Teachable Agents in Virtual Learning Environments: a Case Study

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Abstract: As intelligent agent and virtual world technologies advanced to new heights in the current decade, researchers from diverse fields have started to look into possible ways of applying these emerging technologies to improve e-learning systems. Nevertheless, most attempts focused on using pedagogical agents to achieve traditional e-learning goals which place heavy emphasis on learning outcomes. In addition, the high technical barrier presented by the agent oriented software engineering (AOSE) paradigm have limited the complexity and wide acceptance of many pedagogical agents in virtual learning environments (VLE). In this paper, we leverage on our previous research results – the Multi-Agent Development Environment (MADE) - which drastically reduced to the technical hurdle of incorporating pedagogical agents into VLEs. We present a VLE augmented with teachable agents designed based on the experiential learning model (ELM) to facilitate the learning of high school science topics and demonstrate the efficacy of MADE in designing complex learning activities, designing teachable agents that complement immersive experiential learning and supporting the design based research (DBR) development model.

Introduction

For a long period of time since their respective inception, learning science, virtual worlds and intelligent software agents have been remaining as separate threads of development in the research community. Although there have been attempts to apply intelligent agent technologies in the e-learning field, due to the focus of traditional e-learning systems on helping the educators deliver learning contents to the students and offering objective information about the students' performance, the roles that agent play in these applications have been mimicking that of the real life instructors and the interactions between these agents and the students remain simple (Baylor 2003). In recent years, as the virtual world technologies mature to a point where massive number of users can be supported at the same time with acceptably high fidelity of rendering of the 3D environment, leading scientists have identified their potential to drastically alter the outlook of many research fields including that of e-learning (Bainbridge 2007). Moreover, a recent paradigm shift in the educational research field placing more emphasis the students' learning experience has motivated leading researchers in this area to investigate the possibility of harnessing the power of virtual worlds to form virtual learning environments (VLE) which offer learners a highly immersive learning experience (Dede 2009).

In our opinion, the future of e-learning lies in the successful synergy between the virtual world technologies, the intelligent pedagogical agent technologies and advanced learning theories. Although agent oriented software engineering (AOSE) is highly technically challenging and has been hindering the wide spread adoption of agents in e-learning systems, recent development on a more intuitive agent model – the Goal Net methodology - that enables less technically inclined people to understand the AOSE concept (Shen et al. 2006) as well as the associated development environment that simplifies the design, implementation and maintenance of a multi-agent system which can be easily plugged into an existing application – the Multi-Agent Development Environment (MADE) (Yu et al. 2008) - have paved the way to usher agent technologies into the e-learning research field. Preliminary study of using the MADE system to design agents for a VLE has demonstrated the feasibility of infusing agents into this kind of environments to offer a more natural way for the students to interact with the objects and the storylines of the VLE (Yu et al. 2008 pp. 487-495). Nevertheless, the goal net agents under the previous study (Yu et al. 2008 pp. 487-495) only implemented the basic functionalities of agents in the traditional e-learning settings which focus on delivering the learning contents and monitoring the students' progress. In this study, we explore the use of goal net agents in helping reflect on their knowledge through interactions in a VLE. We will give particular attention to the design of the teachable agents (TA) and study how they could enhance the students' learning experience in a VLE. To our best knowledge, this study is the first to incorporate teachable agents into a virtual world based learning environment.

In the rest of this paper, we will first review existing literatures relevant to our study. Then a detailed discussion of the design of our VLE and the design of the goal net based teachable agent with the possibility of incremental enhancement will follow. With the overview of the system in mind, we will then briefly touch on a pilot study conducted among a group of secondary school students in Singapore with our prototype system. Finally, we will offer a concluding remark and potential ways to further our study.

