Cognitive Teachable Agent in Virtual Learning Environment with Fuzzy Cognitive Map

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Abstract

Today more and more learning technologies are developed in the virtual environment with intelligent agents to promote students' learning experience and efficiency. Teachable agent is a kind of pedagogical agent that promotes the students' learning through teaching it with concept maps e.g. Betty's Brain [1]. However, the knowledge representation with concept map may be insufficient for a complex knowledge structure, and there will be a limited number of quizzes derived from the concept map. As a result, the teachable agent is taught with limited knowledge.

In this paper we propose a cognitive teachable agent modeled with Fuzzy Cognitive Maps (FCM). FCM is a soft computing model that models a set of concepts and the causal relationships among them. By teaching the concepts of a knowledge, causal relationship strength, and causal relationships probability to the agent, the students are able to master the learning in a profound way. The teachable agent is planted in the virtual environment, so that the students can interact with it immersive to enhance the learning interest.

In our case study, a teachable agent is built up for secondary school students to learn plant biology; and the experiment result receives positive feedback of learning efficiency and achievements compared to concept map based teachable agent.

Keyword: teachable agent, learning environment, fuzzy cognitive map

I. Introduction

Education is increasingly gaining importance in everyone's life as modern society advances. Brute hard work and dedication may be the pre-requisites to nurture the young minds, but it is also equivalently important to tap on effective ways to do so. However, every generation of students differs from the other because of the environment in which they grew up. Hence, it maintains as a great challenge of paramount importance for the public education sector to develop a suitable education curriculum for the students. Intensive researches have been conducted into this problem and they present various solutions where students learn by teaching through a teachable agent [1][8][12][13]. However, these teachable agents still present certain limitations, for example, limit of interaction methods, limit of rules customizations to the agent. Thus we turn to look at how we can enhance the design of a teachable agent (TA) to enrich the learning process of the students.

II. Literature Review

A. *Learning by Teaching Paradigm*

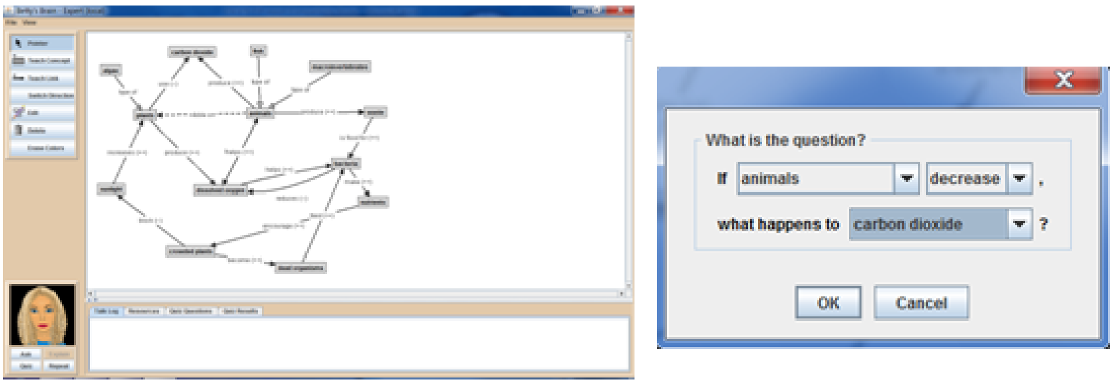
Teaching is an opposite processing of learning. However, recent research [1] shows that students can have a deeper learning through teaching others the contents they have learnt. In fact, many then discover that they can truly evaluate on their own understanding only after they teach. However, it is not feasible for people to always find someone else to teach. Hence, we can instead simulate the teaching process by incorporating a TA in the virtual learning environment.

To make the interactions between the student and the TA more realistic, artificial intelligence is used to program the TA to simulate a human tutee. The TA, like a human tutee, can answer questions according to what it has been taught. The TA also presents another feature that human tutees usually cannot, i.e., it is able to visually represent what it has learnt back to the student in an interactive and animated way. This helps the student to view and conceptualize the TA's knowledge database more easily.

