Learning by Playing in Agent-Oriented Virtual Learning Environment

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Abstract. Virtual environments have gained tremendous popularity among young generation in recent years. Learning in the virtual environment becomes a new learning perspective that helps to promote the learning interests of students. However, there is a lack of methodology to develop and deploy a personalized and engaging virtual learning environment to various learning subjects. In our paper, we propose an *A*gent-oriented *VI*rtual *L*earning *E*nvironment *(AVILE)* as a new "learning by playing" paradigm, in which each learning object is built up as a goal of a *G*oal-*O*riented *L*earning *A*gent *(GOLA)*. In AVILE, students conduct the personalized virtual experiments through the simulations and engaging role-playing games for knowledge acquisition by interacting with the intelligent *GOLAs*. Each *GOLA* provides most appropriate instructions by analyzing the students' learning process, and stimulates the students to make deeper learning within the exploration and knowledge transfer on real problems in the virtual learning environment. We adopted this methodology to teach plant transportation for secondary school students and received very positive results.

Keywords: Virtual learning environment, agent, virtual experiment, personalization.

1 Introduction

Virtual environments have gained tremendous popularity among young users in recent years for its openness, convenience, and mobility, e.g. World of Warcraft, Second life. People are able to communicate with each other in the virtual community and share information easily and efficiently in 3D virtual presentation, which is rather limited in the real world. Learning in the virtual environment becomes a new learning perspective that helps to promote the learning interests of students in the new era. The potential for innovative and ground breaking research in virtual learning environments has been recognized by leading education research scientists [1] [7]. Preliminary studies on using virtual worlds as learning environments to promote highly immersive experiential learning have achieved encouraging results [6]. However, it is still a big challenge to make a personalized

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virtual learning environment for designers (e.g. teachers), based on the students' preferences and real-time interactions, due to a lack of systematic methodologies. Agent-based learning environment has been studied by researchers as a research tool for investigating teaching and learning [2], which presents a new perspective to the future learning method in virtual environment with intelligent virtual entities.

In this paper, we propose an Agent-oriented Virtual Learning Environment (*AVILE*) as a "teaching by learning" paradigm targeting to the raised challenges. In our system, each learning object is modeled as the goal of a goal-oriented learning agent (*GOLA*). *AVILE* is constructed as a multi-agent system of *GOLAs*, which construct the virtual laboratory that students perform the virtual simulations, and a virtual world environment that students can engage and interact with. *GOLAs* are created to perceive the students' actions and simulate customized laboratory and playing experience in the virtual environment, in the form of non-player characters (NPCs) or invisible observers (or instructors). In order to model different related learning objects in consequences, Fuzzy Cognitive Goal Net (FCGN) is used to model the hierarchical goals with alternatives, through which *GOLA* selects the goals and actions by reasoning the real-time interactions and context variables. Evolutionary Fuzzy Cognitive Maps (E-FCMs) is used as the reasoning model about the dynamic causal relationships among the user interactions, contexts and agent goals, thus to present a personalized learning object.

The rest of the paper is organized as below. Section 2 will illustrate our agent oriented virtual learning environment system and the involved agents. Section 3 will focus on Fuzzy Cognitive Goal Net which models leaning objects as the goals and cognition model to provide personalized playing and learning. We will show a case study of using the paradigm to teach secondary school students plant transportation system in Section 4. Lastly we will draw the conclusions and future plan.

2 Agent-Oriented Virtual Learning Environment (*AVILE*)

Agent-oriented virtual learning environment (*AVILE*) provides a new approach for students to learn by playing in the virtual environment, which might not be easy to achieve in the conventional classroom learning (CL) or the real-life experiments, due to the communication constraint, physical limitation, and building cost etc. Each student is unique, in terms of the learning curve of new knowledge and learning habit, while a generic virtual learning environment or virtual laboratory might not suit the needs of all the students easily. Therefore, there is a need to customize the virtual learning experience with many alternatives to serve different learners.

In current agent-based virtual learning environment, learning contents are mainly delivered through the non-player characters [5, 8, 9, 11] with limitations of delivering knowledge. In our approach, agents are not only used to model non-player characters, but also to model any learning object which can be either visible or invisible.

