Effective User Interface Design for Teachable Agent Systems

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ABSTRACT

This paper discusses the improvements to the user interface of a system designed to promote learning through teaching. The system is an intelligent agent developed at Vanderbilt University for studying the learning by teaching paradigm and is called Betty's Brain. In the Betty's Brain system, students teach a computer agent, named Betty, by creating a concept map using a visual interface. Students themselves learn through the process of instructing the agent. Fifth grade students in Nashville public schools are participating in studies on this system. In this work, we analyze the interface components of Betty's Brain that enable the user to organize and input problem solving knowledge about a domain for the purpose of instructing the intelligent agent. The existing interface was also streamlined. We then conducted a comparative user study to evaluate our changes to the interface. Both qualitative and quantitative improvements in the user's performance are reported. These results should provide useful guidance for designers of the next generation of learning by teaching systems.

Keywords
Teachable Agents, learning by teaching, human computer interaction, user interface design.

1. INTRODUCTION

The idea that teaching others is a powerful way to learn is both intuitively compelling, and one that has garnered support in the research literature. For example, it was found that people who prepared to teach others to take a quiz on a passage learned the passage better than those who prepared to take the quiz themselves [1]. The literature on tutoring suggests a similar conclusion in that tutors have been shown to benefit as much from tutoring as their tutees [2, 3]. Biswas et al. [4] report that students preparing to teach made statements about how the responsibility to teach forced them to gain deeper understanding of the materials; other students focused on the importance of having a clear conceptual organization of the materials.

The Teachable Agents group at Vanderbilt University [5, 12, 15] has built an environment where students can explicitly teach and directly receive feedback about their teaching through interactions with a computer agent. In this environment, called *Betty's Brain*, students learn by explicitly teaching computer agents to solve problems and answer questions with cause and effect structures in a variety of scientific domains. The effectiveness of this environment in producing learning-related outcomes has been reported in [5, 14].

This paper focuses on the user interface components of a Teachable Agent system. In Davis et al. [5], the main features of the user interface were described. This paper represents the first refinement of that design. We describe the interface components of the *Betty's Brain* system that enables a user to organize and input problem solving knowledge about a domain for the purpose of *instructing* an intelligent agent. We then discuss refinements made to the system. We conducted a set of user studies to evaluate these modifications and report on them here.

2. BACKGROUND

An automated learning by teaching system requires a representation scheme for students to create their knowledge structure as a part of the teaching process. Since the primary users are middle-school students solving complex problems, this representation has to be intuitive but sufficiently expressive to help these students create, organize, and analyze their problem solving ideas. A widely accepted technique for constructing knowledge is the concept map [6, 7].

Concept maps provide a mechanism for structuring and organizing knowledge into hierarchies, and allow the analysis of phenomena such as cause-effect relations [6, 8, 9, 10]. Moreover, an intelligent software agent based on concept maps can easily employ reasoning and explanation mechanisms that students can easily relate to. Thus the concept map provides an excellent representation that serves as the interface between the student and the teachable agent.

2.1 The Concept Map

A concept map is a collection of concepts and relationships between these concepts. It is also a mechanism for representing domain knowledge [6]. A partial concept map in the domain of river ecosystems is shown in Figure 1. The labeled boxes correspond to entities (the labels are entity names), and the labeled links correspond to relations. The arrow indicates the direction of the relation, and its name appears by the arrow. The parenthesized phrase indicates the relation type.

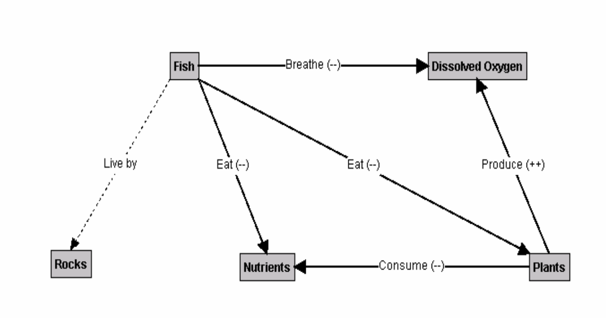


Figure 1: A partial concept map.