In [7], the researchers presented some core principles on TA and compared the results of using TA with traditional methods of learning. A posttest then revealed that students who taught the TA showed more complicated chains of reasoning.

B. *Betty's Brain*

In this paper, we highlight a teachable agent named Betty's Brain [8] which helps students to learn about the interdependence and balance in the river ecosystem. It has often been investigated as a case study, as in [1], on how TA can help students to learn their subject contents better. Figure 1 (a) shows the main interface of Betty's Brain.



(a) (b)

Figure 1. Main interface of Betty's Brain (a) and Interface to ask Betty a question with limited rules (b)

Betty's Brain runs along the concept of organizing knowledge using cognitive maps. Students teach the TA Betty via a graphical drag and drop interface and create a cognitive map. Betty can then use the knowledge acquired from the cognitive map to reason and answer questions. Figure 1(b) shows the interface to ask Betty a question. It can be seen that asking Betty a question is constrained within the parameters offered. For example, Betty would only answer questions that relate two concepts. The students are not able to question Betty how the properties of a concept can affect the entire knowledge map.

Betty's Brain application also contains a set of quiz questions that students can use to test Betty. Another agent named the Mentor agent then feedbacks on how Betty fared in the quiz. Our research aim is to build on this teachable agent and add in features to make it more realistic and interactive.

III. Teachable Agent with Fuzzy Cognitive Map

In this paper, we have made an extension to the Betty's Brain to make it more realistic and interactive. Fuzzy Cognitive Map (FCM) is used to teach the teachable agent, which includes a quantitative analysis of the causal relationships. Moreover, artificial intelligence is equipped into the TA to achieve intelligent question and answer experiences.

A. Fuzzy Cognitive Map (FCM)

A Fuzzy Cognitive Map (FCM) is a kind of qualitative modeling tool proposed by Kosko [10]. It provides a simple and straightforward way to model causal relationships among different variables. Currently, FCMs have been widely used in many real-time applications. For example, FCMs was used to model the movements of the sheepdog and sheep [11]. Kosko and Dickerson [10] used FCMs to model the hunting process among sharks, dolphins, and fishes.

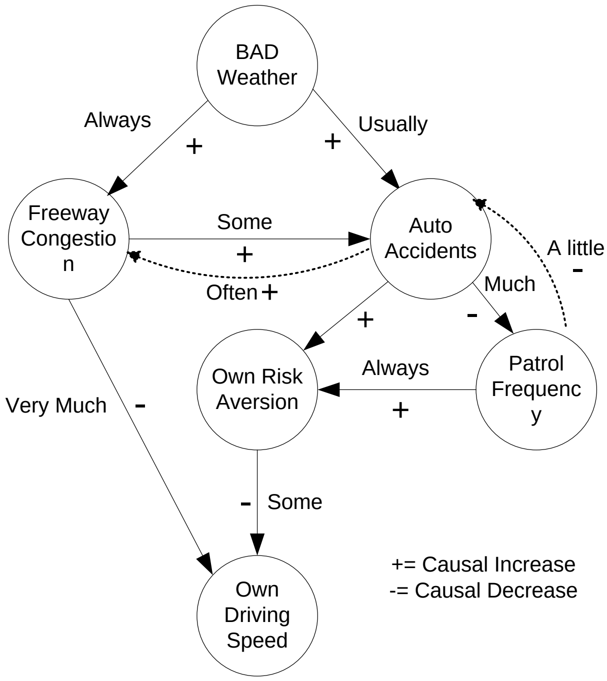


Figure 3. A sample Fuzzy Cognitive Maps about Highway Traffic Control [10]