2.1 Learning Structure

Personalization is a key to promote the learning experience of the student at knowledge acquisition. Agent-oriented virtual learning environment (*AVILE*) augments the virtual learning environment with a number of intelligent goal-oriented learning agents (*GOLAs*), which enable personalized virtual learning to students by reasoning the students' preferences and real-time interactions with the students.

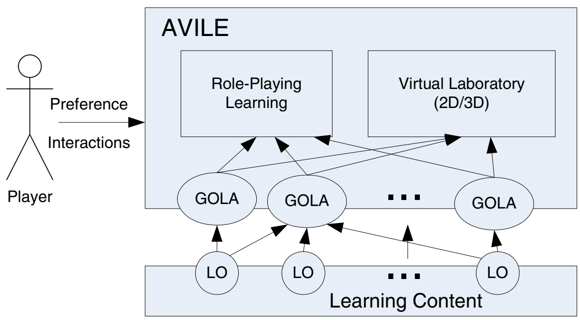

Fig. 1. Learning structure in the Agent-oriented Virtual Learning Environment

Figure 1 shows the learning structure of agent based virtual learning environment. Learning content is decomposed to a series of learning objects (LO), e.g. "diffusion" and "osmosis" are two learning objects in plant transportation chapter. Each LO is assigned to one or more *GOLAs* as their goals. For example, water molecules and plat root are two *GOLAs* to show the "diffusion" concept. The *GOLAs* are created in the role-playing learning virtual environment and virtual laboratory that the students can learn from the interactions.

In order to provide a fast-responsive and personalized learning experience, the user preferences are firstly gathered off-line for each student, e.g. age, gender, interests and prior knowledge. After that, the students play and learn in the agent mediated virtual learning environment by two methods: virtual laboratory and role-playing learning. In the virtual laboratory, the students are able to conduct 2D or 3D simulations of learning objects, by acting as a "God". Moreover, the students are able to immerse through a role-playing learning by acting as a "Player", to verify the concepts they have learnt in the virtual laboratory. Stories are created to motivate the students in the role-playing learning by linking the learning objects together seamlessly. Agents perceive the real-time interactions of a student, reason about them and act back to the student, i.e. to provide a unique learning experience eventually.

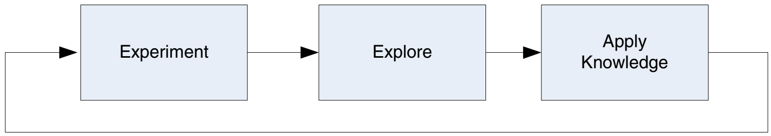

Fig. 2. Learning model in *AVILE*

There are three learning phases in *AVILE* as shown in Figure 2, which are carried out iteratively:

Experiment: The students conduct the virtual simulation in the virtual laboratory to study the basic concepts of learning objects.

Explore: The students explore the virtual environment and interact with *GOLAs* to verify the concepts they have learnt in the virtual laboratory.

Apply Knowledge: The students transfer their knowledge they have learnt to solve real problems in the virtual world.

2.2 Goal Oriented Learning Agent (*GOLA*)

Different from other agent-based virtual environment, each learning object in *AVILE* is modeled as a goal-oriented learning agent (*GOLA*), which can be visible or invisible in the virtual environment. Visible *GOLAs* include the non-player characters (e.g. humans, animals, and context objects) that deliver the knowledge to students directly through interactions; while invisible *GOLAs* include the contexts (e.g. temperature, weather, time and instructions) that deliver the knowledge indirectly.

A capable agent is able to perceive, reason and act in the virtual environment by defining its goals and cognitive variables initially. Fuzzy Cognitive Goal Net is used as the goal model for *GOLAs* to act in the agent-oriented virtual learning environment, which is explained in details in next section.