Related Work

One of the earliest attempts to incorporate pedagogical agents into virtual learning environment was proposed by Johnson in 1998 (Johnson 1998). At a time when 3D computer graphics rendering had little to offer in terms of photo realism and the AOSE paradigm had little influence beyond the intelligent agent research community, the application of agent technologies in e-learning was highly novel. The focus of their study was geared towards supporting the traditional goal of e-learning systems which mainly revolve around delivering learning contents and monitoring the students' progress on behalf of the educator. An agent called Steve was created to demonstrate to the students how to operate machinery and answer simple questions. The author was visionary to realize that the success of an agent augmented e-learning application rests on how the creation of the pedagogical agents could be simplified so that only a lower level of expertise in AOSE techniques is needed to design and implement the system. The author offered several possible ways of tackling this problem including making basic actions of Steve reusable and using machine learning approaches to let Steve learn about the tasks it needs to perform etc. Nevertheless, these proposed solutions were organized in an ad hoc manner and did not reduce the technical hurdle which hinders the vast majority of educators from actively participating into the design process of an agent augmented VLE.

The Multiple Intelligent Mentors Instructing Collaboratively (MIMIC) system proposed by Baylor (Baylor 2002) offered a new angle of view for the use of pedagogical agents in e-learning environments. This study focused exclusively on the agent part with little regards to the underlying e-learning environment they are deployed in. They employed multiple agents to offer the students both the benefits of the traditional e-learning system (the *instructivist* view) and the possibility of enhanced learning experience by offering the students the opportunity to reflect on what they have learnt (the *constructivist* view). The MIMIC system was primarily designed to be a test-bed for different types of instructional methods and it has achieved good results in that sense. However, the high technical hurdle of implementing the agents using the AOSE paradigm limited the easiness of reconfiguring the instruction styles used by the agents and, to some extent, the success of the system.

In the field of teachable agent research, the hitherto most popular one is the agent Betty (Blair et al. 2006). It is an agent using a cognitive map (CM) to represent its knowledge. By doing so, Betty is able to understand and infer the causal relationships among various concepts. Nevertheless, due to the limitation of CM being able to denote only the causality but not the degree of causality between any two concepts, the level of sophistication of the concepts that users can teach Betty is low. Furthermore, the original Betty was not built with an incremental development and easy incorporation into other applications in mind. This resulted in the extra effort needed to deploy Betty into a more complex e-learning system.

More recently, Linn et al. (Linn et al. 2009) proposed Choice Adaptive Intelligent Learning Environment (CAILE) which provided standardization to the monitoring of student behaviors and modularization of the system architecture to allow for easy future expansion. It allows the behaviors of the pedagogical agents to be designed hierarchically in a graphical form with the aim to simplify the process enough to allow more active participation of educators with little technical background in the development of the system. The available services and behaviors are organized into libraries for the reuse. The designers of the system combine them in the form of rules to build the behavior models of the agents and the events in the system. The CAILE framework has taken the modular approach of designing pedagogical agents for VLEs to a higher level. This model is used to enhance the reusability of the popular teachable agent Betty. However, with little facility to specify the interaction and relationship between the behaviors and events, the complexity of the mental state of the agent and the unfolding of the events is limited.

The Virtual Learning Environment

For a virtual world based virtual learning environment, the activities the students can perform does not follow a strict script except at critical junctures where certain prerequisite learning tasks need to be completed before the students can move on. Being a sandbox style environment in nature where the students are free to explore and initiate different events at any time and place, VLE poses a unique challenge to educators and system designers in terms of how to incorporate the essential and innovative learning activities to preserve the sandbox style interaction. In order to achieve this goal, we adopted the Experiential Learning Model (ELM) proposed by Kolb (Kolb 1984) to guide the design of the structure of the learning activities in our prototype VLE.

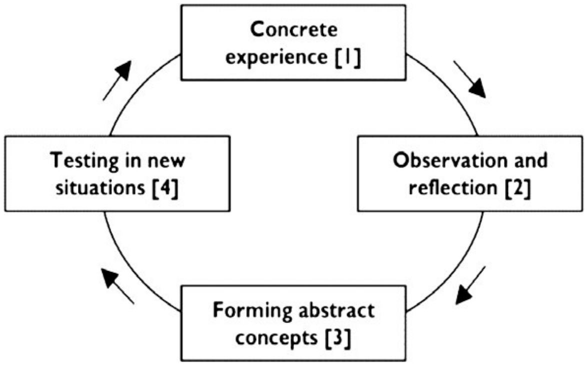

Figure 1. The Experiential Learning Model (ELM) (Kolb 1984)

The ELM, as illustrated in Figure 1, is a descriptive model of how we learn. It emphasizes on the seamless integration of four important aspects of the learning: the experience, allowing the students to reflect on what they have learnt, facilitating them to form abstract concepts from what they have learnt and testing on them on their abilities to apply what they have learnt to real or simulated situations.

