

The Development of the Simulation Modeling System and Modeling Ability Evaluation

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Abstract

This research intended to develop and evaluate the computer simulation software of pendulum, and explore junior high students' scientific modeling ability. Firstly, the researcher analyzed pendulum modeling software development. Secondly, this researcher considered the validity of the software and the assessments of the whole system, and he revised the software to make it more suitable for the purposes of junior high students' pendulum modeling with computer simulation. Finally, the purpose of this research is to contend the suggestions of application of the software for junior high science teacher, and to develop synthetic software of pendulum modeling in this research. The conclusions are as follows: 1. There are six kinds of variables of simulation pendulum: mass, length, angle, force, air-force, and width of string. Based on the modeling processes, the researcher needed to develop relevant software tools to help students' modeling, such as Time-recorder, grid chart and the film of Galileo's history of science. 2. The fuzzy synthetic evaluation was implemented for assessing modeling ability. Five aspects, with totally 19 sub items together, are contained in the evaluation system, which can be regarded as the evaluation for student's modeling ability. 3. Via the evaluation in discipline content, media interface and the user attitude, etc., this simulation software is suitable for the stage of junior high student pendulum modeling.

Keywords: Evaluation, Fuzzy set, Modeling Ability, Pendulum, Simulation.

1. Introduction

Computers play a central role in developing and applying scientific knowledge, and they can also facilitate the learning of science. Computer simulation software could provide opportunities to explore concepts and models which are not readily accessible in the laboratory. For example, it is hard for students to conduct experiments requiring expensive materials, unavailable equipment and hazardous procedures. Furthermore, the students do not have so much time to stay at general laboratories. Computer simulation can provide students with adaptive environment which enable students to learn what they need.

Assessment and evaluation applied to education play a crucial role in teaching and learning processes. They can reveal information not only about students' learning results but the related problem-solving abilities. Also, students' learning results can indicate their levels of abilities. Therefore, teachers can modify their teaching content based on students' learning results.

1.1. Pendulum Modeling Simulation

Models take many forms, including physical objects, plans, mental constructions, mathematical equations, and computer simulations [1]. Scientist also depends on the model to express the phenomenon of natural science. For example, the mathematic model, $f = m a$. Even a picture or a chart can express the relationship between the two variables that is a concept model, for instance: the relationship between length and period. In today science education, educator focus more and more on scientific inquiry, that is, students do the experiment by themselves; rather than just receive teachers' lectures passively. We suppose that students experience the exploration of the knowledge of science just as scientists do. We call it "authentic science".

Modeling is a kind of inquiry. Models help scientists and engineers understand how things work, and point out that models and modeling are key tools for scientists [2], science teachers and science learners. Modeling can enable students to share modeling and their perspectives of real scientists' characteristics; that is, it can provide one situation to foster students' knowledge of constructing and combing content, inquiry, epistemological realization [3]. Many modern scholars in the history of science and cognitive studies of science now view the process of how models are constructed in science as a cyclical process of hypothesis generation, rational and empirical testing, and modification or rejection.

Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power [4]. A model is, in general, a representation of an idea, an object, an event, a process, or a system. A mental model is an internal representation of an object, states of affairs, or a sequence of events or processes, of how the world is, and of physiological and everyday social actions. To sum up, model has the function of representation, and it can express some of features.

Some researcher explored that experts focused on making definitions, and then continued to design, establish and test the models in the linear series via applying the modeling instrument of "Model-it" when beginning to construct the models [5]. Namely, experts present an object, like a stream or a variable, like the quality of water with clear focus in the beginning of constructing the model and that takes experts even more time to contemplate the whole model. Furthermore, experts predicted the executions of models and contemplate the relationship among objects, variables, and interactivities before they put what they consider into practice. Accordingly, experts construct the models in a linear way from the start to the end.

The psychologist put forward "hypothesis development (model construction) cycle of conjecture, evaluation, and modification or rejection" model [6]. Furthermore, merge relevant documents with the teacher's view explore the model of modeling [7]. The five stages: observing phenomenon and abstract variable, producing mental model and expressing model, thought experiment: reasoning, empirical tests, and reflection. In accordance with what are mentioned above, how do student's mental models change and how many categories of students' modeling are? That is an important question for teaching science and technology courses.

