Providing Students Hints and Detecting Mistakes Made by Students in a Virtual Experiment Environment

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Abstract—This study models a virtual experiment environment (VEE) by adopting the Petri net theory. Petri net-based VEE can record the experimental activity processes of students and evaluate the students' learning abilities. Petri nets can be used as visual-communication aids, and are similar to flow charts, block diagrams, and networks. Consequently, the experimental steps can be easily transferred to the Petri net model. Analysis of the collected data with the Petri net model indicates that errors made by students during experiments can be categorized into two major types, namely, measuring and procedural errors. This work implements a Petri net-based VEE for physics experiments. A total of 72 third-year junior high school students participated in this research. Both pretesting and posttesting are performed to ensure that the Petri net-enhanced VEE is useful.

Index Terms—Learning control systems, learning diagnosis, Petri nets, student experiments.

Fig. 1. Four parts of a VEE.

I. INTRODUCTION

VIRTUAL experiment environment (VEE) in e-learning provides students with a visualized social learning environment by simulating experiments on the Internet [1], [2]. A VEE includes a set of simulated virtual equipments for students to perform experiments [3]. Researchers recently classified VEE systems into three major types: real lab, visual lab, and virtual lab.

1) Real lab requires a set of external experiment devices and a software kit [4].
2) Visual lab utilizes video-media and some manipulation tools to cover both the realities of a real laboratory and conveniences of a simulated laboratory (also called a software laboratory) [5], [6].
3) Virtual lab simulates experiments in either 2-D or 3-D forms [7], [8].

Although VEE offers students an environment to perform laboratory experiments on the Internet, teachers cannot easily monitor the experiment progress or provide appropriate instructions to students in real-time. Many interactive intelligent tutors or
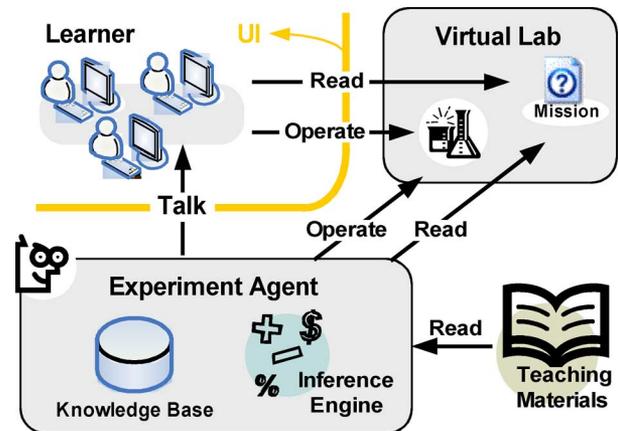
environment solutions in VEE have been presented to solve this problem [9]–[12].

The main objective of this research is to create a VEE in which students' activities can be recorded during experimenting, and students' experiment processes can be evaluated in real-time. This investigation applies a Petri net to model experiments in order to allow comparisons between the experiment processes of the students and teacher. The VEE can then automatically identify the errors made by students and provide timely assistance.

The VEE in this research is a physics experiment environment. The physics experiments cover the physics of the third-year junior high school in Taiwan, including measurement, velocity, and free-falling. Seventy-two third-year junior high school students participated in this study.

II. VEE AND PETRI NET

A. VEE

As mentioned in the previous section, an interactive VEE comprises four major integral parts, namely, the knowledge base, user interfaces (UIs), teaching materials, and interactive protocols. The diagram in Fig. 1 indicates that these four components cooperate with each other [12], [14].

Learners can perform many scientific experiments with appropriate tools and UIs. The teaching materials and UIs should conform to some basic educational concepts, such as the seven problem solving stages and skills in scientific processes [15]. Experiment agents and/or the system might be able to read the teaching materials directly without supervision, and

Fig. 2. Design process for VE.