In our environment, concepts are **entities** that are of interest in the domain of study. For example, common entities in a river ecosystem are fish, plants, bacteria, dissolved oxygen, carbon dioxide, algae, and waste. Relations are unidirectional, binary links connecting two entities. They help to categorize groups of objects or express interactions among them.

In the current implementation of domain knowledge, such as for a river ecosystem, students can use three kinds of relations, (i) **cause-effect**, (ii) **descriptive**, and (iii) **type-of** relations to build a concept map. The primary relation students use to describe relations between entities is the causal (cause-and-effect) relation, such as "Fish eat Plants" and "Plants produce Dissolved oxygen". The causal relations are further qualified by **increase** ('++') and **decrease** ('--') labels. For example, "eat" implies a decrease relation, and "produce" an increase. Therefore, an introduction of more fish into the ecosystem causes a decrease in plants, but an increase in plants causes an increase in oxygen.

The descriptive relation is similar to the cause-effect relation. It also expresses a dependency, but the change in one entity does not cause a change in the other entity. For example, consider the relation "Fish live by Rocks". In this case, the "live by" relation is categorized as a descriptive relation. Fish use rocks, but an increase or decrease in fish does not directly change the amount of rocks. More complex forms of the "descriptive" relation, e.g., "Plants need Sunlight to produce Dissolved Oxygen" have not yet been implemented in Betty's Brain.

Type-of relations let students establish class structures to organize the domain knowledge. Consider an example where students deal with a variety of fish, such as trout, bass, blue gill, and catfish. All of these fish types breathe dissolved oxygen and eat plants. To simplify the knowledge construction process, students can first create the entity "Fish", and express the "Fish eat Plants" and "Fish breathe Dissolved oxygen" relations. Then, they can create individual fish entities, such as "trout" and "bass", and link them to the "Fish" entity using "type-of" links. All relations associated with entity "Fish" are inherited by these individual types unless they are over-ridden by more specific links [11].

2.2 Description of Betty's Brain

This section presents the user interface as described by Davis et al. [5]. Figure 2 illustrates the Betty's Brain interface. The system possesses multimedia capabilities. Students use a graphical drag and drop interface to create and modify their concept maps. When queried, Betty can provide explanations for how she derives her answers, and simultaneously depict the derivation process on the concept map by animation. The interface of Betty's Brain is implemented in Java with Java Swing components. In the sections below, we describe the software's three modes: TEACH, QUERY and QUIZ.

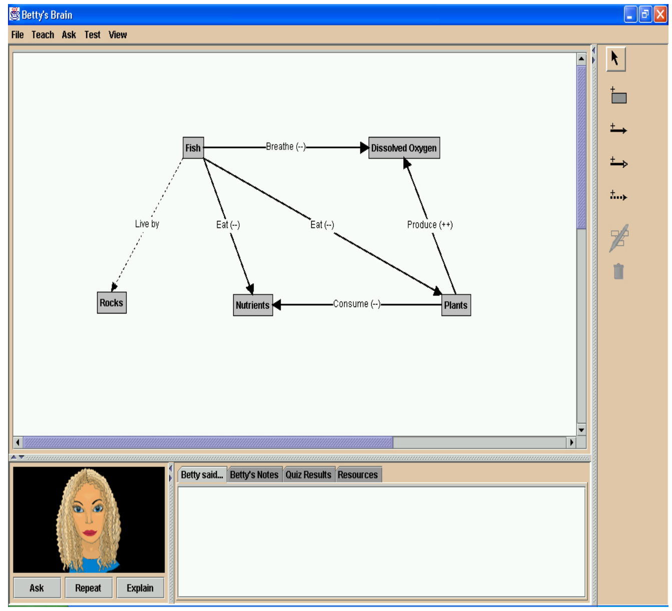


Figure 2: Existing Betty's Brain Interface.