In science education, teachers should help students realize the importance of every question, and appreciate the need for such a comprehensive process for successful problem solving. Models and modeling already play an important role in teaching and teachers commonly use models to explain ideas to students. The modeling ability includes 5 aspects [8].

1) **Model Selection:** Solving textbook problems often involves basic models and/or emergent models which are combinations of specific basic models.

2) **Model Construction:** In this stage, students are guided to construct a mathematical model that helps them solve the problem.

3) **Model Validation:** Validation includes different forms of assessment that provide students with opportunities to fulfill a major objective of science education: critical thinking.

4) **Model Analysis:** Model analysis in solving textbook problems consists primarily of processing the mathematical model, getting answers to the questions asked in the problems, and interpreting and justifying the answers.

5) **Model Deployment:** Once a model is analyzed and fully validated, implications can be inferred with respect to the original purpose, as well as with respect to other valid purposes.

Pendulum is an important unit in junior high's science learning. Because it can help students easily learn how to control the variables, and understand the construction of scientific models. Figure 1 shows an idealized mathematical model of a pendulum composed of a weight on the end of a massless cord suspended from a pivot without friction. The time for one complete cycle, a left swing and a right swing, is called the period.

The gravity of pendulum is the product of mass(m) and g, and the result is written in mg. The restoring force can be divided into two parts, $mg \sin\theta$ and $mg \cos\theta$. The $mg \cos\theta$ and the tension of cord are in balance; therefore, there is a force $F = mg \sin\theta$. Amplitude(A) multiplies angle(θ) equals shift of bob. After the calculation mentioned above, we can know the acceleration(a) equals:

$$a = \frac{d^2x}{dt^2} = \frac{d^2(A\theta)}{dt^2} = A \frac{d^2\theta}{dt^2} \tag{1}$$

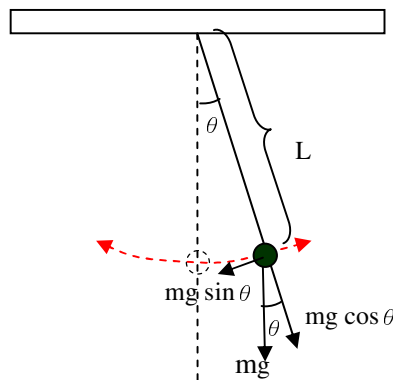


Figure 1. The formula of pendulum movement
(revised form [9])

According to the Newton's second law of motion ($F = ma$), we can derive the pendulum equations of movement.

$$mA \frac{d^2\theta}{dt^2} = -mg \sin \theta \Rightarrow mA \frac{d^2\theta}{dt^2} + mg \sin \theta = 0 \Rightarrow \frac{d^2\theta}{dt^2} + \frac{g}{A} \sin \theta = 0 \tag{2}$$

It means that θ is changed in law by t . This is a second order nonlinear ordinary differential equation which looks very simple but has a profound meaning in mathematics [9] The period of pendulum is independent and will not be affected by the mass of the bob. If the amplitude is limited to small angle, the period T of a pendulum, the time for a complete cycle, is:

$$T \approx 2\pi \sqrt{\frac{L}{g}} \quad (3)$$

Furthermore, we can develop the computer software based on these mathematical equations. Since the computer simulation software puts emphasis on establishing students' models of imitating the real phenomena in the world [10], it helps students to make specific and appropriate representation of problem. It also helps students to find out patterns or theories behind these phenomena [11]. Computer imitation takes a significant part in modern scientific research. Based on authentic science, experts of science education emphasize that students should behave like scientists during scientific activities [12]. Consequently, with the help of computer imitation, students can discover the natural phenomena by themselves in specific lessons of science teaching. Thus, if we hope students to experience scientific inquiry just like what scientists do, the computer simulation is a good tool for students to do scientific inquiry or science learning.

In general, teachers assess students' works with their intuition, and they are hasty to give scores to them. They even only see one aspect of the works. Therefore, this situation usually causes big differences among students' scores. Therefore, we shouldn't evaluate the works in numeric way.

