concept was recorded in the log file. The period of time students spent on each activity was also recorded.

Hard copies of the log files were analyzed by the researchers and a summary log file that contained the activity name, specific information about the activity, and time spent on the activity was created in tabular form. The case study summaries generated from the log files to study qualitative differences in students' use of the system are described next.

Case Study Analysis

For the case studies, we picked two subjects each from the three groups. One of the subjects in each group performed well, i.e., they created maps that answered all of the quiz questions correctly. The second subject picked did not do as well, i.e., some of their quiz answers were incorrect. Within each category we picked randomly. The names in the case study are not the real names of participants.

The two ITS participants were Josh and Sally. Josh constructed a map that correctly answered all of the questions on the quizzes, while Sally's behavior was typical of many participants in the ITS condition. She could not construct a map that answered all of the quiz questions.

Josh began by checking the quiz questions, and then read the online resources to get information about river ecosystems. When constructing the concept map, he kept going back to the quiz questions to determine if he was selecting the entities that appeared there. From the second session on he began a pattern of taking a quiz, checking quiz results and mentor feedback, reading the resources, editing the map again, and taking the quiz to check the effect of his changes on his quiz performance. Occasionally he asked causal questions and traced the answer by asking Betty to explain her answer. By the end of his third session, he had successfully constructed a map that answered all of the questions on all three quizzes. Overall, he did read the resources periodically, but mostly used the quiz, mentor feedback, edit, and quiz again feature to build his concept map.

Sally used the quiz-edit-quiz pattern of behavior but unlike Josh did not pay much attention to the mentor feedback, nor did she read the resources much. Only toward then end of the session 4, she began to use a strategy similar to Josh's: she edited her map, took a quiz, checked feedback, read the resources, asked a question to see how her map answered it, checked resources again, and took the quiz to check her performance. In her fifth session, Sally went back to the quiz, edit, quiz strategy, and was unable to complete the quizzes. She had 6 out 10 correct on quiz 1 and 2, and did not attempt quiz 3.

The LBT logs analyzed are those of Rose and Devon. Rose demonstrated an effective strategy for finding information and teaching Betty, and was successful in getting her to pass all of her quizzes. Devon's pattern of behavior during the five sessions was similar to Sally's in the ITS condition. He could not get Betty to pass all three quizzes.

Rose's initial concept map had more descriptive information than causal and Betty could not answer any quiz question. After this, she went through a process of reading the resources and teaching Betty about causal relations. Betty still could not answer any of the quiz questions. Rose used the quiz questions and the mentor's feedback to determine what needed to be in the map, and taught Betty by editing her concept map. This pattern of sending Betty to take a quiz, checking quiz questions and feedback, and then editing the concept map continued till she succeeded in getting Betty to answer all the quiz questions correctly.

Devon also began by teaching Betty descriptive information and Betty could not answer any of the questions. He looked at the quiz questions and mentor feedback, and then began teaching her causal relations. He checked the resources but spent very little time reading them. Devon mostly followed the quiz, edit, quiz pattern and mainly taught Betty concepts that were on the quiz. Most of his queries to Betty were descriptive questions, and he could not get Betty to pass all three quizzes.

Rose and Devon parallel Josh's and Sally's patterns of behavior with very similar outcomes. Note that feedback from the mentor was the same for the two systems, and, Rose and Josh used them in the same way – check the concept map errors pointed out by the mentor, read the resources, and correct the errors. Sally and Devon did not use the mentor feedback well, they spent very little time reading the resources, and their quiz performances were not as good.

The SRL participants selected were Ashley and Sarah. Ashley successfully taught Betty to pass all three quizzes, and demonstrated an effective strategy for finding information while teaching Betty. Sarah failed to identify all of the concepts that Betty needed to learn in order to pass the quizzes.

Note the SRL Betty discouraged use of the quiz, edit, quiz pattern. She refused to take quizzes if she hadn't been taught enough causal relations, and if she was not asked causal queries to see if she was prepared. This behavior encouraged the SRL participants to ask Betty more causal questions.