In this study, we built an agent augmented virtual learning environment – The Uncharted Island of Singapura - to teach high school students science topics following the exploratory learning model. The topic of focus is the transport system in plants. In order to enable the less technically inclined educators to take a more active role in the design and implementation of the system, we leverage on our previous research results on the MADE framework to develop both the storyline of the VLE as well as all the pedagogical agents involved in it.

An Overview of the MADE Framework

The MADE framework is built on top of the Goal Net methodology which offers a goal oriented view on the mental state of an agent and the state of the environment it is situated in. Being an autonomous entity, an agent can be regarded as being driven by its goals when performing its activities. Shen et al. (Shen et al. 2006) identified a set of basic building blocks and semantics that can concisely define a hierarchy of goals and activities that can dictate the actions of an autonomous entity. These building blocks include *goals* (also known as *states* once they are achieved), *transitions* which contain actions in the form of references to either locally stored functions or published web services which can be executed to cause the subsequent goals to be achieved and *arches* which indicate the direction of flow of the logic as shown in Figure 2. Complex *composite goals* can be recursively decomposed into simpler goals and transitions to simplify the design.

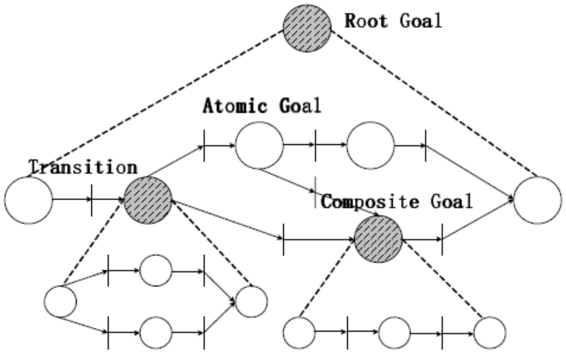

Figure 2. A Hierarchical Goal Net

The MADE framework consists of two major components: 1) the Goal Net Designer (GND) and 2) the MADE Runtime. GND offers the users a flexible tool to graphically manipulate the goals of an agent, design appropriate functions for the transitions and specify any reasoning process needed to select the next goal to achieve. The functions that can be associated with a transition are stored in a function library for reuse. Once the design data is captured by GND, it is stored into a goal net database and passed on to the MADE Runtime. The MADE Runtime then creates, executes and manages the necessary agents as specified by the design data automatically. The MADE framework essentially delegates the AOSE process to the MADE Runtime and hides it from the view of the system designers so that even people with little knowledge in the AOSE paradigm can create agents up to a certain level of sophistication. The MADE framework has been packaged into a dynamic linked library (DLL) so that it can be plugged into an existing application relatively easily. Since the design data is interpreted only at runtime, the detailed design of the MADE agents can be changed even after the application has been deployed without the need of recompiling the whole system. The MADE framework has been proven to reduce the time and effort required to develop and enhance an agent augmented application. The possibility to easily modify a goal net design even after the application has been deployed offers a unique and convenient way to follow the Design Based Research (DBR) approach in the system development process which is especially valuable to e-learning applications. For a more detailed treatment on the Goal Net methodology and the MADE framework, readers are suggested to refer to (Shen et al. 2006, Yu et al. 2008) respectively.

A Virtual Learning Environment for Teaching High School Science Classes

In the context of secondary level education in Singapore, high school science classes often involve wide ranging concepts with the aim to give the students various levels of knowledge into many of the everyday phenomena. Some of them require the students to take a microscopic view in order to understand the inner working of a subject matter which is usually accomplished via graphical illustrations in a classroom environment as shown in Figure 3. The details in the actual illustrations used in different classes may vary but the students are typically positioned in an observing capacity only, passively taking in the knowledge points.