There are two ways to evaluate the modeling. The general evaluation of modeling ability is according to three domains such as ontology, epistemology and methodology. In this way, the researcher uses a questionnaire to evaluate the modeling ability. Another one is the "authentic evaluation", it does the evaluation of modeling ability based on experimenters' performance in modeling processes. So, this research develops not only a set of pendulum modeling simulation system, but also develops the "authentic evaluation" "which is fuzzy synthetic evaluation system.

The research question of this research is to develop the simulation pendulum modeling, the result is isPM system. Then, the research wants to develop a synthetic fuzzy evaluation of modeling ability and the software's evaluation.

1.2. The Fuzzy Evaluation System

In the field of the automatic control of engineering and the assessment of social science, the application of fuzzy theory has already been very popular. In the classic set theory, we explain the relationship between elements and sets by dichotomy logic. Fuzzy set theory is treated of fuzziness in data, which was proposed by Zadeh in 1965 [13]. For the fuzzy set theory, the grade of membership can be taken as a value between 0 and 1. We make decision in fuzzy environments by using fuzzy variables. In order to simulate human decision making in computer environment, fuzzy variables should be represented in computer. All of them can use the theory of fuzzy set. Therefore, fuzzy set theory can play a significant role in our student evaluation process.

1.2.1. Fuzzy Set Theory: Fuzzy set theory is treated of fuzziness in data [11]. For the fuzzy set theory, the grade of membership can be taken as a value between 0 and 1. Although in the normal case of set theory, the grade of membership can be taken only as 0 or 1.

[For example] supposes domain of discuss μ is the area [0, 100], and element u of μ represent model select. At this moment, the concept of the model select can be expressed for the intensity of a fuzzy set A of μ , its membership function can be defined as,

$$\mu_A(u) = \begin{cases} 0 & 0 \leq u \leq 50 \\ \left[1 + \left(\frac{u-50}{5} \right)^{-2} \right]^{-1} & 50 < u \leq 100 \end{cases} \quad (4)$$

Therefore, Model Selection or Model Construction ability is not good, can define with the following membership functions,

$$\mu_A(u) = \begin{cases} 0 & 0 \leq u \leq 25 \\ \left[1 + \left(\frac{u-25}{5} \right)^{-2} \right]^{-1} & 25 < u \leq 100 \end{cases} \quad (5)$$

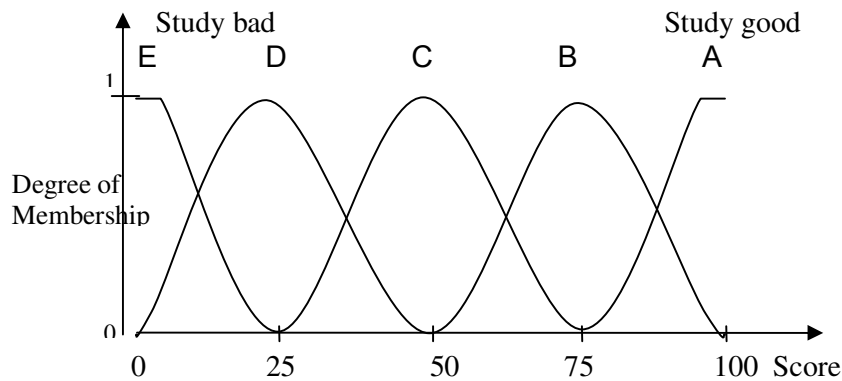


Figure 2. Membership function curve

We also use the membership function curve, show in the following: the students' learning achievements are kinds of relative comparison. In general evaluation, the full score is 100, however, some students get high score but others do not, which depends on their ability. That is shown in the following the Figure 2. The X axle expresses the Score, the behavior of student's ability, from 0~100 points, and the right as study good, the left as study bad. A = "Excellent", B = "Good", C = "Average", D = "Lower" and E = "Bad". The Y axle expresses the degree of membership, its value is between 0~1. The degree of membership indicates to what degree the score represents the semantic class. The fuzzy terms are substituted for numeric data, and the fuzzy membership is decided by experts. Finally, the evaluation of ability will attain coherent perspective and enhance the reliability of evaluation, which is the purpose of this research.