Ashley began by teaching Betty four concepts and corresponding causal links but when she asked Betty to take a quiz, she refused. When Ashley succeeded in getting Betty to take a quiz, she used the quiz questions to find relevant concepts. From session 2 on, Ashley began a pattern of teaching, querying Betty, checking the resources for a couple of minutes, and then sending Betty to take a quiz. Toward the end, Ashley didn't need to check the resources much, and at the end of session 4, Betty answered all questions correctly.

Sarah was not as successful as Ashley. She started off teaching Betty about fish and plants then got stuck and asked the mentor for help. However, she did not get into the details of the help topics. In the sessions that followed, Sarah kept trying the quiz/edit/quiz strategy, but Betty refused most of the quiz requests. Sarah persisted and Betty would eventually relent. She asked few causal queries, and failed to teach Betty to pass the three quizzes.

Summary of Log Analysis

A number of interesting patterns emerge from the case study analysis. Like our previous study (Biswas et al, 2004a), it is clear that participants who primarily used the quiz/edit/quiz pattern did not do as well on the quizzes as those participants who spent blocks of time reading the resources, querying Betty, and then looking through her explanations. Further, those who seemed to look at the resources for very short time periods, primarily to seek information that they had been directed by the mentor, did not perform as well.

The quiz questions turned out to be the important scaffold that helped students realize the importance of causal relations. Independent of group, students' initial concept maps primarily had descriptive links. Betty's inability to answer quiz questions, and in some cases her refusal to take the quiz (SRL group) made the students realize the differences between descriptive and causal links. Fig. 3 shows that on the average all three groups made the same number of quiz requests initially, but in later sessions, the LBT and SRL groups used the quiz feature more than the ITS group (only the pairwise difference between the LBT and ITS groups was significant based on Tukey HSD, $p < .05$).

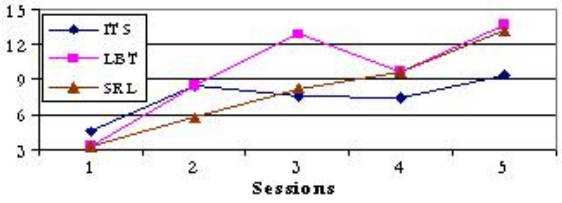

Figure 3: Quiz Requests per Session

Many students did not realize the importance of queries and explanations as a mechanism for (i) debugging their concept maps, and (ii) understanding reasoning through chains of links. The SRL group was forced to ask queries, and this made them realize the importance of causal links in their maps. This is clearly illustrated in the plots shown in Fig. 4. From session 3 on, the SRL group asked more queries than the other two groups, and a large percentage of their queries were causal (all pairwise differences were significant using Tukey's HSD, $p < .05$). However, the number of explanation requests after a query was about $1/4^{th}$ of total number of queries asked. This may be an indication that the explanation mechanism was not used as much as it should have been to understand and debug the concept map structure, especially in the early stages of the teaching and learning process.

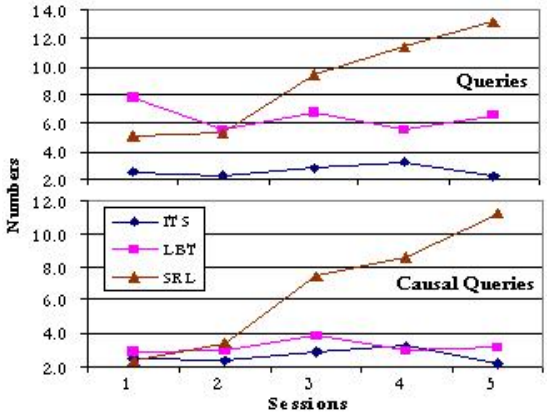

Figure 4: Average Numbers of Queries per Session

Figure 5, shows that the groups did not differ much in the number of resource requests. Overall, though the SRL group seems to have spent much less time reading the resources than the other two groups. This can be attributed to what happened in the first two sessions. The SRL Betty refused to take a quiz until the students had created a map with at least four concepts and two causal links. This was unlike the other two groups where Betty took a quiz whenever she was asked, and, therefore, students had access to the quiz questions and directed mentor feedback from the time they took the first quiz. It took most SRL students through the middle of the second session to figure out what causal links were. We discuss this issue in greater detail in the next section.