Fig. 3. Simple Petri nets. (a) One-to-one. (b) Many-to-one. (c) One-to-many selection architecture.
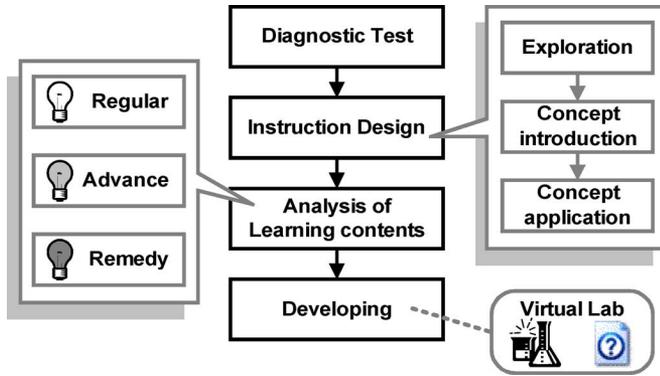
store some well-organized knowledge (or information) in its "artificial brain," the knowledge base. After understanding specific experiments, the agent and/or system can guide learners in performing laboratory work; provide learners with some useful and suitable instructions for the next step; demonstrate the whole experiment process automatically by manipulating UIs; and even predict whether a learner's action will work correctly.

B. Designing a Virtual Experiment

The process of designing a virtual experiment (VE) should be determined before adopting Petri nets to analyze a VE. Fig. 2 shows a revised process of designing a VE based on Shin's idea in 2003 [16].

First, teachers should use a diagnostic test to measure the prerequisite knowledge of learners. Second, teachers design instructions to introduce new knowledge to learners. The instruction design has three stages, namely exploration, concept introduction, and concept application.

1) In the *exploration stage*, a learner discovers the problem and tries to solve it on his own.
2) In the *concept introduction stage*, teachers discuss some concepts with the learners, including those that students have not learned yet, and help them to resolve intellectual conflicts.
3) In *the concept application stage*, teachers evaluate what students have learned, and students also learn how to solve similar real-life problems in the future.

Third, teachers classify the learning content into three levels, namely remedial, regular, and advanced, according to difficulty. Finally, developers can build a suitable VEE for the VEs.

C. Fundamentals of Petri Net

Dr. Carl Adam Petri (1962) introduced *Petri nets* in his doctoral dissertation [17]. A Petri net is a systematic analysis and developing tool based on a mathematical and state-oriented, diagramed model. Petri net has been applied to many domains today and is a promising tool for describing and studying systems that are characterized as concurrent, asynchronous, distributed, parallel, nondeterministic, and/or stochastic [18], [19]. Thus, a graphical tool, a Petri net, can be utilized as a visual-communication aid similar to flow charts, block diagrams, and networks.

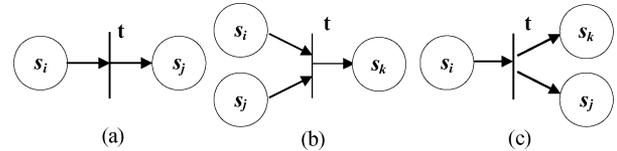This investigation adopts a Petri net as its analytical tool. The Petri net contains the states, transitions, and directed arcs connecting the places and transitions, and shows the flow relationship.

As in Fig. 3, the transmission rules can be divided into three categories, namely, one-to-one, one-to-many, and many-to-one.

1) **One-to-One** is the basic transmission rule and is depicted in Fig. 3(a). This rule states that target activity s_j starts immediately after the source activity s_i is complete.
2) **Many-to-One** is an AND transmission rule and is depicted in Fig. 3(b). This rule states that the target activity p_k starts when both s_i and s_j are complete.
3) **One-to-Many** is a parallel trigger transmission rule and is displayed in Fig. 3(c). This rule states that the target activity s_j or s_k is chosen after the source activity s_i is complete.

D. Expert Systems: Rule-Base versus Petri Nets

Rule bases are usually used in expert systems. The representation form of a rule is the "IF … Then …" structure. Rules can be determined by patterns in facts [20]. A Petri net is also a rule-based system. Moreover, Petri net uses tokens to control the flow in the system. In this study, the whole experimental process is represented by a set of states, and each student's action is represented by the token. A VEE can monitor and evaluate the student's experiment process according to the location of the token.

E. Relations Between VEE and Petri Net

This work applies Petri net to develop a VEE with the following abilities:
- analyze the experiment standard procedures;
- record the students' experiment processes;
- identify the mistakes that the students might make during the experiment.

III. ANALYZING VE BY PETRI NET

A VEE needs seven types of knowledge instructions to enable students have ability to manipulate the VE.