1.2.2. The Synthetic Fuzzy Evaluation: Assessment not only reflects the students' works but also students' abilities. Speaking of the evaluation, the most important thing is the reliability. If a teacher gives a student 87 points, he/she gives the same works 78 points the next time, which is hard for anyone to accept this situation. Because a traditional approach of score is more dogmatic, the teachers always reluctantly score in the percentile rank, and if they want to score carefully, they may consider for a long time, which does not accord with the simple and perfect principle at all.

Modeling ability has the fuzzy characteristics and the researcher recommends teachers evaluating with synthetic fuzzy theory, whose steps are as follows:

- Determine the evaluation factor.

The domain of discourse, $R = \{R1, R2, R3, \dots, Rn\}$

For example: There are 5 Items of Modeling ability:

{ Model Selection (R1), Model Construction (R2), Model Validation(R3), Model Analysis(R4), Model Deployment(R5)}

- Determine the weight set.

$W = [W1, W2, W3, \dots, Wn]$

The weight set of each evaluation factor,

For example: [Item 1, 30%. Item 2, 25%. Item 3, 25%. Item 4, 10% Item 5, 10%]

- Determine the assessment set.

$E = [E1, E2, E3, \dots, En]$

Ex: [Excellent, Good, Average, Lower, Badly]

- Create a fuzzy evaluation matrix

$$R = \begin{matrix} R1 \\ R2 \\ R3 \\ R4 \\ R5 \end{matrix} = \begin{bmatrix} r11 & r12 & r13 & r14 & r15 \\ r21 & r22 & r23 & r24 & r25 \\ r31 & r32 & r33 & r34 & r35 \\ r41 & r42 & r43 & r44 & r45 \\ r51 & r52 & r53 & r54 & r54 \end{bmatrix}$$

The Evaluation set of single variable is:

$R1 = [r11 \ r12 \ r13 \ r14 \ r15]$, the others analogize.

For example: Suppose one student participates in the behavior of model ability, 1. "Model Selection" is excellent. 2. "Model Construction" is average. 3. "Model Validation" is good. 4. "Model Analysis" is lower. 5. "Model Deployment" is lower.

In fuzzy theory, the relationship between element and set is described by membership. According to the value of membership functions of common assessment set, can get fuzzy synthetic assessment sets.

To integrate and analyze the above literacy, the researcher found that "models" play an essential role in the development of scientific knowledge as well as theory. Nevertheless, to erect models is based on the procedure of modeling, which is of importance for scientists to reveal new knowledge [2]. Hence, it is necessary for students to experience how to construct models via the approaches, which is different from the traditional pedagogies of teaching, as

scientists do. As a result, how students establish their models and the mental procedure of modeling will be an imperative basic issue.

$$R = \begin{matrix} \begin{bmatrix} R1 \\ R2 \\ R3 \\ R4 \\ R5 \end{bmatrix} \\ = \end{matrix} \begin{bmatrix} .90 & .10 & .00 & .00 & .00 \\ .40 & .50 & .05 & .05 & .00 \\ .80 & .15 & .05 & .00 & .00 \\ .05 & .30 & .50 & .15 & .00 \\ .05 & .30 & .50 & .15 & .00 \end{bmatrix}$$

- Fuzzy synthetic evaluation.

$$B = W \circ R$$

$$= \begin{bmatrix} .30 & .25 & .25 & .10 & .10 \end{bmatrix} \circ \begin{bmatrix} .90 & .10 & .00 & .00 & .00 \\ .40 & .50 & .05 & .05 & .00 \\ .80 & .15 & .05 & .00 & .00 \\ .05 & .30 & .50 & .15 & .00 \\ .05 & .30 & .50 & .15 & .00 \end{bmatrix}$$

$$= \begin{bmatrix} .30 & .25 & .15 & .10 & .00 \end{bmatrix}$$

- Normalization.

$$B' = \begin{bmatrix} .30/.75 & .25/.75 & .15/.75 & .10/.75 & .00/.75 \end{bmatrix}$$

$$= \begin{bmatrix} .40 & .33 & .13 & .13 & .00 \end{bmatrix}$$

- The result of evaluation of ranking.

$$Q = B' * \begin{bmatrix} 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{bmatrix} = 4.0$$

- Percentile rank.

$$P = Q * 100 / 5 = 4.0 * 100 / 5 = 80$$

2. Research Methods

This research aims to probe into the understanding of students' cognitive process, so the researchers manipulated both computer simulation pendulum and pendulum simulation software evaluation. The research participants were junior high 15 eighth grade students, 5 IT and 5 physics education experts.