In the *AVILE*, the following agents interact with students to help them and to analyze the learning process in real-time:

- **Instructor Agent** Each instructor agent is responsible to provide meaningful instructions to the students. By monitoring the learning process of the students (e.g. difficulty, speed), the agent is able to tune the instructions in terms of difficulty, speed and detail.
- **Assessment Agent** An assessment agent evaluates the learning progress of the students, in order to master the learning efficiency of the students. Then it will send feedbacks to the instructor agent.
- **Inhabitant Agent** Inhabitant agents are the believable non-player characters to deliver the learning contents in the virtual learning environments, which could be a human or a tree, etc.

In order to provide an engaging learning experience, each *GOLA* presents the following properties:

Interactive: The agents are able to interact with the students in real-time. Protocols of interactions are defined, e.g. dialog or interaction mechanisms.
Intelligent: The agents are able to "perceive, reason and act" in real-time in order to create intelligent interactions.
Adaptive: The agents are able to learn from the students' behaviors and context changes, in order to provide "believable" interactions to the students.
Emotional: The agents are emotional as a feedback to user interactions.

As a result, the students are able to immerse into the virtual learning environment.

2.3 Virtual Laboratory

3D virtual laboratory is a good place that allows students to do experiments intuitively. In our *AVILE*, both 2D and 3D virtual experiments are designed as simulations in the virtual laboratory.

Table 1. Comparison of 2D and 3D Simulations

	2D Experiment	3D Experiment
Implementation	Easy	Hard
Immersion	Low	High
Role	"God"	"Player"
Collaboration	No	Yes
Suitable Contents	Intuitive	Explorative

2D or 3D virtual simulations have their own strengths and limitations. Table 1 shows a brief comparison between the two kinds of simulations. 3D simulation provides a better immersive experience to the students, and allows the interactions and collaborations of students at the learning. It is more suitable for students to explore and induct new knowledge in the science learning. However, the implementation of 3D simulation is more expensive at the implementation. On the other hand, 2D simulation is more suitable to present the intuitive concepts, e.g. specific science terms. In our real implementation, we use a hybrid of 2D and 3D simulations as a balance of production cost and user experience.

Virtual laboratory provides a basis of concepts for the students to learn through the simulation. Thus, the students are able to recall the simulation when they explore the virtual learning environment and explain the concepts in the real activities.

2.4 Role-Playing Learning

In *AVILE*, role-playing learning is a main concept that the student can immerse into the virtual environment to learn. Inhabitant agents are distributed in the virtual environments to deliver the related learning objects. Thus, the students need to compare, evaluate and induct the knowledge gathered at different places, which would help them to achieve the deeper learning. Moreover, students are encouraged to apply the knowledge they have learnt in the virtual experiments or exploration to solve real problems in the virtual learning environment. Stories are incorporated in the virtual learning environment to motivate the students to acquire new knowledge step by step.

3 Fuzzy Cognitive Goal Net

How to model numerous earning objects in an organized way is a big challenge. Fuzzy Cognitive Goal Net is a computational model to simulate the goals that *GOLA* pursuits in the virtual environment. As shown in Figure 3, *goals*, denoted as circles, are used to represent the goals that an agent pursues. *Transitions*, represented by arcs and vertical bars, connecting from the input goal to the output goal, specify the relationship between the two goals. Each transition is associated with a task list which defines the possible tasks that an agent needs to perform in order to transit from the input goal to the output goal. Here, each learning object is modeled as a goal of *GOLA*. A simple learning object (e.g. "diffusion") is modeled as an atomic goal; while a complex learning object (e.g. "molecule movement" is modeled as a composite goal, which can be further divided to "diffusion" goal and other goals.

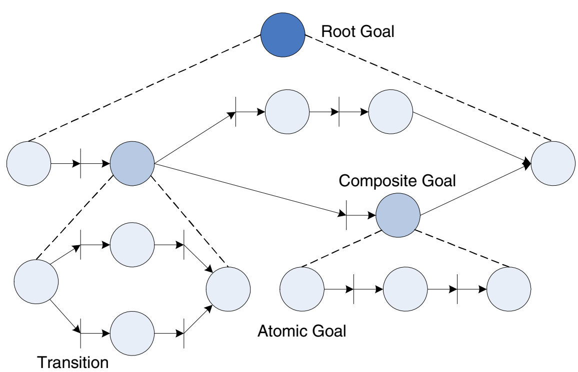

Fig. 3. A sample Fuzzy Cognitive Goal Net which is composed of goals and transitions

As an extension to generic Goal Net model [10], Fuzzy Cognitive Goal Net perceives and reasons the goal-related variables/events to choose the suitable goals in real-time [3]. With the "choice" transition, different goals can be achieved based on fuzzy context, user preferences or real-time interactions. For example, the agent can present different learning objects to different learners based on the learners' levels, past activities etc.