1) *Load* instruction to load experimental tools and components;
2) *Measure* instruction to gather the required experiment data;
3) *Select* instruction to access the experiment tools and components in the VE desk;
4) *Release* instruction to release the experimental tools and components;
5) *Operate* instruction to manipulate the attributes of the experimental tools and components;
6) *Move* instruction to move the experimental tools and components by holding down the left mouse button;
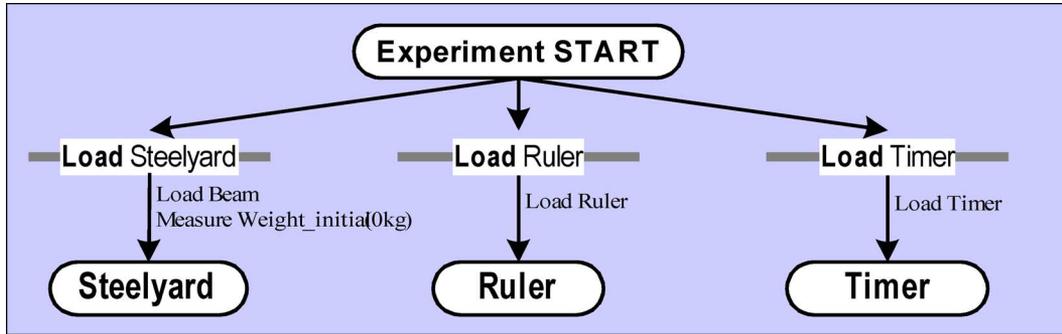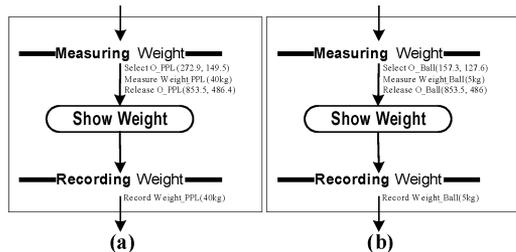
Fig. 4. State model (one-to-many model).

Fig. 5. Action model. (a) Measuring and recording the man's weight. (b) Measuring and recording the ball's weight.

7) *Record* instruction to store measurement data obtained by experimental tools and components.

The system can record all operations performed by the student with the above knowledge instructions. Furthermore, the system can diagnose the student's experiment procedure and provide the student manipulative demonstration and suitable hints.

A. Modeling VE With Petri Net

The basic elements of a Petri net analytical mechanism are states, transitions, and directed arcs. Since a Petri net is employed to design a VE, two different models for developing a VE are needed.

1) **State Model**: The state model adopts the "one" state in the Petri net as the *entry point*, and one/many state(s) as the *terminal(s)*. Many actions and related transitions (state-to-transition and transition-to state) exist between the entry point and the terminal(s). The State Model generally uses a one-to-many transmission rule. Fig. 4 shows an example of a state model.

2) **Action Model**: The action model generally denotes an action that might be performed by the student in the VEE. The action model uses transition as the *entry point* and *terminal(s)*. The transmission rule presented by the action model can be either one-to-many or many-to-one. For instance, measuring and recording a free-falling object's weight, as illustrated in Fig. 5, is the simplest action in the VEE.

B. Example

Fig. 6 shows an example of a VE based on a complete free-falling Petri net. The free-falling experiment contains an object, which can be either a ball or a person. The system gives students the following question (or mission).

"There are two objects (one ball and one man) in the experiment. Which one is the correct statement about this experiment?"

1) The man is heavier than the ball, thus the falling time of the man is shorter than that of the ball.
2) The falling times of both the man and the ball are equivalent, and the falling time is not influenced by the falling object's weight.
3) The falling heights of the man and the ball are different, thus the falling times cannot be compared.

C. Revisited Experimental Process

Based on the question above, the whole experiment process can be decomposed into six parts.