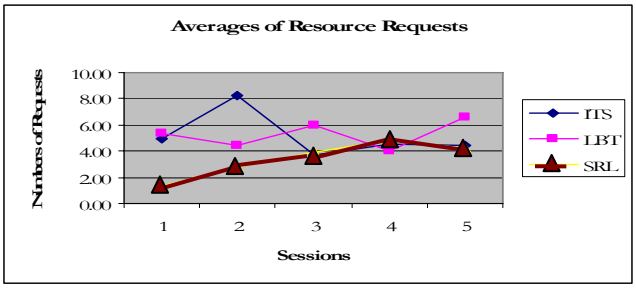

Figure 5: Average number of resource requests

Implications on Learning and Transfer

If quiz scores are used as the sole measure of learning performance (Fig. 2, at the end of session 5, mean score for ITS group = 11.6, LBT group = 11.7, and SRL group = 8.0; pairwise comparison of means using Tukey's HSD not significant

at the .05 confidence level), one may come to the conclusion that directed learning approaches are more effective than guided learning environments. A dominant behavior observed in the ITS and LBT groups was the quiz/edit/quiz pattern, with the mentor's directed feedback being employed to make local changes to the concept map till the quiz answers were correct. Students who took this approach used the resources, mentor feedback, and the query and explanation mechanisms sparingly could not complete all three quizzes in the main study. It is very likely that this group of students did not develop a good overall understanding of the river ecosystem domain, nor did they pick up the self regulation strategies required to become good learners.

Figs. 2-5 also established that it took the SRL group more time before they started using the quiz and query features. As discussed earlier, this can be attributed to self regulation features built into the system. Betty refused to take a quiz till the students had (i) taught her at least four concepts and two causal links, and (ii) asked her at least one causal query to see if she understood what she had been taught. When the SRL students asked Mr. Davis for help, his initial feedback to them was general: read the resources, find important concepts, and use this information to build the concept map to teach Betty. However, the students did not find this to be very useful, and as is evident from Figs. 3-5 the SRL students did not achieve much in the first two sessions. If anything, they learnt some about self-regulation learning strategies.

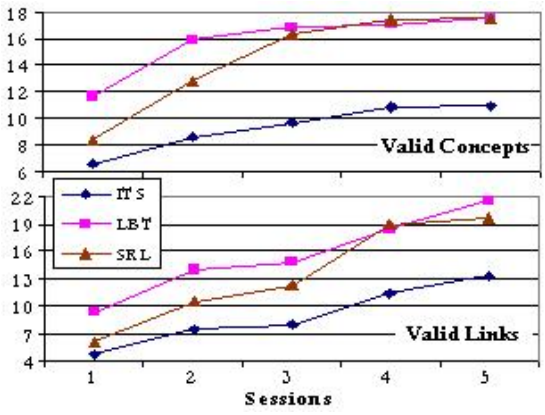

Figure 6: Valid Concepts & Links in the Students' Maps

We believe that the focus on SRL strategies may have produced positive long-reaching outcomes in terms of the students' abilities to learn new domains. Toward the end of the second session, the SRL students realized the importance of causal links and the query feature. After the students asked Betty a causal query, she agreed to take the quiz. Access to the quiz questions provided the reinforcement and direction this group needed to learn about river ecosystems, and create the maps that improved Betty's quiz performances significantly. However, because of the late start, they were not able to catch up with the ITS and LBT groups.