The pseudo code of running fuzzy cognitive goal net is shown here to select learning objects in real-time. By modeling the learning objects as goal net in

Algorithm 1. *RunningofFuzzyCognitiveGoalNettoSelectLearningObject*

```
Require: Root Goal G
Push G into Goal Queue Q
while Q is not empty do
  Pop goal g from Q
  Perceive Environment e
  if g requires e then
    if g is Atomic then
      Get action A from g
      Execute action A
    else
      Get Sub-goals g1, g2, ..., gn
      Push Sub-goals g1, g2, ..., gn into Goal Queue Q
    end if
  end if
end while
```

a hierarchical way, the students are able to take a smooth learning curve systematically, from the easy learning object to difficult learning object, and from atomic learning object piece to complex learning object cluster.

In the "learning by playing" paradigm, a personalized learning is achieved by the goal selection mechanism of *GOLAs*. Each *GOLA* can use different goal selection mechanisms to choose an appropriate goal to handle user interactions correctly at playing. Evolutionary Fuzzy Cognition Map is a soft computing model to simulate the dynamic context variables and to conduct real-time reasoning [4]. It is adopted as the reasoning and simulation tool in the Fuzzy Cognitive Goal Net for goal selection. It models two main components: *concepts* S_i and *causal relationships* R_i. *Concept* can be input (context variables, user interaction variables), intermediate (i.e. variables that connect input and output), or output (agent goals, states etc). *Causal relationship* represents the interconnection from one concept to another. In the virtual learning, the concepts includes students' preference (i.e. gender, age, interests), students' activities in the learning environment and learning objects. By studying the causal relationships among the students and the learning objects, *GOLA* is capable to select a most appropriate learning curve to each student in real-time. The details of the model and its inference process can be found in [4].

4 Case Study: Plant Transportation in Banana Tree

4.1 Learning Content

The agent-oriented virtual learning environment is used for secondary level science learning about plant transportation in Catholic High Secondary School, Singapore in year 2011. The learning content of the virtual learning environment is plant transportation system. The related learning concepts (LO) include:

Xylem and Phloem of Root, Stem and Leaf: the cross section and functionalities of xylem and phloem inside the plant.

Osmosis and Diffusion: different movement methodologies of the water and mineral molecules.

Photosynthesis: chemical reaction of how the energy and oxygen are generated inside the leaf with water, light and carbon-dioxide.

4.2 Implementation

In order to motivate the students to learn the concepts in the plant transportation, we generate a story scenario, namely "saving the dying banana tree".

> "The banana trees in Singapura town are quite sick. The farmer *Uncle Ben* asks the investigators to explore the whole plant transportation system of the tree, in order to find how to save them."

We have implemented our agent-oriented virtual learning environment with Torque 3D Game Engine.

4.3 Sample *GOLAs*

There are a set of agents involved in the virtual learning environment to facilitate the students at the learning of plant transportation system as investigators. Three main *GOLAs* that provide the personalized learning are illustrated here.

Lab Supervisor. Lab supervisor "Miss Lee" is a tutor in the virtual laboratory, who determines the learning objects of the student based on the student's current level and preferences.