2.1. Research Framework

The framework of the synthetic fuzzy evaluative modeling ability system is shown in the following the Figure 3. The assessment needs to be divided into several aspects so that we can assess each part of the works. The concept assessment R1, R2, R3... Rn express the difference assessment unit, and r11, r12, r13,... express the sub item. All of sub items will be count in the modeling ability with the synthetic fuzzy logic. For example, R1 is composed of 5 sub-concepts. We could evaluate these sub concepts which are r11 to r15, so that can get the value of R1. And with this method we can get each domain's value. Finally, the system via fuzzy synthetic evaluation and with membership, we can get the result of students' modeling ability. The "Analysis Database" included membership of fuzzy set, and it provided the counting value to conduct fuzzy synthetic evaluation. As a result, the evaluation of modeling ability will be more reliable.

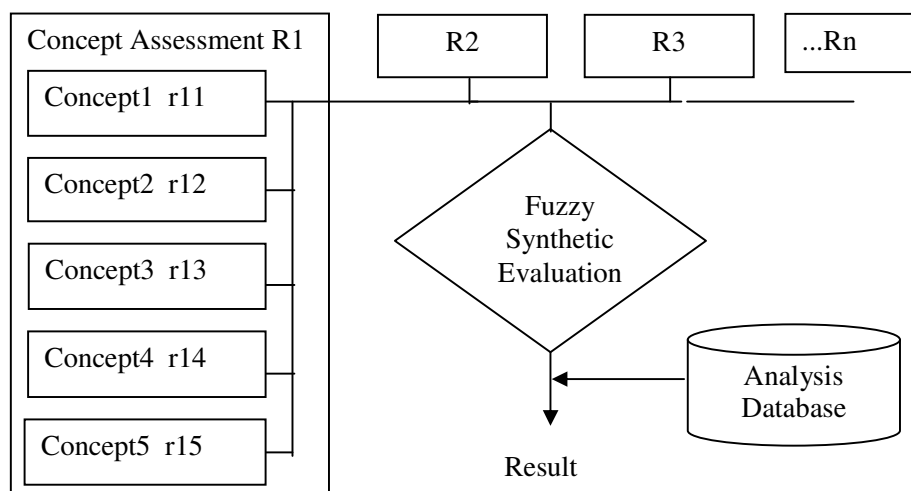


Figure 3. A framework of Pendulum Modeling Synthesis evaluation

2.2. Tools of System development

The research is focus on development of pendulum modeling simulation and development of synthetic of modeling ability evaluation. The researcher develops the software with Macromedia Flash action script. The Macromedia's Flash player is plug-in software for web browsers which allows Flash animations to be incorporated into web pages. The advantage of the Flash plug-in is that it allows a very immediate form of interactivity, at low bandwidth, and without the programming expertise.

2.3. Pendulum Simulation Software Evaluation and Participants

The questionnaire, designed with Likert five-points scale of software evaluation is inclusive of three dimensions: Subject content— Evaluation of modeling consistency between objectives and content of knowledge, Media interface— Evaluation of interface and graphic design, and the last one is, Users' attitude— according to Technology Acceptance Model (TAM) evaluation includes perceived usefulness (PU) and the perceived ease of use (PEOU).

The samples of this research were public junior high 15 eighth grade students. They have not studied courses of pendulum of the eighth grade in the junior high school, and have not learned pendulum at cram school yet. In addition, 5 IT and 5 physics education experts are involved.