TEACH Betty. Students teach Betty by means of a concept map interface. Figure 2 displays an example of a concept map used to teach Betty about the river ecosystem. The map shown is not totally accurate or complete.

QUERY Betty. Students are able to query Betty about what they have taught her. Currently, Betty has templates for two question types:

What will happen to concept A when we increase/decrease concept B?

Tell me what you know about concept A.

To answer questions, Betty uses a simple chaining procedure to deduce the relationship between a set of connected concepts. After Betty answers a question, the student can then ask her to explain how she derived her answer. Betty verbally explains her answer while simultaneously animating the concept map.

QUIZ Betty. During the quiz phase, students observe Betty's responses to a set of pre-scripted questions. The teaching expert informs Betty (and the student) if Betty's answers are right or wrong. The teaching expert also gives hints for each question to help the student debug errors in the concept map they have created. Currently, the system implements three levels of hinting, from suggesting that the student read a section of the resource materials to directly telling the student how to correct the concept or link in the concept map.

3. AN ENHANCED INTERFACE FOR THE TEACHABLE AGENTS SYSTEM

Based on a study conducted in the Nashville Metro School system and reported in Davis et al. [5], we felt that the user interface needed improvement. This data suggested that students should be more focused on domain knowledge rather than on specifics of the interface. The cognitive load involved in operating the interface should be minimized.

Figure 3 displays the enhanced interface for the Teachable Agents system, *Betty's Brain*. The changes focused on making the system easier to use for novices. Our goal was to make the interface self-explanatory so that the users found it easy to learn the interface with minimal amount of training.

The changes made to the interface can be categorized broadly as dealing with the visual and the cognitive aspects of the interface. Visual aspects of the interface deal with its aesthetic appearance and its look-and-feel. Cognitive aspects deal with functionality and how information is represented in the interface. These two aspects are clearly interrelated. Thus, simple changes done to the user interface can make the interface easier to learn for the user.

In the existing interface buttons are used for creating and editing the concept map. Their function was identified by the user either by recognizing the icon or by reading the pop-up text that appears while the mouse pointer is over the button. Though this design reduces space consumption and might be very easily comprehensible by an expert user, it poses an unnecessary cognitive load on novice users. Some of the important features of the existing interface, like the options to zoom-in and zoom-out, were hidden in the menu. Thus, users must search through the interface or have prior knowledge of such tools.

In the new interface, the visual importance of these buttons was enhanced by giving them a 3-D effect. Also, labels were provided on the buttons indicating their functionality. The important options are all available as buttons visible on the main screen.

A fully developed concept map expresses significant, complex relations between entities. Visualizing the relationship is easier to do if the concerned objects are visible on the screen, without the need for scrolling. Scrolling of the window – though a necessary evil in some cases – is a cause of distraction and interrupts the thought process of the users, more so if they are often novice users of computers. Students also spend a considerable amount of time creating and debugging the concept map. Though the panel shown in Figure 4 was important it was unused for long periods of time and ended up consuming extremely valuable screen space.

In the new interface, a design was developed to increase the screen space available for drawing the concept map and also to reduce the amount of scrolling needed. This change does not reduce the functionality of the previous system. The interaction panel automatically appears when required without intervention by the user. The user has the option of minimizing the panel. Figure 5 shows an example of such an instance. Another important aspect of the design was letting the captions on the panel remain visible even in the minimized state. This relates to the point of view: "Out of sight out of mind." Thus, in the new interface, the minimized panel was a constant reminder to users of the features that were available at their disposal.