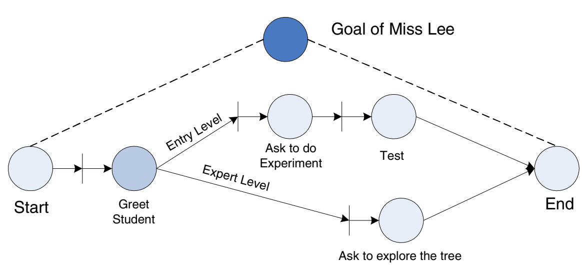

Fig. 4. Fuzzy Cognitive Goal Net of lab supervisor agent to choose the learning object

The goal net used by the supervisor agent is shown as Figure 4. If the student is at the entry level, she will lead the student to do the virtual experiment, e.g. diffusion or osmosis; otherwise, she will recommend the student to enter into the banana tree to watch the diffusion or osmosis process of water molecules at the

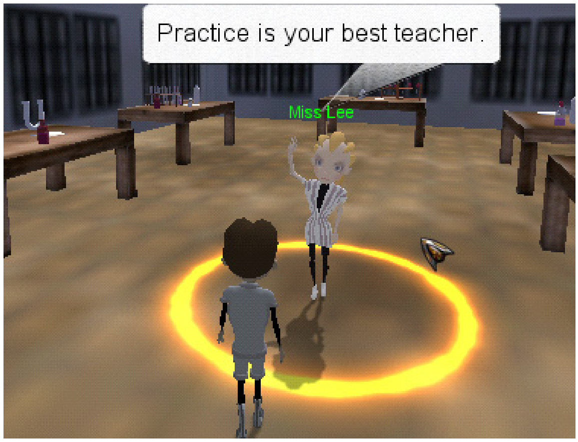

Fig. 5. Lab supervisor "Miss Lee" greets students with an introduction ('greet student' goal in Figure 4)

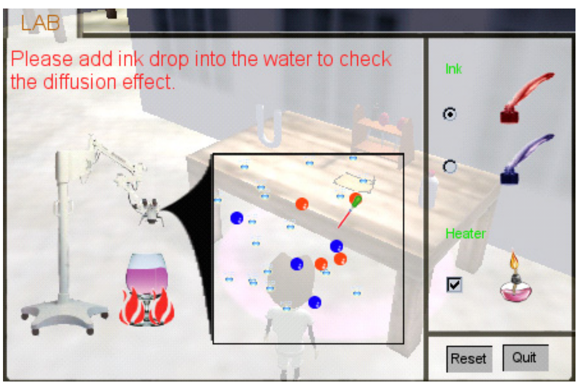

Fig. 6. Diffusion experiment with 2D simulation: add ink drops to observe the movements of molecules of diffusion ('experiment' goal in Figure 4)

root. Figure 5 shows a snapshot that the lab supervisor "Miss Lee" greets the student with some introductions by pursuing "greet student" goal (Figure 4). Figure 6 illustrates a 2D diffusion simulation that the student can play. Through this observation, the students are able to learn the diffusion concept by checking how the ink molecules move in the water and the variables that might affect the diffusion process.

Director Agent. Besides the simulations in the virtual laboratory, the students can watch the diffusion or osmosis at plant root immersively, which is impossible in the real world experiments. The invisible director agent directs the whole role-playing learning. It provides hints and analyzes the students' behaviors at the students' playing.

The goal net used by the director agent is shown as Figure 7. It can schedule the students to talk to different non-player characters to find the sick banana tree to start the plant transportation journey. The "visit plant transportation" is a composite goal. When the director agent pursues this goal, it will load the sub-goals of it, which is shown as Figure 8. Figure 9−11 are some screenshots of the students at the playing when the goals of the director agent are executed. In Figure 9, the student is exploring the stem xylem through flying upward. Through this, the students are able to observe the inner structure of the stem xylem and the molecules that flow in it. Figure 10 shows the cross section of the leaf (i.e. xylem is on top of the phloem), which is different from the cross section at the root or at the stem. Figure 11 shows that the student pushes the water molecule to carbon-dioxide molecule to generate food and oxygen in the leaf. Through this process, the students are able to learn the photosynthesis intuitively.

