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Autonomous Pedagogical Agents to E-Learning in Elementary School

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Abstract. *The main purpose of this study is to construct a learning system with a pedagogical agent to assist grade 6 elementary school students to learn mathematics. In order to make up for the shortage of feedback in traditional on-line learning systems, this system manipulates a pedagogical agent mechanism to raise student motivations and give them prompt feedback to support and improve their mathematics learning. Concerning the purpose of understanding this systems various effects for different level students (high, average, and low), this study uses an experimental approach with 62 students as the sample and conducts t-test for statistical processing among levels. In addition, the researchers interviewed participants for greater understanding of the learning effects utilizing this system. The study found that the pedagogical agent has a valuable, positive, and efficient effect on students mathematics learning no matter if their mathematics levels are high, average, or low.*
Keywords: pedagogical agent, computer-assisted instruction, e-Learning

1. **Introduction.** Among the educational levels in Taiwan, the elementary level, the foundation of all others, plays a vital role. Due to the significance of the elementary education system, the Taiwan government issued 1-9 Curricula guidelines for elementary and junior high schools in 2001. The guidelines explicitly indicate that computer instruction should be integrated into all subjects, and students should possess the ability to access information and use computer science systems [1].

However, since the 1-9 Curricula was issued, the greatest challenge for teachers remains the limitation of teaching hours, especially in the area of mathematics. The current teaching hours for mathematics in the 1-9 Curricula is only four 40-minute periods per week for grade 6. With the finite hours and sometimes with huge class and notable individual differences in level of mathematics proficiency, it is not easy for the teachers to give students prompt feedback or even to do individual instruction. Daily homework has a restricted effect in mathematics learning for the student at home. Therefore, we hope to help the instructors to teach the mathematics by combining computers with the Internet for assisting the students to learn mathematics effectively and easily.

At the moment most on-line learning systems display teaching materials on the web in multimedia styles and interact with students through the varied technologies of Scripts. The best advantage of this technique is that the students can do the on-line learning at any time and at any places via the Internet [2]. The multimedia technology can make the presentation of materials lively, diverse, and vivid. However, the lack of feedback mechanisms in the system renders all learning activities superficial; teaching objectives will not be achieved.

Therefore, the idea of an agent mechanism in the on-line learning system has been proposed[3]. The learning agent has become an important topic in the field of computer-assisted instruction [4]. The so-called agent is the computer which is a simulated teacher and provides prompt feedback to the learners. For example, in the Intelligent Tutoring System (ITS), the computer is not only a material provider or a learning tool, but a channel to offer individual instruction and instant feedback, even a strategy to interact with learners for understanding their learning conditions [5]. In Learning Companion System (LCS) which addresses the partner interaction learning model, the computer is a learning partner and can interact with students while they are learning. The LCS has three traits: (a) real students, (b) simulated students in the computer, and (c) simulated teachers in the computer.

Researchers have designed several kinds of agent systems for the purposes of education and training [6][7]. They include AMPLIA, an intelligent learning system with multiple pedagogical agents for assisting medical students learning [8]. Although some studies have shown that the pedagogical agent is helpful in aiding students learning, we can not neglect the related educational foundation theories in a website instruction system.

In agent learning systems, the most widely applied theory is the scaffolding theory [9]. This study will construct a mathematics pedagogical agent learning system. Through the combination of the pedagogical agent mechanism and scaffolding theory, the instructors will be able to help students learn mathematics by interacting with a computer in the website environment, where the students can receive feedback and learn mathematics effectively.

In next section, we will briefly describe the meaning and traits of the pedagogical agent and scaffolding theory. Then, we will discuss the framework and the operation of the system in section 3. In section 4, we will discuss methods to evaluate the systems efficiency in experimentation. In section 5, we will reveal the empirical results. Finally, we will make a conclusion based on the results of section 6.

2. **Pedagogical Agent and Scaffolding.**

2.1. **Pedagogical Agent.**

From the software point of view, the agent is a program which has a specific plan of action defined within a limited domain and a pattern of action which allows for changing its own interaction. And the agent is the architectural components which the program uses for collecting information about the environment and acts upon that environment using effectors. [10][11].