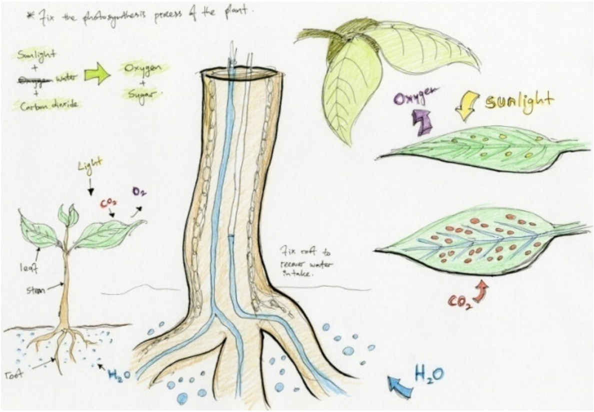

Figure 3. A typical illustration of how water molecules can be transported from the roots to the leaves of a plant for photosynthesis used in high school science classes.

In order to add the element of immersive exploration into science teaching at high school level, we believe the virtual world based learning environment is one of the best choices at the moment. Apart from the sensory immersion created by high quality 3D rendering of the subject topics in the learning environment, the VLE can provide other types of immersive experience through careful design. The most notable new concept of immersion proposed by Dede (Dede 2009) is *actional immersion* which empowers the students in an experience to initiate actions impossible in the real world that have novel and intriguing consequences. Based on this concept, we design the skeletons of our learning activities in the proposed agent augmented VLE to accomplish the "experience" part of the ELM with actionally immersive learning tasks.

The learning activities take place in an environment modeled according to the 19th Century Singapore to provide the students with a culturally familiar place to explore. Teacher agents are used to instruct the students on the basic knowledge points on the designated learning topic. Equipped with the basic knowledge on the subject, the students can then choose to proceed to explore the process of the transportation of water, mineral salts and glucose up and down a plant as well as the photosynthesis mechanism that produces glucose. Instead of just observing the process passively, the students act as tiny movers through their avatars to initiate the different processes of diffusion, osmosis and active transport at the appropriate places to guide the water and mineral salt molecules from the roots to the leaves and facilitate the photosynthesis process in a game-like manner. These activities form the basis for the implementation of the "experience" phase of the ELM. Along the way, questions with various levels of difficulties designed to stimulate in-depth thinking on the part of the students are raised and the students answer them through either individual or team effort in order to advance further. These questions implement the "testing" phase of the ELM. Figure 4 shows the micro-world view which take the students to a novel place inside the plant to take part in activities that are not possible in real life.

You are at the distribution point. Press F to distribute food

Figure 4. Micro-world inside the plant facilitating actional immersion and exploratory learning

The background program that controls and monitors this whole storyline that knits various learning activities together has been abstracted as an agent with the ability to react to the changes in the environment caused either by the actions of the students, their interactions with the various types of agents or the built-in system processes. Its detailed mental state diagram designed using the Goal Net designer is illustrated in Figure 5. The transitions (round rectangles) each contain one or more DLL functions that either updates the environment variables in the underlying game engine (which is the Torque Game Engine in our case) or communicates with other agents managed by the MADE runtime system; and the goals (circles) contain reasoning mechanisms that decide the best course of subsequent actions (i.e. transitions) to take under certain circumstances. The network forms a high level logic map for the learning activities involved in teaching the selected topic in the prototype VLE. With this design in place, future modifications to the learning activities can be made with minimal overhead after the system is deployed and incremental addition of more topics is possible.