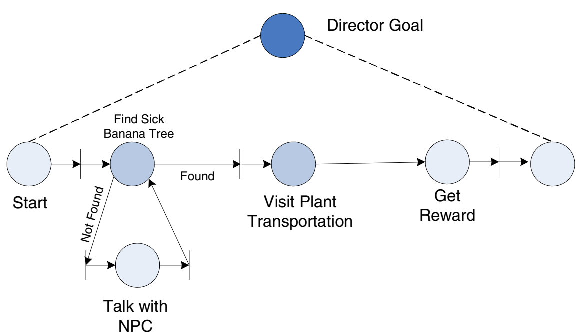

Fig. 7. Fuzzy Cognitive Goal Net of director agent to control the role-playing of students

Water Molecule. Water molecule is an inhabitant *GOLA* in the learning adventure, who asks for help from the student to take them into the leaf where the photosynthesis is carried out. The goal net used by the water molecule agent is

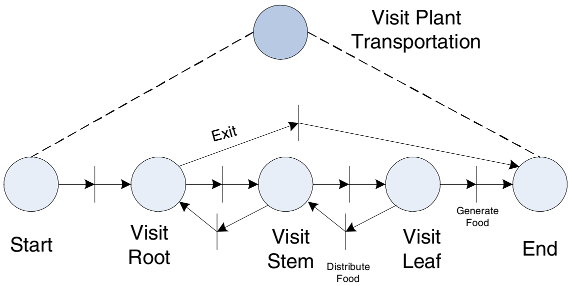

Fig. 8. Sub-goal of director agent to visit plant transportation

Fig. 9. Student meets panic water molecules at the root ('visit root' goal in Figure 8)

Fig. 10. Cross section of leaf: xylem on top and phloem at bottom ('visit leaf' goal in Figure 8)

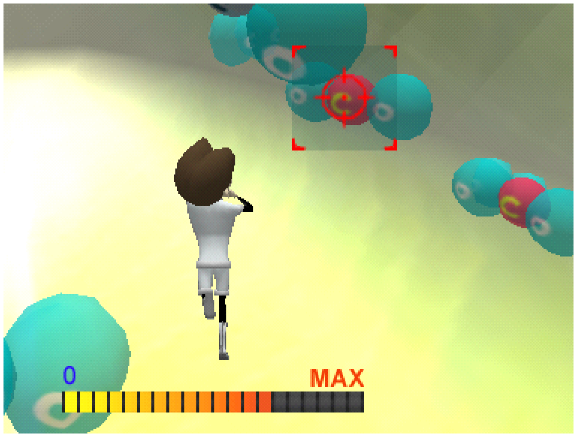

Fig. 11. The student pushes the water molecule to carbon-dioxide molecule to generate food ('generate food' transition in Figure 8)

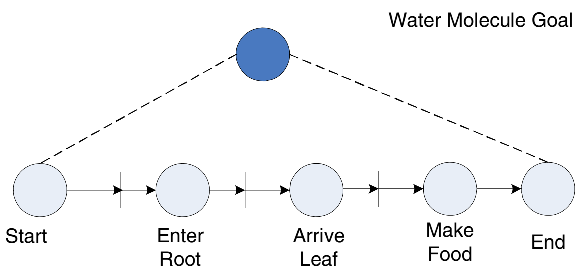

Fig. 12. Fuzzy Cognitive Goal Net of water molecule agent to go through root, stem, leaf and generate the food

shown as Figure 12. Depending on the learning scenario, the water molecule's goal is composed of a series of goals linearly.

4.4 Assessments

We conducted a comparative study in the Catholic High School to evaluate the students' performance in the agent oriented virtual learning environment. One group of 36 students (Group 1) used the agent-mediated virtual learning environment to learn and another group of 34 students (Group 2) used the formal classroom learning as a comparison. Group 1 used a same learning time as group 2 which is around 2 hours. After the learning, both groups were given a MCQ test about plant transportation. The group using *AVILE* has a mean score of 13.55 and the group using CL has a mean score of 14.05. As shown in Figure 13, *AVILE* group's learning result is quite close to that of CL. Considering that the students need to use around 1 hour to be familiar with the virtual learning