1) **Loading tools**: This experiment employs three tools, namely steelyard, ruler, and timer. The Petri net forms a state model with a one-to-three parallel structure (Fig. 4).
2) **Measuring and recording the man's weight**: The man's weight should be determined first. Hence, the object (man) is moved to the steelyard to measure his weight. The weight is recorded in the experimental notes [Fig. 5(a)].
3) **Recording the man's free fall**: To determine the man's free-falling time, the man is moved to the platform in the environment. The timer is then reset to zero. Next, the "start falling and counting time" button in the environment is clicked. After clicking, the man falls down until he touches the ground, when the timer is stopped. A parallel action model is used; the system can either record the falling time on the experiment note, or check whether the ruler is loaded and then measure the distance from the platform to the ground. The falling height is also recorded on an experiment note immediately after measurement. The architecture is based on a parallel model because the recording time and measuring height must both be recorded to get the experiment result. Fig. 7(a) displays the Petri net model for this step.
4) **Measuring and recording the ball's weight**: The measuring and recording process for the ball is the same as that for the man. The object is simply changed to a ball. Fig. 5(b) illustrates the Petri net model for this step.
5) **Recording the ball's free fall**: The ball's free-falling process is the same as the previous man's falling process, with the object changed to the ball. The process is not executed. Fig. 7(b) shows the Petri net model for this step.
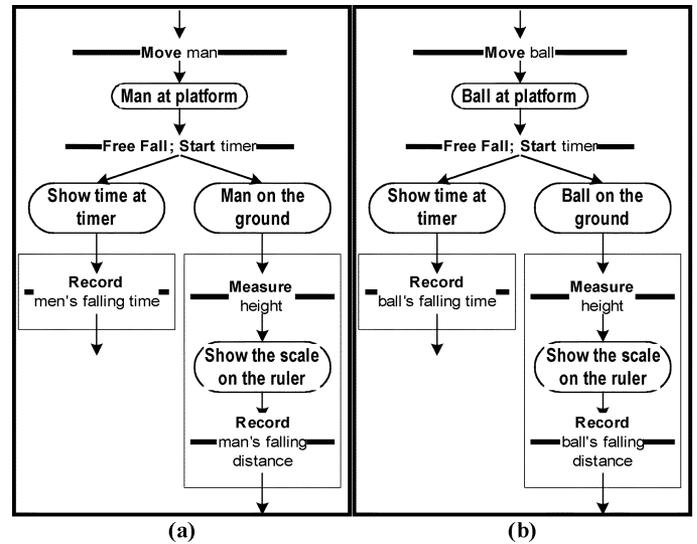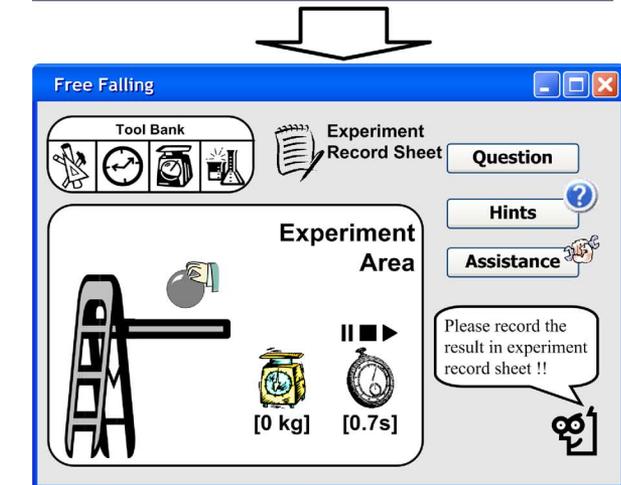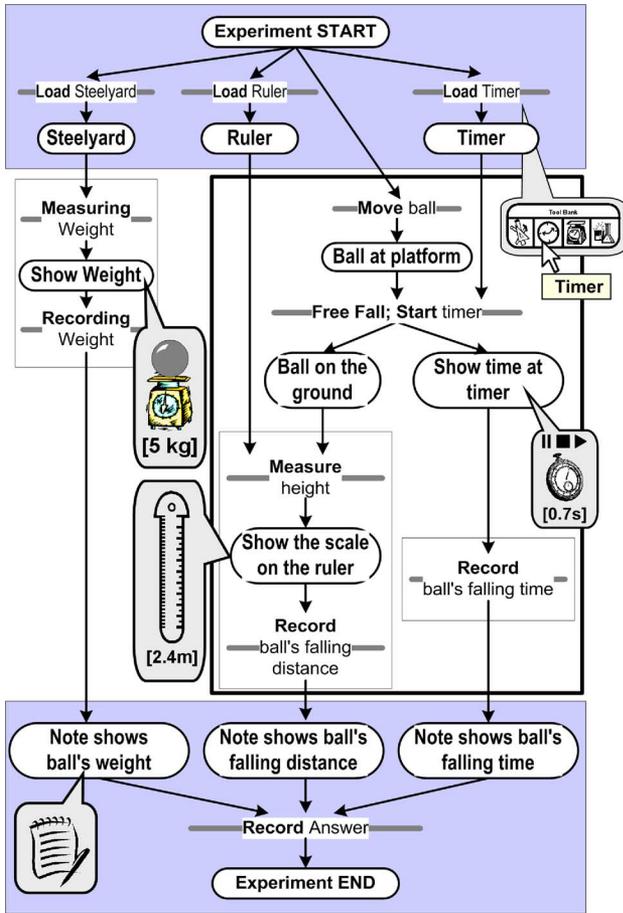
Fig. 6. Complete Petri net-based VE example.