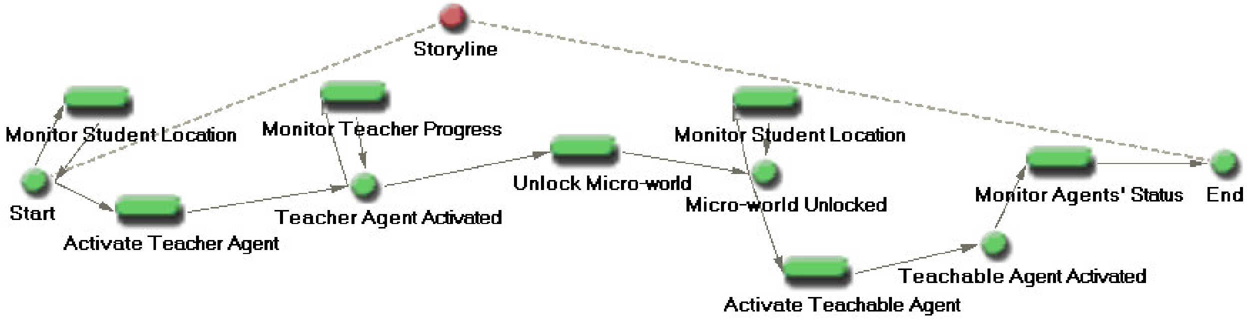

Figure 5. The goal net design for the agent controlling and storyline of the learning activities for the topic of transport systems in plants

The Goal Net based Teachable Agent

Learning by teaching others is a well known educational theory (Sinclair & Beverley 1989). Studies in peer-assisted tutoring (Cohen et al. 1982), computerized learning companions (Chan & Chou 1997) and classroom teaching (Sherin 2002) have all supported the effectiveness of learning by teaching. When in a position to prepare to instruct others instead of just learning for one's own knowledge gain, the students often take on a higher sense of responsibility. This motivates them to organize their knowledge they have acquired in anticipation of the needs of their pupils.

Figure 6. A student specifying rules for the teachable agent "Little Banana Tree" based on the knowledge he/she acquired during exploratory learning process in the VLE to teach the agent and counter check his/her own understanding.

Incorporating a teachable agent into a virtual learning environment supporting the experiential learning model introduces many new challenges. Firstly, teachable agents in a VLE should enhance the learners' sense of immersion. This requires the TA to be believable. To accomplish this, the TA needs to be reasonably smart but not super genius. The mode of interaction between the current teachable agents (characterized by the popular agent Betty) and the user is restricted to users inputting concepts and the causal relationships among these concepts and asking Betty questions on the relationship between any two concepts; and Betty answering with a qualitative relationship (e.g. if the number of fish increases, carbon dioxide level increase etc.) and showing its inference process using the CM. This mode of teaching helps the learners form a concept map that give them an overview of the interdependency between the various concepts involved in the topic. However, in order to prompt the learners to reflect more deeply on the knowledge they have acquired, stopping short at this level of teaching is not enough. For example, watering a plant makes it grow bigger. This simple rule can be captured by a CM. However, there are several parameters (e.g. frequency of watering and the amount of water used etc.) involved in this simple relationship that could alter the outcome of this rule. Thus, it is desirable for a TA in a VLE to possess different knowledge representation mechanisms to enable the users to teach it on different levels of sophistication. Secondly, since agents in a VLE normally take the form of a virtual character which is embodied by an avatar, it should take some initiative in the interaction with the learner in order to appear believable. The current TAs such as agent Betty are largely passive when being taught and only respond to the learner's question when asked. This level of engagement is not adequate for a VLE which emphasizes on the students' learning experience. Thirdly, in a VLE, students often participate in learning activities collaboratively in teams. There may be occasions when the many students need to teach the same TA on the same topic. However, students could make mistakes when teaching the TA. This is not necessarily a bad thing in itself since it gives the students an opportunity to learn from their mistakes and understand the concepts more thoroughly. In order to accomplish this, it is critically important that the TA is able to detect the mistakes and raise the issue to the students in a non-conspicuous manner. In this research, we propose to design a teachable agent for our prototype VLE using the goal net methodology to address these challenges.

We incorporate enquiry based learning and collaborative learning in teachable agents based on fuzzy rule inference – "Little Banana Tree" as shown in Figure 6 – into the learning experience to enable the students to reflect upon what they have learnt in the VLE and to counter check the coherence of their knowledge. After the learning tasks are completed, the students will be directed to a teachable agent interface where they can compete or collaborate with each other to impart as much knowledge to the respective teachable agent companions belonging to their teams as possible in the form of rules (i.e. if…then…else… clauses). Here, we choose the let the students decide the details of the rules to facilitate the rule conflict checking process. During the teaching process, the teachable agents will check the acquired rules for potential conflicts and raise questions to the students if any of them were found to prompt the students to think deeply about how these conflicting rules may arise. The algorithms to check the consistency of the rules are implemented as DLL functions and associated with the "Check Rule Coherence" transaction in Figure 7. Should the need for different algorithms arise, the designers of the system can simply package them into a new DLL file and associate the new functions with this transition via the Goal Net Designer interface. Through this interaction, the students could be prompted to reflect on the relationship of the various knowledge points they have learnt and possibly form a more in-depth understanding of the various concepts. The detailed mental state design of the teachable agent using the goal net methodology is illustrated by Figure 7. The teachable agent enhances the "experience" phase and implements the "reflection" and "forming abstract concept" phases of the ELM.