When one looks at the quality of the concept maps (see Figure 6), the LBT and SRL groups had more valid concepts than the ITS group (pairwise comparisons were significant using Tukey HSD, $p < .05$) and the LBT group had more valid links than the ITS group (pairwise comparison significant using Tukey HSD, $p < .05$). Not surprisingly, more than 80% of the concepts in ITS group maps were expert concepts. For the LBT and SRL groups, only 53% and 50%, respectively, of the valid concepts were expert concepts. These percentages were similar when one compares the percentage of expert links in the student maps. A concept or link was termed valid by our raters, if they appeared in the expert concept map (created by the science teacher), or if they were considered to be relevant to the river ecosystem domain These numbers clearly indicate that the ITS groups focus was mainly on the mentor feedback, and they made very little effort to learn on their own. The two learning by teaching groups showed greater desire for learning on their own, perhaps because of their motivation to teach Betty and get her to succeed on the quiz questions.

Even though the SRL group did not illustrate significantly better performance in the transfer test discussed in section 2, this group, using their learnt self regulation strategies, demonstrated better learning characteristics in the transfer test than the other two groups. This is clearly illustrated in Table 2. There was no mentor feedback to help the learning process in the transfer study. The only feedback the mentor provided was whether Betty's quiz answers were right or wrong. The quizzes did not have the scaffolding structure of the main study. In the main study the quiz questions helped students progressively build the concept map structure to the point where the map contained most of the information to answer the main question in each quiz. The three quiz questions in the transfer study were the main questions. There were no intermediate questions that gave students clues about concepts and links they needed to add to the concept map.

Table 2: Log Analysis of the 2nd Session of the Transfer Test

Activity	ITS Mean (sd)	LBT Mean (sd)	SRL Mean (sd)
Numbers of Resource Requests	2.8 (1.4)	9.3 [a] (4.7)	8.7 [a] (3.5)
Time Spent Accessing Resources (minutes)	8:31 (4:2)	8:59 (4:4)	13:33 [a,b] (4:5)
Numbers of Causal Queries (Times)	0.8 (0.2)	1.2 (0.7)	2.4 [a,b] (0.7)
Numbers of Explanation Requests (Times)	0.2 (0.1)	0.6 (0.3)	0.7 [a] (0.2)
Numbers of Quiz Requests (Times)	3.8 (3.5)	5.6 (3.1)	6.2 (3.5)

[a] Significantly greater than ITS, $p < .05$
[b] Significantly greater than LBT, $p < .05$

It is clear from the results of Table 2 that the SRL group outperformed the ITS group in all but one category, i.e., number of quiz requests, and they also outperformed the LBT group in two very important categories: time spent reading resources and the number of causal queries asked (all significant at the $p < 0.05$ level). These results show that the SRL group developed better learning and debugging strategies than both the LBT and ITS groups, a clear indication that the SRL strategies helped students develop the necessary attributes for future learning in new domains. Perhaps, if the students were

given more time in the transfer study, the SRL group would have truly outperformed the other two groups in terms of the performance measures in table 2.

Conclusions

In conclusion, the two directed learning groups, ITS and SRL did well in terms of incorporating mentor feedback and improving their quiz performances. The SRL group did not show immediate performance gains, but outperformed the other groups in their preparation for future learning. The LBT group was intermediate; they used the directed feedback from the mentor to improve immediate performance, but like the SRL group the social interactions with Betty motivated them to learn on their won so that they could teach her better.

Table 3: Summary Characteristics

	ITS	LBT	SRL
Immediate performance	√	√	×
Motivation to learn	×	√	√
Preparation for future learning	×	×	√

This study demonstrates that the learning by teaching environments outperform the environment in which the student is taught. The analysis has informed us that we need to refine the SRL strategies to give students better guidance on how to learn and debug their knowledge early in the learning process. The new version of Betty is more insistent on students using the query and explanation feature. She also makes sure that students focus on chains of links, and keeps more detailed accounts of how her quiz performances change with time. A new study run in Spring 2005 will determine whether the new system helps students become more efficient learners.

Acknowledgments

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