Fig. 7. Recording. (a) Recording the man's free-fall. (b) Recording the ball's free-fall.

Fig. 8. Answering the questions.

6) **Answering the questions**: The final answer in the experiment note can be recorded when all previous five parts are finished. If the user records the answer without finishing the experiment, then the diagnosis system detects the error. Fig. 8 shows the Petri net model for this step.

D. Error Types Analysis

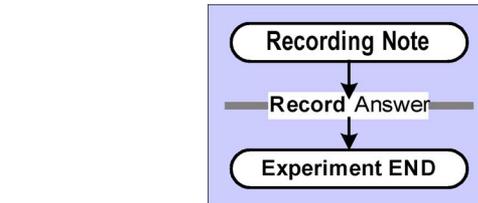The most important goal of this study is to enable the system (either the VEE or the agent) to determine what actions the student took, and to diagnose the mistakes made by the student during the experiment. The system can classify the mistakes made by the student once it has understood the operations manipulated by the student according to the Petri net. The most obvious error type is a *procedural error*, since the standard experimental procedure is designed by the Petri net. As well as the procedural error, the *measuring errors* can be discovered from the action logs.

1) **Procedural Error** occurs when a student manipulates the experiment in one Petri net model (model A), such as a state model or an action model, and then jumps to another model (model B) before reaching the terminal of the original model (model A).

2) **Measuring Error** is divided into three error types.
   a) *Recording error* occurs when the experimental data entered by the student are inconsistent with the real data recorded automatically by the system.
   b) *Estimation error* occurs when the answer calculated by the student is inconsistent with the real answer stored in the system.
   c) *Operation error* occurs when the student picks the wrong experiment tool. For instance, the experiment asks the student to measure an angle, but the student picks up a ruler.

IV. EXPERIMENTAL SYSTEM

A VEE was implemented by the above methodology. The VEE included some VEs on the basic kinematics, which are (suitable or appropriate) for students at the junior high school
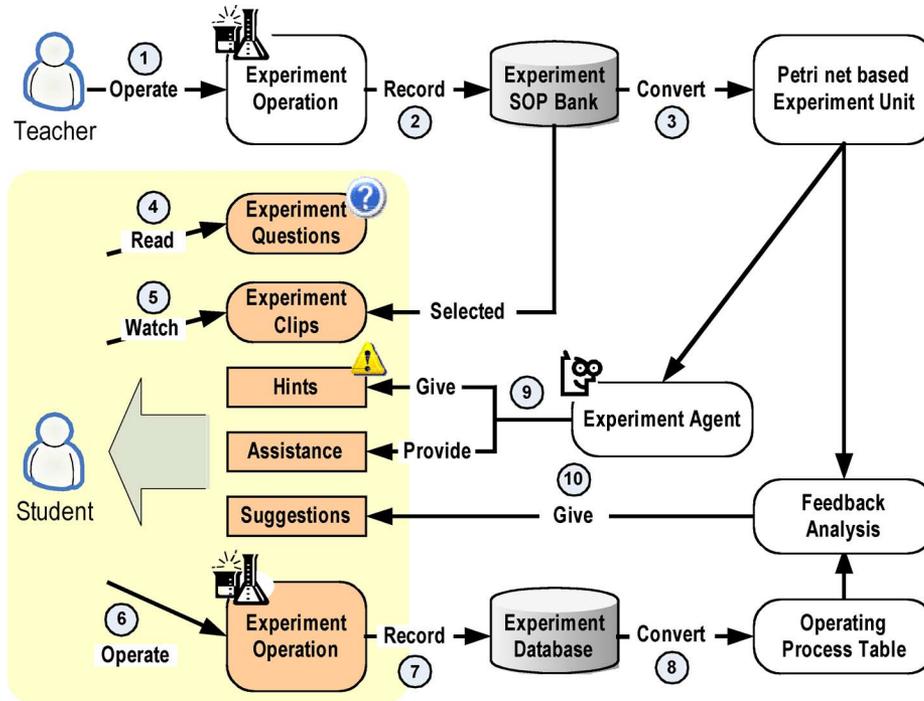
Fig. 9. Procedure diagram of the system.