An agent is a physical or virtual entity capable of solving given problems by improving problem-solving ability, and capable of interacting with an inherently social environment. The agent works and communicates with other agents or people in a flexible, intelligent, and autonomous way in a particular environment. Ideally, an agent must be able to learn through experience and to cooperate with other agents. All agents share a common world and have different objectives and points of view, even often generating conflicts which must be solved by negotiating with others. Agents must be committed to a shared plan [12][13][14].

An agent should have some characteristics that are used to connect with human intelligence and that must satisfy agent to be called an agent. The characteristics include [7]:

1. Some degree of autonomous execution.
2. The ability to communicate with other agents or users.
3. A responsibility for monitoring and reacting to the state of its environment.
4. An adaptable internal representation of its working environment.
5. Some degree of mobility.

The agent that consists of a set of normative teaching goals and strategies for achieving these goals and associated resources in the learning environment is a pedagogical agent that is a new approach for making students computer-based learning more engaging and more efficient [3][14]. The pedagogical agent is autonomous, and it facilitates students learning by interacting with them in instructional environments. In addition, a pedagogical agent can animate users who have enough understanding of the learning context and content and are able to perform useful roles in learning settings. Moreover, the pedagogical agent provides an opportunity to simulate human, peer-like interaction. Such social interaction is a key mechanism in computer-based learning [15]. In general, the pedagogical agent can act as a virtual tutor, virtual student, or virtual learning companion that can help students in the learning process.

A pedagogical agent is always designed to be involved in social learning activities for a specific educational purpose [9]. In social learning activities, social interaction plays an important part in contributing to motivational outcomes such as learner self-efficacy and self-regulation [16].

There are several motivations for using an animated presentation agent for teaching/learning purposes. They include:

1. Adding expressive power to a systems presentation skills.
2. Helping the students to perform procedural tasks by demonstrating them.
3. Serving as guides through the elements of a scenario.
4. Engaging students without distracting or distancing them from the learning experience.

With the above mentioned in mind, to construct a new paradigm with a new metaphor for human-computer teaching and learning interaction based on face-to-face dialogue, animated pedagogical agents present two key advantages. They broaden the bandwidth of communication between students and computers. They increase the computers ability to engage and motivate students [17].

2.2. **Scaffolding.** Scaffolding is a learning approach or model of social-cultural constructionism, proposed by Vygotsky (1978) [18] and has become widely applied in the educational environment and is usually adopted in designing educational agents. Scaffolding is often used to describe the instruction or intervention that helps learners achieve goals that are impossible for them to do without this support. Sharpe defines scaffolding as a means of supporting the meaning making process and identify various strategies that constitute a scaffolded environment in the classroom [19]. Graves and Braaten (1996) [20] define scaffolding as a process by which an expert provides temporary support to learners to help bridge the gap between what the learners know and can do, and what they need to accomplish in order to succeed at a particular learning task.

Vygotsky (1978) used the notion of the zone of proximal development (ZPD) to characterize scaffolding. ZPD is defined as the distance between [a learners] actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers [21]. ZPD is a notion that has been widely applied in psychological research and educational settings. ZPD can be regarded as an area where scaffolding is needed to promote learning. In other words, the scaffolding teaching strategy provides individualized support based on the learners ZPD.

Furthermore, scaffolding to be provided includes vertical and horizontal levels as adjustable and temporary support in the zone of proximal development [22]. Depending on the learning performance, the instructor gradually gives more control of the learning activities to the student. Bernard and Sandberg (1993) [23] proposed that a student in a learning environment should be placed within the context of surrounding entities that facilitate the students access to learning resources. A student has access to many learning resources, which can be classified into three categories: content, community, and computational support [24].