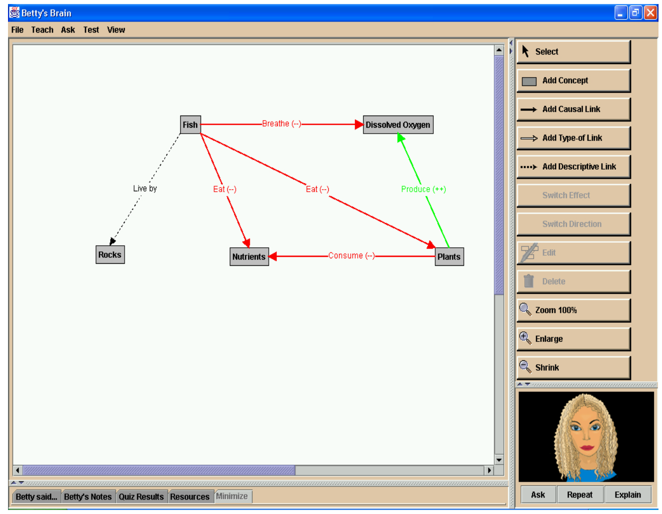


Figure 3: Enhanced Interface for Betty's Brain.

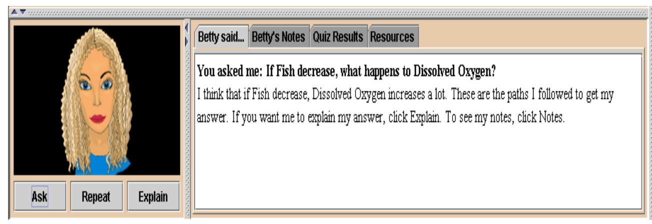


Figure 4: Interaction panel in the existing interface.

Causal links form an extremely important part of the Concept Map structure. The existing interface differentiated between the increasing and decreasing effects by using the symbols (++) and (--), respectively. In retrospect, this design seems confusing and a burden to younger users.

The new interface uses colors to depict the meaning of the causal links: red for a decreasing effect and green for an increasing effect. However, we decided to keep the symbols (++) and (--) along with the colors. This additional information has the positive impact of providing reinforcing information about the causal links. It should also be helpful to any users of the system who are color-blind.

Data from the prior study indicated that a common error students made was the incorrect representation of the effect of a causal link (creating a causal link with increasing effect instead of a decreasing effect) and specifying the direction of the arrow incorrectly. During the query or quiz phase, when students discovered these errors, it was frustrating for them to correct them using the existing interface. For example, changing the direction of "type-of" link from "Animal" to "Frog", involved first selecting the link, deleting it and recreating a "type-of" link from "Frog" to "Animal".

In the new interface, two buttons – "Switch Effect" and "Switch Direction" – were provided to help students easily rectify these commonly occurring mistakes with a single click. For example, to change a trend in the relation "Animals eat plants causing plants to increase", the student would just have to select the link and click on the "Switch Effect" button to rectify the mistake. The "Switch Direction" button changes the direction of the link selected. Figure 6 shows the use of the button "Switch Effect".

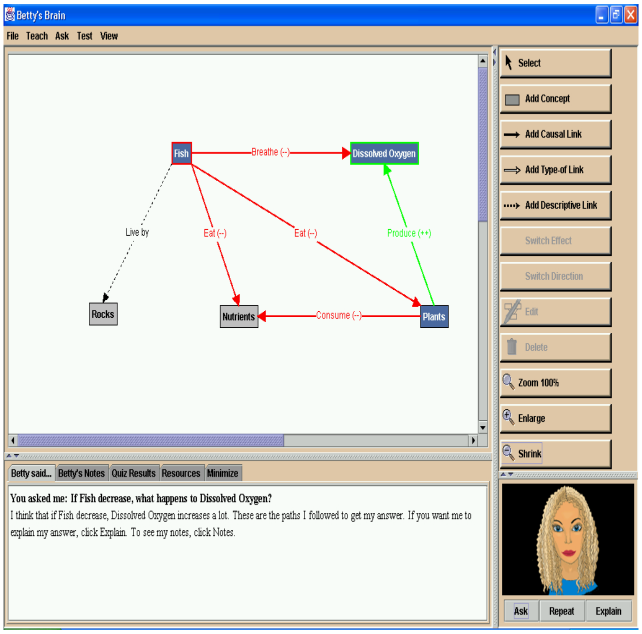


Figure 5: The interaction panel pops up automatically when Betty is asked questions.