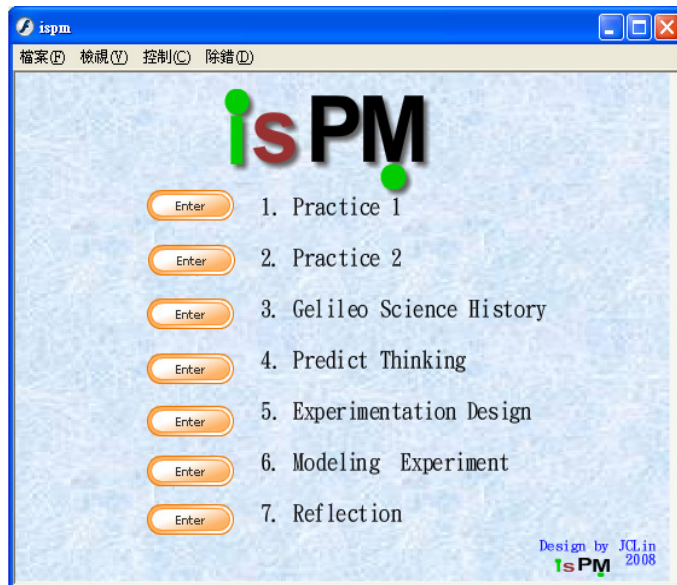
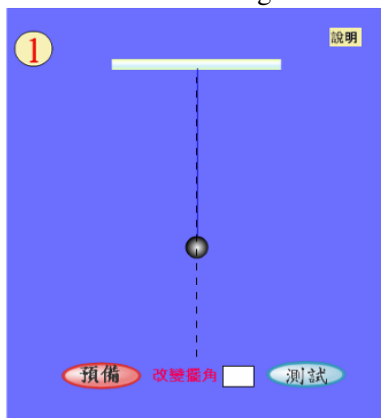
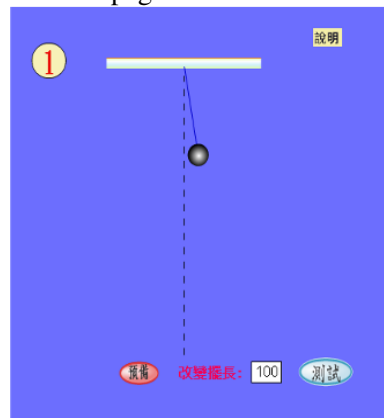


Figure 4. The isPM system home page

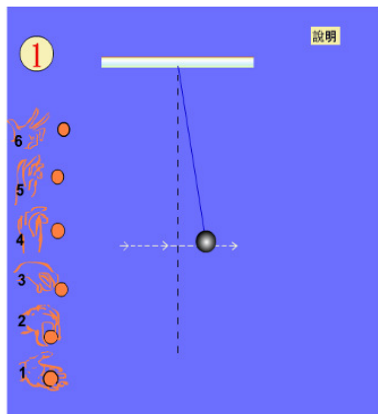


Angle

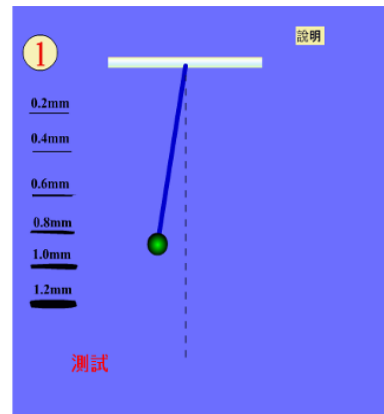


Length

- Students can input any degrees in the blank. In this simulation test.
- Students can input any figure. In the blank, the length here is 100cm.



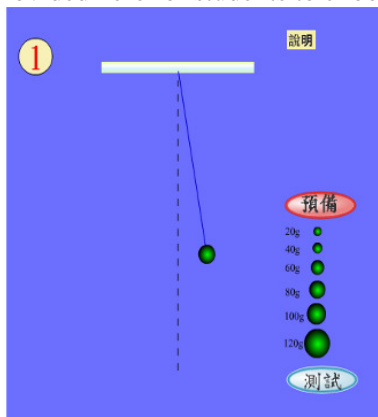
Force



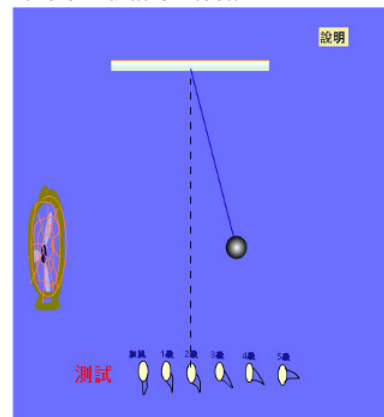
String

- Six types of degree of force are provided here for students to choose.

- There are six different width of strings in the simulation test.