According to scaffolding, learning occurs when children are under the guidance of adults or capable peers. The computational instructive support can be a kind of learning scaffolding under the designed content and the build-in of smart learning assistance, such as feedback, orderly procedures, diverse data displays, and anticipated developmental activities. Because the agent can be computational support, therefore, in this study, we implement a system and use three pedagogical agents to interact with grade 6 students in order to help them to learn mathematics.

In this system, because scaffolding stresses temporary support, the agent just shows up at the right moment when students can not solve questions and gives them adaptive feedback. If the feedback that the agent offers still does not assist the students to learn, the agent will give them more feedback until the students can understand and solve the questions presented. In addition, since the questions that the system presents are gradual, from easy to difficult, the question solution skills the students gain are the basis for learning in the next level. For this reason, when the students proceed to higher learning stages, they can solve more difficult questions with the skills they acquired previously and thus need less scaffolding support and agent feedback.

3. **System Outline.**

3.1. **System Architecture.** The system stresses the use of the pedagogical agent mechanism for increasing interaction with students and giving them prompt feedback. Therefore, it should have the following functions and the system framework as shown in Fig. 1.

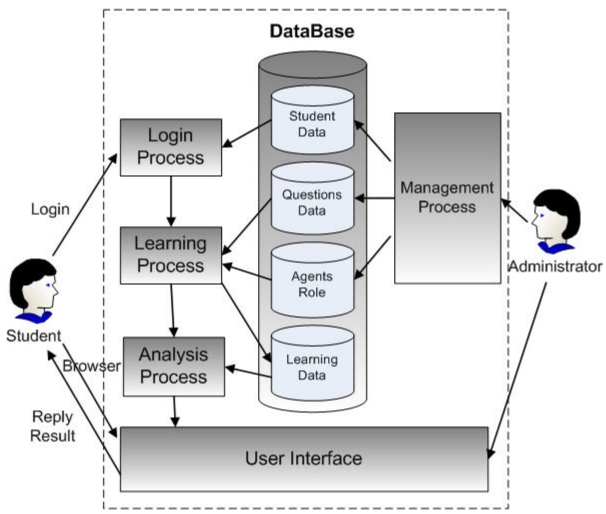

FIGURE 1. System framework.

3.2. **Friendly user interface.** For the students, the unfriendliness of user interface and the unclearness of systematic function indication will impede smooth learning. So, how to operate the system will be introduced on the homepage. Besides, when the students log in, the system will remind them how to choose the answer and will guide them about how to do independent study and to finish all the questions one by one.

3.3. **Perfect and initiative feedback mechanism.** In order to help students learn mathematics effectively and to simulate the interaction between teacher and the students in the classroom, the pedagogical agent plays a teacher role and provides the students with on-line learning feedback. The system will interact with the students once they do the questions. If an answer is correct, the agent will praise them. If the answer is incorrect, the agent will guide them in solving the problem correctly.

3.4. **A complete record of students learning history.** The system stresses the functions of the pedagogical agent for helping the students learn. In order to know if the agent is really helpful for the students learning, the agent will record the choice-making so that the instructor can check the learning history and further assist the students to understand the questions.

3.5. **Integrated arrangement and management of the question database.** The system will display the questions in an orderly manner based on levels, from easy to intermediate to difficult. Once the students complete the first question, they can do the next one until all questions in that level are solved. In order to increase the learning effectiveness after the students do one question, the computer will check the answer and give appropriate feedback through the support of the pedagogical agent.

3.6. **The Role Definition of the Pedagogical Agent.** In order to thoroughly utilize the pedagogical agent as a feedback mechanism for attracting students learning interest, the system uses three different kinds pedagogical agent to interact with student. Role definitions of the three agents are shown in table 1.

After the students log into the system, they can see Merlin showing up on the homepage and interacting with them, asking them to key in their names and student numbers. The system will immediately check the data the students have keyed in. Consequently, if the data is correct, the system will turn to the learning interface.

TABLE 1. The Role Definition of Pedagogical Agent.