4. User Study

We conducted a user study among 26 college-age students to compare the existing interface for *Betty's Brain* and the enhanced version that we designed. The subjects chosen had no prior knowledge about the Teachable Agents project. The user study involved four phases – Training, Reading, Testing, and Questionnaire sections.

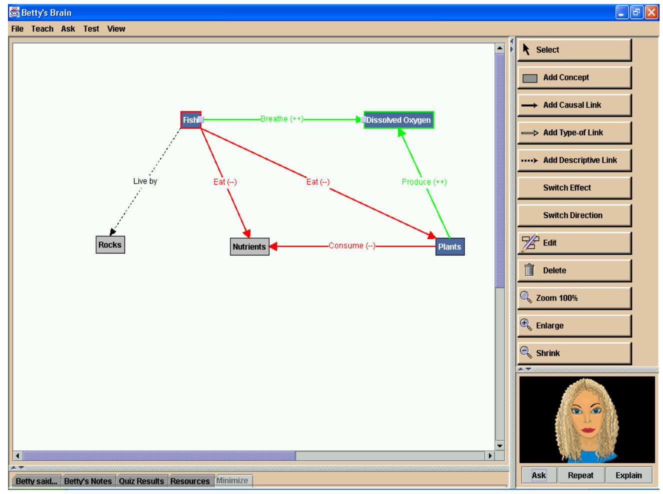
The users were first introduced to concept maps in a presentation. A demo was then given to the users with the current interface of Betty's Brain. The users were shown how to create a concept map, and to use the Query features of Betty for debugging a concept map. Note that users had no knowledge about the new interface and would be seeing it for the first time only when actually taking the test.

The users were then given sufficient time to go through a small resource document explaining the River Ecosystem. In the testing phase, they were asked to perform two tasks in each interface. The first task involved debugging a concept map that had two errors. The second task made the users add concepts and links to the corrected concept map. Half the number of students worked on the new interface first while the other half worked on the old interface first. Then they switched the interfaces they were working on, now carrying out the tasks on a different concept map. The order of the concept maps was also switched to remove any bias that could possibly be created by the different maps used.

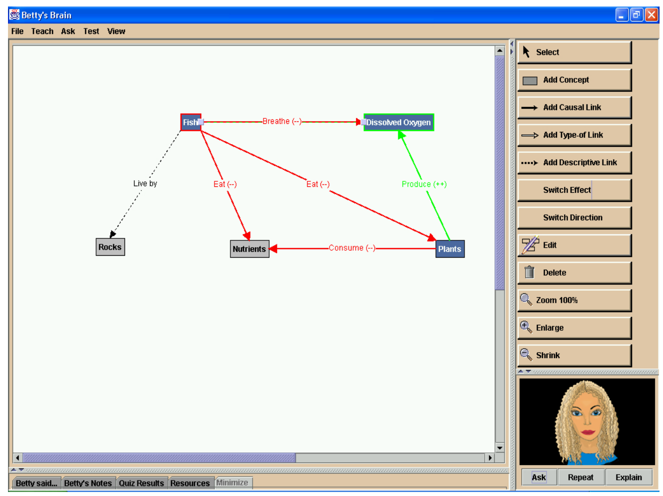
Finally the users answered a questionnaire where they were asked to compare features in the two interfaces.

5. Discussion

Log files were generated for each section of the test tracking every action of the user along with a time stamp. These timings were used for comparing the two interfaces. They were analyzed



(a)



(b)

Figure 6: The interface before (a) and after (b) use of the "Switch Effect" button.

using a two-way ANOVA to control the effect of the ordering of the interfaces.

When making additions to the interface, we found that users were significantly faster using the new interface ($F=9.9$, $p=0.004$, $MS=2850$). The effect of the ordering of the interfaces was not significant, and neither were the interaction effects.

When debugging a concept map, users were again significantly faster using the new interface as opposed to the old ($F=15.37$, $p=0.0006$, $MS=16171$). However, the effect of the ordering of the interfaces on their time was also significant ($F=4.85$, $p=0.0004$, $MS=5104$). This result is reasonable since having once debugged a concept map we would expect users to be able to do it reasonably effectively the second time. Again, the interaction effects were not significant.