Mass



Air-force

- Six different sizes of balls are provided here for students to conduct the experiment.

- There are six levels of wind in the air-force simulation test.

Figure 5. The 6 kinds of simulation pendulum variables

3. Result

The results of this research include the pendulum modeling simulation system development, the development of synthetic fuzzy modeling ability of learning evaluation system and the expert user evaluation system.

3.1. Simulation System Development

Seven procedures included in the simulation software system:

- 1st Practice is the basic drawing practice;
- 2nd Practice is to measure the period with the stop watch, the aims is offered the drawing tool for students practice the basic skills of experiment;
- In the 3rd stage students watch Galileo's science history on the computer about a context of calculated period of lamps in the Pisa Cathedral;
- In the 4th stage students need to predict results of the experiment;

- In the 5th stage students need to design the Experimentation and draw the picture to show their experimentation method;
- In the 6th stage, the students are really to execute the pendulum experiments, and the modeling experiment provides an opportunity for student empirical test. The aim of this stage is to let students find out the pattern from the experiment's data and relationship between variables and period. In the last stage students have to reflect.

The procedures of isPM (Integration Simulation Pendulum Modeling) software would be shown in the Figure 4.

In order to achieve the procedure of modeling experiment; it is necessary for students to proceed Practice1 and Practice2, and watch the film of Galileo's history of science to express physical situations. Then, students understand the period after watching film. They apply the simulation software to explore how various kinds of variables impact the period of pendulum.

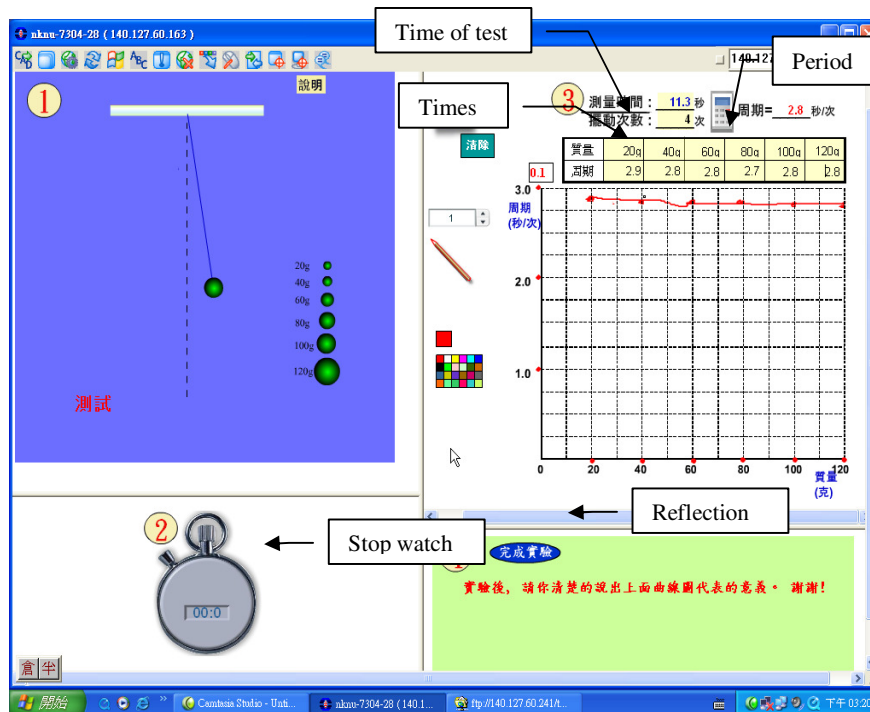


Figure 6. The isPM physics experiment interface

3.2. Fuzzy Synthetic Evaluation Modeling Ability System

According to relevant literature “Schematic Modeling for meaningful learning of physics [12]”, survey and revise, the main abilities of modeling include: “Model Selection”, “Model Construction”, “Model Validation”, “Model Analysis”, and “Model Deployment”. In relevant researches viewpoint, the “Model validation” is similar the “Model deployment”. According to the modeling process, the application of modeling is important ability during the model construction [7]. Therefore, the hierarchy of modeling ability item was shown as Figure 7.

Then, we choose each assessment for the sub items of abilities, for example, in the aspect of "model selection", there are 4 sub items including "system consist of", "what type of", "what reference", and "appropriate for".