Image	Role	Explanation
 Merlin	Guider	Once the students log into the system, Merlin will tell them how to learn. For example, calculation expression must be written in the word frame, then click on the right answer choice, then press *ENTER*.
 Genie	Prompter	If the answer is incorrect, Genie will appear and give the students the prompt for solving the question and help further learning.
 Peedy	Encourager	If the students make a good choice and press *ENTER*, Peedy will appear and say that the answer is correct.

After the students enter the learning interface, the system will greet them and show which question they are in. For example, the current place is in question 1. At this moment, Merlin will emerge and interact with the students, guiding them about how to learn. For instance, Merlin will instruct the student about how to key in calculation expressions and answers. Once the students send their answer, the system will instantly check it and record the students calculation expression and answer. If the answer is correct, the system will encourage them through Peedy agent, then show question 2. If the answer is incorrect, the system will tell the students and give the solution promptly through Genie agent. So, the students successfully handle the first question and go on to the next one.

4. **Experiment.**

4.1. **Participants.** The subjects of the study are two grade 6 classes from one elementary school in Tainan County, Taiwan. Class A, 30 students, is the control group, while class B, 32 students, is the experimental group. For the purpose of distinguishing more exactly the effects of mathematics learning among high, average, and low level students, the researchers conducted a test to determine the students levels. After discussing with several experienced mathematics teachers, the researchers assigned the students with scores between 85 to 100 points in the test to the high level, students with scores between 70 to 84 to the average level, and 69 and below to the low level. The detailed score distribution in the test is shown in Table 2

TABLE 2. The Population of Different Level Groups.

Math levels	Control group	Experimental group
High	10	12
Average	12	10
Low	8	10

4.2. **Experimental Design.** The main purpose of the study is to investigate the effect of the pedagogical agent mechanism in helping elementary students to learn mathematics. In order to understand the importance of the pedagogical agent mechanism, the researchers built two different learning systems, one with a pedagogical agent for the 32 students in the experimental group, the other, without a pedagogical agent for the 30 students in the control group. Each learning system included 20 questions from easy, to moderate, to more difficult, to most difficult.

For learning strategy, both systems asked students to complete one question before going on to the next one. For this reason, when an answer was incorrect, the system showed the words I want to do again to the students, giving them more chance to practice. The system simultaneously displayed the words I will quit to quit the question. In the aspect of learning feedback, both systems tell the learners if their answer is correct or incorrect. The only difference is that the system with the pedagogical agent gives the students a solution prompt so that the students can learn how to effectively deal with the tough questions then go to the next question.

Through the control of learning strategy, the researchers analyzed the different effects of the pedagogical agent on three different groups based on the students mathematics scores and quitting times while they learned in the system. During the whole process, the quitting times determined the students scores of mathematics learning. If the students did not quit learning at all, they got 100 points for their performance; if they quit one time, they got 90 points; and so forth.

The data from students were analyzed with SPSS for Windows 12.0. Independent sample t-test is determined for analysis in .05 p value in order to learn if the pedagogical agent had significantly different effects among the students of high, average, and low mathematics level.

In addition, the researchers also ran a survey using a quantitative questionnaire and conducted interviews with the participants for further understanding of their opinions and attitudes about the pedagogical agent. Through the analyses of the questionnaire and the interview, the researchers could better understand the effects of the pedagogical agent on students learning of mathematics. The results and findings will become the suggestions and references for future improvement of the pedagogical agent system.

For comparing the learning impacts of the pedagogical agents in each of the two systems to students learning of mathematics, both systems, one with a pedagogical agent and the other without a pedagogical agent, have 20 questions that include various degrees of difficulty and are highly interrelated to the learning content. Because of this, the researchers selected 60 questions from different groups in the unit Factor and Multiple of the mathematics database developed by the publisher Kang-Xuan, and conducted a test of 100 students from an elementary school in Tainan County, Taiwan.