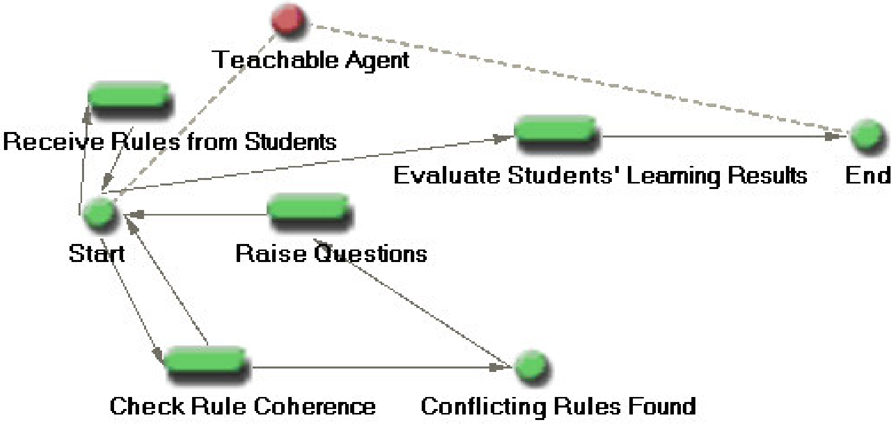

Figure 7. The goal net design for the mental states of the teachable agent

During the process of development, the structure of the learning activities and the agents have been jointly reviewed by the development team together with the education researchers from the both the National Institute of Education (NIE) Singapore and the teachers from the school where the field study was to be conducted. Feedbacks from the researchers and the teachers on both the design and organization of the learning activities as well as the design of the pedagogical agents were incorporated into the system incrementally through a design based research approach. With the different modules of the program organized visually into different goal nets, the update process is hassle free and does not require coding unless new features are needed.

The Field Study at a Secondary School in Singapore

The current prototype has been deployed in a secondary school in Singapore to facilitate the teaching of lower secondary level science classes. A total of 68 secondary two students participated in our study. In this section, we will describe the design of our field study and analyze the results on the learning in detail.

The Design of the Field Study

The students were divided into two groups according to their respective classes. The treatment group consists of 35 students who would only use our prototype agent augmented VLE to learn the designated topic without any classroom-based instruction; the control group of 33 students would learn the same designated topic through standard classroom-based instruction. Both groups were of comparable academic standing. The students from the treatment group formed into sub-groups of either 3 or 4 to collaboratively explore the VLE and complete the tasks as a team. Two separate sessions of 45 minutes each were conducted to allow the students from the treatment group to go through all the learning activities in the prototype VLE. Both groups took the same set of questions on a standard post-test (consisting of 15 multiple choice questions (MCQ) and 3 open-ended questions) that is part of the prescribed curriculum. The students from the treatment group also completed a questionnaire of 19 rating questions on the scale of 1 (strongly disagree) to 7 (strongly agree) and 3 open-ended questions to evaluate their learning experience in the prototype VLE.

While most of the data is currently being collected and processed, general feedback from the students on their learning experiences with the prototype system are favorable. Some of the comments from the students include: *"I could do things like fly, float and walk on water, I also could shrink and teleport. This is not life-like, and it is fun, as it receives a lot of imagination"; "I found the process of progressing up the xylem and answering questions rather innovative and enjoyable. We actually had to rise up the xylem, which demanded a lot on scientific information, we recalled from Uncle Ben's teaching"; "Working together with my teammates to achieve much more, for instance, we would split ourselves into smaller groups, one concentrating on creating food while the other two collect and transport it".* The overall rating for the learning experience was 5.0.