level. The details of the VEE are described before discussing the study results and the collected data.

The VEs were analyzed and developed in the VEE using Petri nets. The system was applied to record and discover the students' learning progresses and experimental mistakes. Fig. 9 shows the system's procedural diagram.

The procedure has two parts depicted in Fig. 9, namely the teacher and student parts. The teacher part constructs a standard experiment procedure for each VE. This standard procedure designed by teachers with Petri nets enables the system to compare the standard experimental procedure with that built by the student. Moreover, the system can follow the student's learning progress and provide some hints or assistance to the student. The second part is the student part, in which the system can automatically demonstrate the whole experimental operation procedure according to the Petri nets, or simply give the student some hints for performing the specific experiment. The student's operations are recorded in the experiment record bank. These operation data are compared with the standard experiment procedure, as given in the teacher part. After receiving the suggestions from the system, the student can perform the VE again to realize all concepts in the experiment.

Fig. 10 displays a snapshot of the VEE performing a free-falling experiment. A little girl, weighing about 40 kg, is standing on a platform. The student is required to perform an action for the experiment, but might have no idea about what to do. Therefore, the system provides a hint about the next step based on the standard experimental procedure, developed by the teacher with a Petri net. Fig. 10 shows a little person (called an agent) standing on the ground in the middle-bottom position. The agent says, in the dialogue bubble, "Please load the tool, Timer."

The VEE has three buttons, as illustrated on the top-right corner of Fig. 10. The first red button ends the experiment; the second button asks for assistance; and the third button requests a hint. Fig. 11 depicts a snapshot with a diagnosis result immediately after the student has completed the experiment. The VEE pops up an error message to tell the student what errors and mistakes that the students made when performing the experiment. The diagnosis results in Fig. 11 are as follows:

- procedural error: the record of falling duration is incorrect;
- procedural error: the record of falling distance is incorrect;
- estimated error: the weight entered is 40 kg, but the measurement shown on the weighting tool is 5 kg;
- recording error: the weight record is incorrect.

V. RESULTS AND DISCUSSION

Seventy-two students from three classes participated in this experiment. The participants were third-year students in their last year in junior high school and would have insufficient prerequisites. The students were divided into three different groups by class (Table I). All students were asked to take a pretest before performing the VE and a posttest after they had finished the VE. The experiment was run June 10–17, 2004.