After the test, the researchers analyzed the ratio of the correct answers for each question from the 100 students. If over 75 % of the students had the correct answers, then the questions are easy; 50% to 75%, average; 25% to 50%, more difficult; below 25%, most difficult. The researchers picked up 8 questions from each easy groups and average group and 12 questions from each more difficult group and most difficult group. Then the researchers split all questions in each group into two parts. So, each part had 4 easy questions, 4 average questions, 6 more difficult questions, and 6 more difficult questions. These two categories of questions were put in the two different systems for students to learn.

4.3. **Procedures.** Chan et al. (2003) mentioned that the experimental time should not be too short. Hence, the researchers planned to conduct the study for about 3 months, from October to December in 2006. The first 4 weeks were for the students to comprehend the operation of the system, the next 5 weeks were for students to learn on-line. The final 3 weeks were for the researchers to manage the survey and the interviews as well as to analyze the data.

5. **Results.**

5.1. **Analysis of T-test.** The researchers converted the times when participants individually quit the learning system into mathematics performance scores in the test for the two systems, then conducted t-test. The mean, standard deviation, and P value are shown in Table 3. Table 3 shows that no matter what levels the students are in high, average, or low, the mean of class B learning with a pedagogical agent is higher than class A without a pedagogical agent. There are significant differences between class A and class B (P¡.05). We realize that with the support of an agent the students in class B actively solved mathematics questions instead of quitting the learning.

Table 3. The Data Analysis of T-test.

Math levels and classes	Samples	Mean	SD	P-value
High				
Class A	10	91.00	7.38	.001
Class B	12	100.00	0	
Average				
Class A	12	61.67	3.89	.014
Class B	10	95.00	5.27	
Low				
Class A	8	35.00	16.04	.009
Class B	10	82.00	7.89	
Total	62			

5.2. **Analysis of the Questionnaire.** The subjects of the questionnaire are the 32 students in class B who learned in the pedagogical agent system. The researchers used a 5-point Likert format to analyze the mean and SD of each question and to compare the differences in three dimensions: students motivation, satisfaction of function, and satisfaction in mathematics.

Table 4. The Results of Questionnaire Analysis

Questions and content	Levels			Total mean	Total SD
	High	Average	Low		
1. The sounds and actions of the pedagogical agents make me like to spend much more time on mathematics leaning.	4. 1	4. 3	3. 8	4. 1	0. 7
2. I hope the pedagogical agent quickly gives me a prompt once my answer is wrong.	3. 6	4. 1	4.2	3.9	0. 7
3. When my answer is correct, the Encouragement from the Pedagogical agent give me more Confidence for the next lesson.	3. 8	4. 0	4. 3	4. 0	0. 7
4. The clear design of the website lets Me know how to do the learning.	4. 3	4. 0	3. 8	4. 0	0. 7
5. I can clearly hear and see the messages form the pedagogical agent.	4. 0	4. 0	4. 1	4. 0	0. 7
6. The cute and funny actions from the pedagogical agent make me happy to learn.	3. 9	4. 2	4. 3	4. 1	0. 7
7. I am pleased to learn mathematics if the questions come one by one.	4. 3	4. 0	3. 9	4. 1	0. 6
8.The prompt form the pedagogical agent helps me understand better the meaning of the questions.	4. 3	4. 2	3. 9	4. 0	0. 6
9. The prompt from the pedagogical agent lets me realize why my answer is wrong.	4. 0	4. 1	4. 0	4. 0	0. 6
10. When I learn math, I do not feel bored because of the presentation by the pedagogical agent.	4. 4	4. 1	4. 1	4. 2	0. 6

Dimension 1: survey questions concerning promotion of learning motivation.

In Table 4Aall the means of questions 1 to 3 are above 3.5. This shows that most of the students think that the pedagogical agent can improve their learning motivation and interest.

Dimension 2: survey about satisfaction concerning the function of the system.

In Table 4, all the means of questions 4 to 6 are above 3.5. Thus, it becomes clear that most students consider the design of the system is very clear and appropriate.

Dimension 3: survey on the satisfaction of learning mathematics in the system.

In table 4, all the means of questions 7-10 are also above 3.5. Thus, it is evident that most students believe the system can help them to learn more easily.