Overall, the prototype agent augmented VLE offers the students a satisfactory learning experience. The novel learning activities that allow students participate in experiences that are not possible in the real world have elicited positive interest in the VLE from the students. This confirms the findings on the importance of actional immersion to a virtual learning experience by Dede (Dede 2009). The goal net based teachable agent (Little Banana Tree) is generally perceived as helpful by the students. This implies that it has achieved its design goals in terms of functionalities. Through teachable agent, students also have learned when a group of them teach the agent collaboratively, they might feed it with conflicting rules. As the result, students start to talk and argue, trying to sell their views to each other. This results in a co-mingling of ideas among the students.

Conclusions and Future Work

In this paper, we presented our study of applying the MADE framework to design and develop an agent-augmented virtual learning environment according to the experiential learning model. Teachable agents are implemented using the MADE framework which enabled them to effectively address the new challenges in the VLE to supplement the actionally immersive learning activities. The development process further confirms the feasibility of applying the MADE framework to support agent augmented experiential learning. The resulting prototype achieved satisfactory learning experiences among the students.

In subsequent research, we plan to enhance and further apply the MADE framework to enhance the animation of the reasoning process as well as to incorporate emotional capacities (both the ability to generated simulated emotions and the ability to elicit positive emotions from the students) into the teachable agents to study the impact of affect on the learning experience and outcomes in a virtual learning environment.

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References

1. Bainbridge, W. S. (2007). The Scientific Research Potential of Virtual Worlds. *Science, 317*, 472 - 476.
2. Baylor, A. L. (2002). Agent-based learning environments as a research tool for investigating teaching and learning. *Journal of Educational Computing Research, 26*(3), 249-270.
3. Baylor, A. L. (2003). The Impact of Three Pedagogical Agent Roles, *International Conference on Autonomous Agents and Multi-agent Systems*. Melbourne, Australia.
4. Blair, K., Schwartz, D. L., Biswas, G., & Leelawong, K. (2006). Pedagogical Agents for Learning by Teaching: Teachable Agents. *Educational Technology & Society*(Special Issue on Pedagogical Agents).
5. Chan, T.-W., & Chou, C.-Y. (1997). Exploring the Design of Computer Supports for Reciprocal Tutoring. *International Journal of Artificial Intelligence in Education, 8*, 1-29.
6. Cohen, P. A., Kulik, J. A., & Kulik, C.-L. C. (1982). Educational Outcomes of Peer Tutoring: A Meta-analysis of Findings. *American Educational Research Journal, 19*, 237-248.
7. Dede, C. (2009). Immersive Interfaces for Engagement and Learning. *Science, 323*(5910), 66-69.
8. Johnson, W. L. (1998). Integrating Pedagogical Agents into Virtual Environments. *Presence: Teleoperators and Virtual Environments, 7*(6), 523-546.
9. Kolb, D. A. (1984). Experiential Learning. Englewood Cliffs.
10. Linn, J. G., Segedy, J., Jeong, H., Podgursky, B., & Biswas, G. (2009). Reconfigurable Architecture for building Intelligent Learning Environments, *The 14th International Conference on Artificial Intelligence in Education*. Brighton, United Kingdom.
11. Shen, Z., Miao, C., & Gay, R. (2006). Goal-oriented Methodology for Agent-oriented Software Engineering. *IEICE Transactions on Information and Systems, Special Issue on Knowledge-based Software Engineering, E89-D*(4).
12. Sherin, M. (2002). When Teaching Becomes Learning. *Cognition & Instruction, 20*, 119-150.
13. Sinclair, G., & Beverley, H. (1989). *Peer Tutoring - A Guide to Learning by Teaching*: Nichols Publishing.
14. Yu, H., Shen, Z., Low, C. P., & Miao, C. (2008). Transforming Learning through Agent Augmented Virtual World, *the 8th IEEE International Conference on Advanced Learning (ICALT 2008)* (pp. 933-937).
15. Yu, H., Shen, Z., & Miao, C. (2008). A Goal-oriented Development Tool to Automate the Incorporation of Intelligent Agents into Interactive Digital Media Applications *ACM Computers in Entertainment (CIE) Magazine, 6*.