The mean values of the time taken by the users are presented in table 1. Tables 2 and 3 show feedback obtained from the users. The users were given four different options, shown in figure 7, for representing a causal link having an increasing effect and the users were asked to rate them according to the order of preference. As can be seen from Table 2 the users felt that the arrows used in the new interface were an improvement. Table 3 lists the main changes made to the interface. The users specified their preference for the interface and it was found that all the users liked the new interface.

Table 1: Time taken by users in the tests.

	Avg. Time taken to debug (sec)	Avg. Time taken to add concepts and links (sec)
Old Interface First	141.85	85.15
New Interface Second	102.77	60.23

	Avg. Time taken to debug (sec)	Avg. Time taken to add concepts and links (sec)
New Interface First	111.23	72.30
Old Interface Second	142.69	77.00

These findings suggest that the new interface was more effective in helping users in debugging rather than in creating the concept map. On the whole, as one student mentioned as his comment, “My vote is for the new interface.” More extensive studies need to be conducted on middle school students, our ultimate target user group for this project.

Some users made suggestions, such as “The arrowheads could be made slightly bigger.” While reviewing the log file, we also found that the users had problems finding errors related to the direction. When asked why they found it difficult, they said that the arrowheads were too small and thus the direction didn’t catch their attention. One user said that the captions to the buttons can be hidden after the user gets to know which icon represents which tool. Also, some users faced problems while adding concepts. They attempted to draw a box of their preferred size (as we do usually in other software), but both the interfaces let them add a concept by just clicking the required position on the screen. Some users also felt that important concepts could be given more weight by making them bold and that hierarchical information among the concepts could be represented by using colors for the concepts. These suggestions will be considered as a future work for this project that would lead to another design for the user interface.

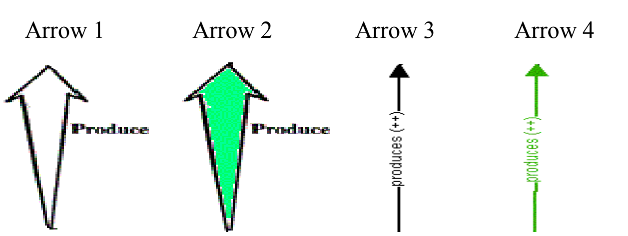


Figure 7: The four options to represent a causal link with increasing effect.

Table 2: User’s feedback in the questionnaire section regarding the causal links.

	Highest Preference → Lowest Preference			
Arrow 1	0	2	6	18
Arrow 2	7	14	3	2
Arrow 3	2	1	17	6
Arrow 4	18	5	2	1

Table 3: User’s feedback in the questionnaire section.

	Preferred Old Interface	Preferred New Interface	Can’t say	Both are good
Space to work with for the concept map	4	21	0	1
Visibility of buttons	0	26	0	0
Captions of buttons	0	26	0	0
Zoom buttons	0	23	3	0
Interface preferred	0	26	0	0

6. Conclusion and Future Work

Results of the study indicate that providing users with an interface that demands less cognitive overload definitely improved the efficiency of the system for college-age students. In particular, creating a simple, easy-to-understand interface, visually self-explaining components, and special purpose tools enable the users to be more effective. However, we would like to add that the present study focused on just the efficiency of the users. Future experiments should evaluate how interface modifications affect learning-related outcomes. For example, it may be that presenting an interface that is sufficiently easy to use allows users to exploit shortcomings in the reasoning portions of the system with the result that they are able to “game” the system, i.e., have Betty achieve good results without themselves learning much.

We plan to conduct extensive experiments on a primary target audience for our system, K-12 students. An important avenue of research is discovering to what extent these results generalize to that age range. Also, future work in this field will explore the judicious use of colors and shapes to represent hierarchies and relationships between entities. The use of these in animations to explain the complex relations in a system should also be investigated.

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