5.3. **Analysis of the Interview.** The population for interview is the students in the experimental group who worked with the pedagogical agent. The following contains the synthesis and analysis of the interviews:

1. The plan and the design of the website layout: Students thought that the screen is clear but a little dull and monotonous. It needs more color to brighten the screen.
2. The presentation of mathematics questions: Students considered that the questions should be presented in audio as well as video in order to help students better understand the meaning of mathematics questions.
3. The guides and prompts to the students: Student thinks that the prompt should not be presented immediately after the first wrong answer. Instead, it should be offered after the second wrong answer so that the students can have more of a chance to think about the problem and figure it out. The students consider that the prompt should be displayed in words as well as in pictures. Then, the students could watch the prompt again and again so that they could understand the questions well and solve them more quickly.
4. The review of the students learning history: the students hope that they can check their learning history, including the time they spent on each question and in the calculation of the solution, in order to help them to avoid the same mistakes in next learning.
5. The use of mathematics symbols: all interviewees indicate that it is difficult for them to use the key-board and to key in the mathematics symbols. They suggest that the system should offer a mathematics symbol table so that they could just call and click them.
6. The actions of the agent: Students express that the agent always gave them the same actions as rewards when their answers were correct. At first, they thought it was very funny, but they were bored after some practice. Therefore, they hope the agent could offer different reinforcements based on the question difficulty so that the learning will be more interesting.
7. The character of the pedagogical agent: Students implied that the system could create some pictures like the cartoon figures such as Pickchu, Doraemon, Mickey Mouse, and so forth. The learners could choose their own favorite character to learn with them. This would help them to improve their learning performance.
8. The voices of the pedagogical agents: All interviewees liked the voices of both male and female agents. They consider that it would be more serious if all the voices were male. Furthermore, students believe that the voices should be more mild and gentle. Furthermore, the voices could be more lively and delightful when the agents offer the rewards. In this way, the learning would be more interesting instead of boring and dull.

6. **Conclusions.** The mathematics learning system with pedagogical agent stresses the agent mechanism to promote interactions with students and appropriate feedback in mathematics learning. From the analyses of the questionnaire and interview, we understand that an integrated and valuable system like the system in this study should offer ideal and lively feedback, completely record students learning history, and possess well-established editing and management functions for the question database. Only these capabilities can effectively help students learn mathematics on-line.

Participating instructors in the study consider that it is difficult to maintain students motivations and interests and present timely one-on-one feedback in the traditional classroom. The pedagogical agents can increase students learning interest in mathematics by giving appropriate feedback and helping them to solve the questions they encounter. Consequently, this system complements the lack of interactions in traditional teaching. But, the instructors must spend much more time on this system to learn how to apply it in order to assist students and give them prompts for solving mathematical challenges. After all, correct and instantaneous prompts cause effective learning.

The system gains support and approval from most students. However, after the analyses of questionnaires and interviews, it is apparent that the system still has some functions to be improved. Therefore, the system should be continuously revised and amended so that is can be used in other levels and areas.

The researchers offer some suggestions:

1. Continue to improve and develop the mathematics learning system with pedagogical agents. (a) The website pages should be kept clear and well-designed; and more colors should be added to brighten the dull pages. (b) Students should freely choose the agent character that they like before beginning so that their favorite agents can accompany them throughout their learning. (c) The prompt of the pedagogical agent should be kept passive; the prompt should appear only when the students need and call for it; giving the students the chance to deliberate the questions by themselves. (d) The system should offer a mathematics symbol table which can be called up when the students need it; they should be able to click on the symbol table instead of keying it in; clicking is more convenient than keying.
2. Extend the subject levels. The pedagogical agent mathematics learning system has been applied to grade 6 students with significant effectiveness. Therefore, it should be administrated to the students of other grades and levels.
3. Extend the study realm. This study focused on mathematics learning. However, the possibility of extending using similar systems in other areas, such as language, social studies, and natural science should be explored in order to integrate information technology into all areas of the curriculum.

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