Table I shows the differences among the three groups. The students in Group A performed experiments in the real laboratory. To ensure that the Petri net-based VEs were useful to students, Groups B and C were asked to experiment with the VEE. The groups performed different VEs. Group B performed a simple VE, and Group C performed a Petri net-based VE, which could provide the students with assistance and hints from the Petri net according to actions performed by students.
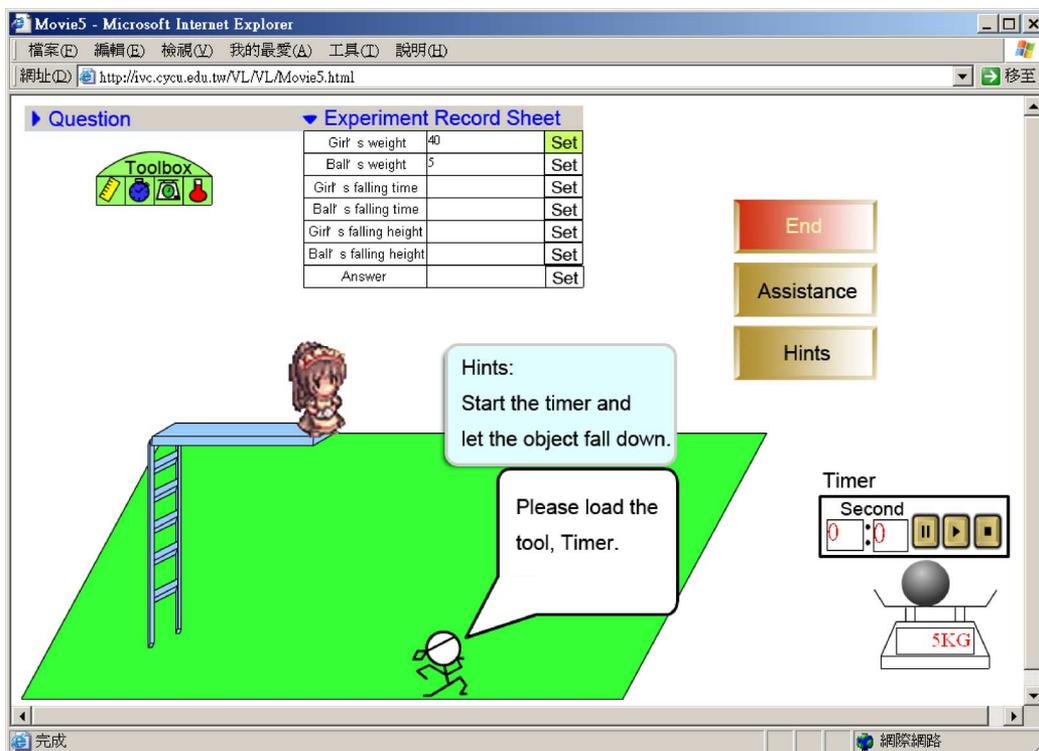
Fig. 10.   Assistance of the agent in VE.

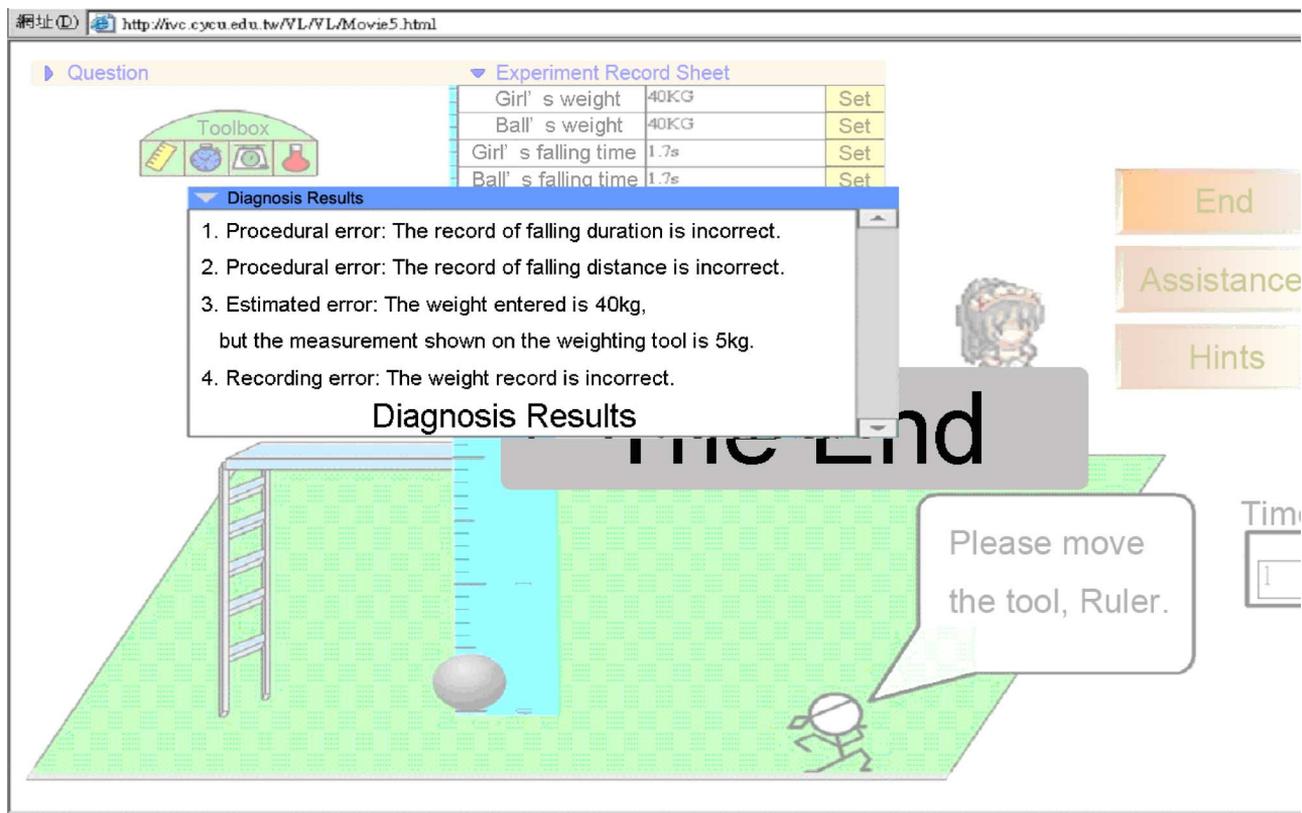Fig. 11.   Diagnosis results.