FCM includes two elements: *concepts* and *causal relationships*. An example is shown in Figure 3. *Concepts* are represented as circles, which denote the related causes and effects in the model. The concepts are represented as fuzzy values. The *causal relationships* are represented as directed arcs, each of which has a sign and a weight. The sign shows the causal relationship between two concepts, which is compulsory. The '+' sign means `positive causal relation', in which the increase of the starting concept value will result in the increase of the ending concept value. The '-' sign means 'negative causal relation', in which the increase of the starting concept value will cause the decrease of the ending concept value. For example, increase of `bad weather' causes increase of `freeway congestion'; on the other hand, `freeway congestion' causes decrease of `own driving speed'. The weights differentiate the significance of causality from the start concept to end concept, and they are represented as fuzzy terms as well. For example, `bad weather' usually causes `auto accidents'. The term `usually' is a fuzzy item used to describe the level of significance. If there is no arc linking two concepts, it means that there is no causal relationships between the two concepts, i.e. the two concepts are independent. A Fuzzy Cognitive Map represents a knowledge base in a domain about how concepts relate to each other. Knowledge from different experts can be accumulated through combining several FCMs into a big FCM. This is done by merging the same concepts. A Fuzzy Cognitive Map provides qualitative information about the relationships. It ties facts, things, processes to values and policies and objectives, which makes it possible to predict how complex events interact and play out.

To facilitate the analysis of a FCM, each concept is represented as a state value whose range is [0, 1] or [-1, 1], while the causal relation is represented as a weight, whose range is [-1, 1]. Suppose the current value of concept i is *Ai*, its new value can be updated as

$$A_i^{t+1} = f(k_1 \sum_{j=0}^{n} A_j^t \cdot \omega_{i,j} + k_2 \cdot A_j^t)$$

where f(x) is the activation function and Aj is the state value vector. As there might be loops involved in the FCM, the values of concepts will evolve to an equivalence point or a limited cycle in the long run.

B. Teachable Agent with Fuzzy Cognitive Map (FCM)

There are three steps of the learning process to create Teachable Agent with Fuzzy Cognitive Maps:

1. The student teaches the agent by drawing Fuzzy Cognitive Maps about some knowledge.
2. Teachable agent applies its knowledge by taking quizzes from database based on the Fuzzy Cognitive Map taught by the student.
3. The student tunes the Fuzzy Cognitive Map based on the quiz results.

The three steps will be run iteratively until the student is satisfied with the final quiz results.

Instead of using the cognitive map models in Betty's Brain, we implement the Fuzzy Cognitive Map (FCM) model to run our TA. FCM is similar to cognitive maps except that the concepts and their relationships are quantified by Bart Kosko [10]. In this way, the students are able to teach concepts and causal relationships qualitatively.

The FCM is running with one of the three threshold functions available. $S_i(x_i)$ represents the node value and x_i represents the sum of all input edges into that node multiplied by their respective weights. The bivalent threshold function gives $S_i(x_i) = 0$ when $x_i <= 0$ and $S_i(x_i) = 1$ when $x_i > 0$. The trivalent threshold function gives $S_i(x_i) = -1$ when $x_i <= -0.5$, $S_i(x_i) = 0$ when $-0.5 < x_i < 0.5$ and $S_i(x_i) = 1$ when $x_i > 0.5$. Lastly, the logistic signal function where $S_i(x_i) = 1 / (1 + e \wedge (-cx_i))$. Working with scientific processes present in plant biology naturally made the nodes take on attributes that are quantifiable with continuous values. However, the bivalent function turns out to be more appropriate for this application. This is because plant biology taught in secondary school is reasonably fundamental and it could confuse students with more details. A simple design will allow the students to map their knowledge more clearly.

In the implementation, we built the FCM modeling to teach the teachable agent based on Mohr's work [5], which provides the basic backbone on the running of FCMs. The tool also allows the FCM nodes to take on initial values and run the algorithm to determine the output value for each node. This running process can also be viewed graphically step by step to check how the teachable agent makes the induction based on the Fuzzy Cognitive Map.