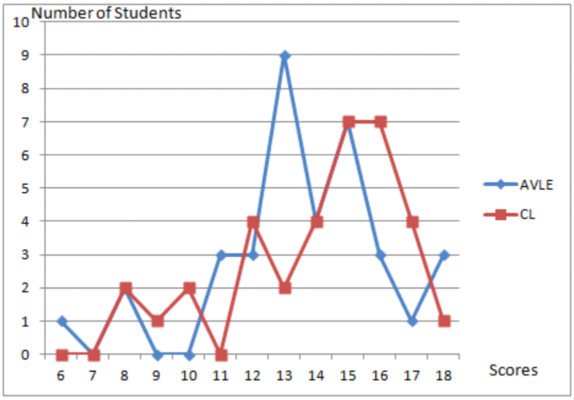

Fig. 13. Distribution of scores in agent-oriented virtual learning environment group (*AVILE*) and classroom learning (CL) group

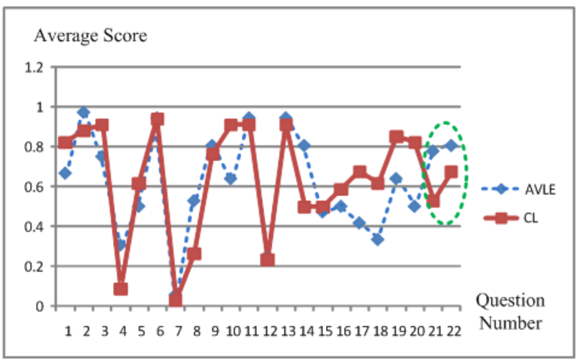

Fig. 14. Average of each question in agent-oriented virtual learning environment (*AVILE*) and classroom learning CL

environment, *AVILE* students still learn quite well. Moreover, more students got highest score (18 scores) in *AVILE* than those in CL. Because MCQ questions include some open questions that require the reasoning of concepts, the students perform well in *AVILE* which stimulates the exploration and thinking at the learning process, rather than just memorizing the knowledge. Figure 14 shows the average score of each question in both *AVILE* group and CL group. It is found that, students of the two groups perform well in different questions.

Some questions require the students to make the reasoning based on what they know, e.g. question 21.

Suppose you killed the plant cell in the Figure of question 14A with poison (that does not destroy the cell membrane) and immediately placed the dead cell in a 25% saltwater solution. 1. Osmosis and diffusion would not occur. 2. Osmosis and diffusion would continue. 3. Only diffusion would continue. 4. Only osmosis would continue.

In this case, students in *AVILE* perform better. On the other hand, students in CL perform slightly better in the questions about concepts memorizing. The students in *AVILE* might focus on the exploration process with less concept memorization, as agents help them at all the memorizing.

4.5 Discussions

Through the test results, we found that agent-oriented virtual learning environment helps the students at deep learning by encouraging them gain knowledge through thinking and reasoning. The students can also transfer their knowledge easily, e.g. they apply the "osmosis" knowledge learnt in the virtual laboratory to help molecules enter into the root.

According to our observation and interview, the students are very engaged and motivated in the learning in the virtual environment. With the similar computer game experience, they adapt to the virtual learning environment very fast. The students are excited to experience in the virtual world differently with their classmates, and assisted well by the learning agents. However, the test results are not as good as expected, which might be due to the following reasons:

1. The students have little training time to be familiar with the virtual learning environment. They need more time to be comfortable with the learning method.
2. AVILE is a good compensation but not a replacement to the classroom learning. Especially when we conduct the virtual learning with the teachers supervised, the students are easy to be panic.
3. We choose the students who have very good academic performance as the test groups, which might not be very sensitive of the different learning methods.

In the future, it will be used an informal learning method as a testbed to prove the concepts which are learnt in the classroom, rather than replacing the whole classroom teaching.

5 Conclusion

In the paper, we have proposed an agent oriented virtual learning environment (*AVILE*) with a mixture of 3D virtual laboratory and role-playing learning. The learning objects are modeled as goals of goal-oriented learning agents (*GOLAs*), which provide personalized learning experiences through real-time goal selection. The results prove the learning efficiency and students' interests boost over that of the classical classroom learning.

Currently, mouse and keyboard are the main interaction methods for students to conduct the virtual experiments. In the future, we expect to have a more intuitive user-computer interfaces to enhance the engaging experience. Moreover, we will continue to improve the learning ability of the agent to study the students' behaviors in real-time in order to provide a better personalization of learning contents.

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