The pretest and posttest contained 25 items constructed and filtered by a practice test in advance. This practice test was performed by high school students who were not part of this experiment. Items that were not in the required standard (difficulty: $0.3 \sim 0.7$ and lowest discrimination: 0.25) according to the practice test results were eliminated. The reliability coeffi-

TABLE I
THREE GROUPS

	Group A	Group B	Group C
pretest-posttest	X	X	X
using V.E.E		X	X
assists and hints			X

TABLE II
GROUP DISTRIBUTION

	Group A	Group B	Group C	Total
High Grade	8	8	7	23
Mid Grade	8	8	8	24
Low grade	8	9	8	25
Total	24	25	23	72

TABLE III
THREE GROUPS' PROGRESS

	Group A	Group B	Group C
Pre-test	61.16	51.04	52
Post-test	61.21	56.16	58.08
Difference	0.05	5.12	6.08

TABLE IV
EXPERIMENT COMPARISONS (AVERAGE DATA)

	Group B	Group C
Procedural Errors	5	5.625
Measuring Errors	14.92	10.75
Experiment Time	25m:33s	21m:05s

cient of the 25 items was 0.79 based on the Kuder–Richardson formulas 21 [21]. Moreover, the reliability of the pretest sheet was 0.82, and that of the posttest sheet was 0.85 based on Cronbach's value [22].

Table II lists the distribution of the three groups. Each group had 23–25 students. The students in each group were separated into three subgroups according to the previous grades in school, namely high, middle, and low grade. The VEs adopted in this study concerned fundamental kinematics.

The experimental results in Table III indicate an obvious performance improvement in these three groups. Although the average pretest score of Group A was higher than those of Groups B and C, the students still showed an obvious improvement when using the VEE. The students in Group C made the strongest improvement when adopting the Petri net-based VE.

Besides improving student performance, the Petri net-based VE also reduced the number of errors made by students during the experiment. As revealed in Table IV, the average measuring error in Group C was less than that of Group B, meaning that the hints and assistance provided by the system to students in the Petri net-based VE was useful to the students. The students in both Group B and C might have made similar procedural errors because students in both groups performed the experiments in the same VEE.

VI. CONCLUSION

This study applies Petri net analytical tools to VE development. Petri nets enable a VEE or related agents to provide students with hints and assistance. Moreover, the system knows what students are doing, and the mistakes that they make during the experiment. Once the system understands the experiment procedure, it can either demonstrate the entire experiment operation, or show the next experiment step to the student, depending on the request made by the student.

This investigation implements a VEE with some Petri net-based VEs involving kinematics. To confirm that the demonstration, suggestions, and assistance provided by the Petri net-based VEs are useful to the students, an experiment involving three classes of third-year junior high school students is performed. Analytical results indicate that even those students who obtained low grades before they joined this study improve their performance sufficiently to enable them to catch up with high-performing students.

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