C. Incorporating Intelligent Question/Answer into the Teachable Agent

In order to make the TA more human-like and interactive, we include the intelligent question and answer with Artificial Intelligence Markup Language (AIML) technology created by Richard Wallace into our teachable agent. We have also tapped on CloudGarden's JSAPI1.0 developments to map the TA's response to speech. The AIML files are also maintained such that the TA can add and remove knowledge into the AIML files while the student adds or removes information to the TA.

IV. Case Study

A. Scenario

The students need to learn the plant biology concepts, which include diffusion, osmosis, particle movement, and concentration gradient, and their causal relationships.

B. Simulation

Figure 4 shows the graphical user interface of our Teachable Agent, namely Beanie. The student will first view a tutorial to learn how to teach Beanie. Then he/she can teach Beanie by choosing concept names via the drop down menu and clicking on "Create Node". He/she can also link up the nodes and assign them weights according to how the concepts influence each other. After which, he can assign input values and run the simulation to view how each node affects the entire graph system.

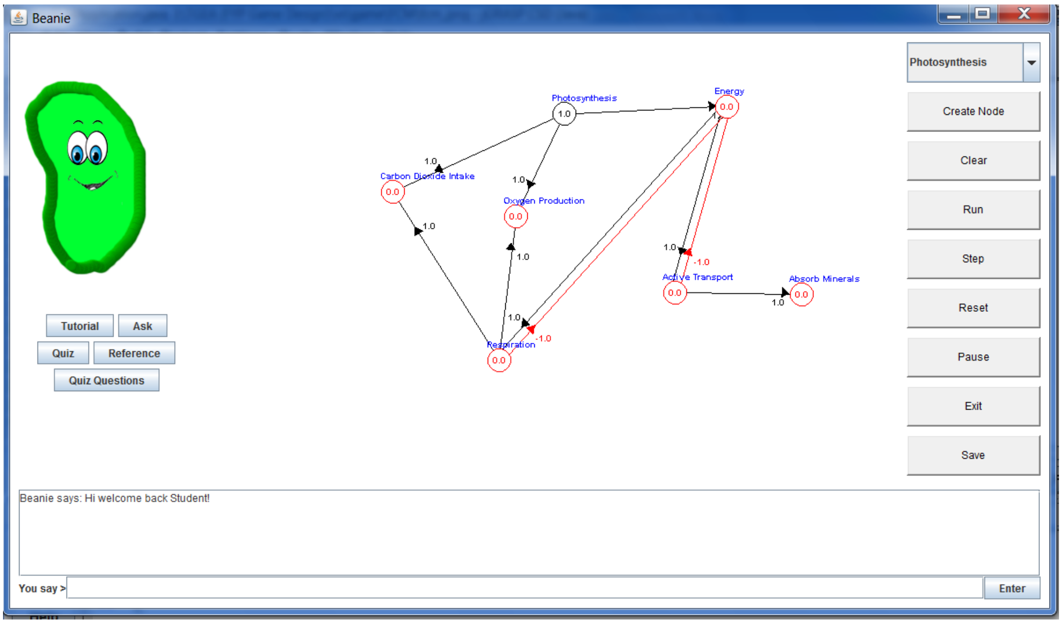


Figure 4. Beanie's Main Graphical User Interface of Knowledge Generated with Fuzzy Cognitive Maps

This allows the student to understand the system in a more intuitive way and decide whether he is teaching Beanie correctly or wrongly. Figure 5 shows an example of a simulation run with "Concentration Gradient" being present as the initial state.

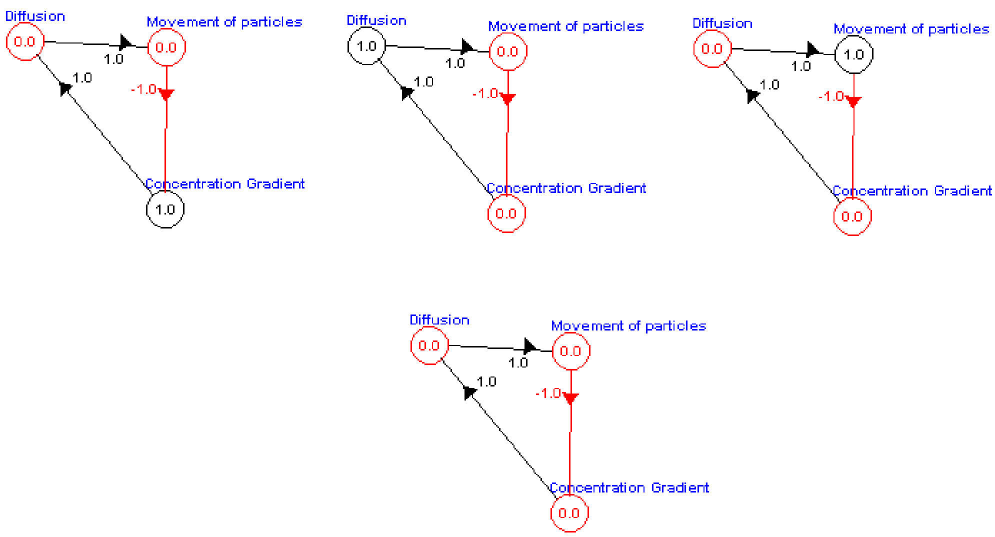


Figure 5. FCM Simulation Screenshots

C. Evaluation

In order to evaluate whether Beanie has learnt well, students can send Beanie to take a quiz by clicking on the "Quiz" button. To prepare Beanie for the quiz, students should look at the quiz questions provided and teach Beanie such that she can answer all questions. Along the way, students can also ask Beanie about the concepts taught by clicking on "Ask" button or via the chat box. Reference is also available if the students need some extra help in the subject content. When Beanie takes the quiz, an examiner will mark and give feedback on each question answered and promotes Beanie to the next level if she answers all questions correctly. A new set of quiz questions will then be available for Beanie to challenge herself. Figure 6 (a) summarizes the feature comparisons of Beanie and Betty's Brain.

15 undergraduate students were also gathered to interact with both TAs and were surveyed to compare their experiences with both agents. They were asked to rate each agent with a scale of 5 being the best and 1 being the worst. Figure 6(b) summarizes the results. As shown below, Beanie generally rates higher than Betty. However, most students gave feedback that Beanie's interface may suffer because of the complex features it provides. Hence, for students who are of secondary school level, it is recommended that TA implementation will need more step to step guidance to maximize the potential of using the software.

	Betty's Brain	Beanie
Agent can answer questions	With fixed dialog interface	With fixed dialog interface and via chat box
Agent can take quizzes and gain feedback on teaching	Yes	Yes
Agent can chat interactively with student	No	Yes
Nodes can be quantified	No	Yes
Model can simulate scenario with inputs	No	Yes
Model processes and states can be animated	No	Yes
Guides student through tasks of increasing difficulty	No	Yes

(a)

	Betty	Beanie
User-friendliness	3.3	4.1
User interface	3.6	4.3
Interactivity with teachable agent	3.3	4.1
Effectiveness in learning through game play	3.3	3.7
Motivation in continuing to use software	3.3	3.7
Ease of getting help	3.2	4.2
Overall experience	3.5	4.1

(b)

Figure 6. (a) Comparing Betty's Brain and Beanie; and (b) Survey Results

V. Conclusion

In this paper, various ways of enhancing the virtual learning environment have been introduced. We discussed how these features can help improve the environment as well as the considerations needed in the implementation. We recommend that further studies can be made to investigate how this application can be brought into a more immersive environment such as 3-Dimensional virtual worlds. It can also be implemented with a multi-player mode to encourage friendly competition and collaboration between students and such that they can learn from one another.

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