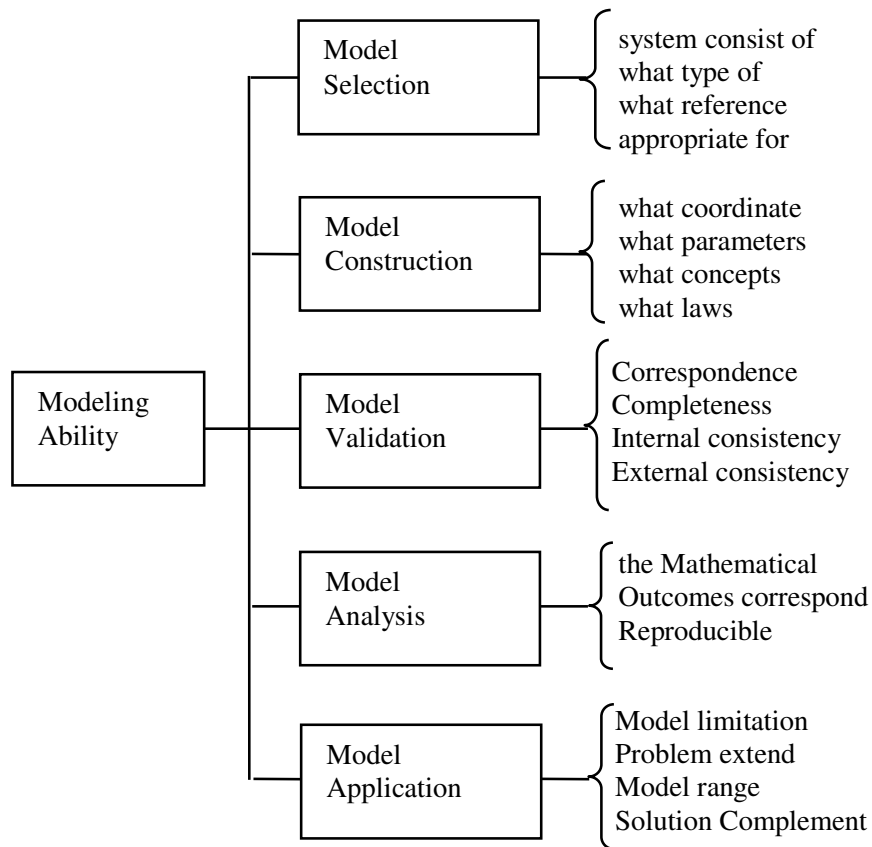


Figure 7. The hierarchy of modeling ability item (Revise from: Appendix of Modeling for solving mechanics problems[8])

In the past, other researchers did evaluation with ambiguous terms or signs based on fuzzy theory. But in this research, we assess abilities with gain/fader, and the evaluation will be fitter for the characteristic of fuzzy theory.

Based on the “hierarchy of the modeling ability item” of Figure 7, this research used flash software to implement the “Modeling Fuzzy Synthetic Evaluation System”, as shown in Figure 8.

There are 5 aspects in modeling ability. In each aspect, there are 3~4 sub items with the gain/fader which can set up their values. Teacher can easily judge students' modeling ability according to their behaviors in processes of modeling just by adjusting the gain/fader. On the fader buttons, each code expresses the difference level from A to E. The A = “Excellent”, B = “Good”, C = “Average”, D = “Lower” and E = “Bad”. Each level has a corresponding value, and the membership function is decided by experts.

3.3. System Using and Evaluation

This research adopts the qualitative method with which researchers have analyzed the characteristics and the categories of modeling process, form the case students abstracting variables stage to the reflection stage. The researchers analyzed the characteristics of mental model that students expressed and finally sum up to five types of modeling process.

In accordance with findings in the process that students formed the initial mental model in the experiment, they applied limited reasons to think; namely they didn't make the detail thought experiment as scientists did. However, owing to the students' explanations of the variables affecting swinging period, the researcher found that the length of the pendulum is correct and that other variables are only the intuitive experiences in students' daily life, so they abstained many misconceptions. Additionally, we can integrate the students' explanations to discover that students regarded the range as the main result affecting the swinging of objects. That is shown in the following the Figure 9.

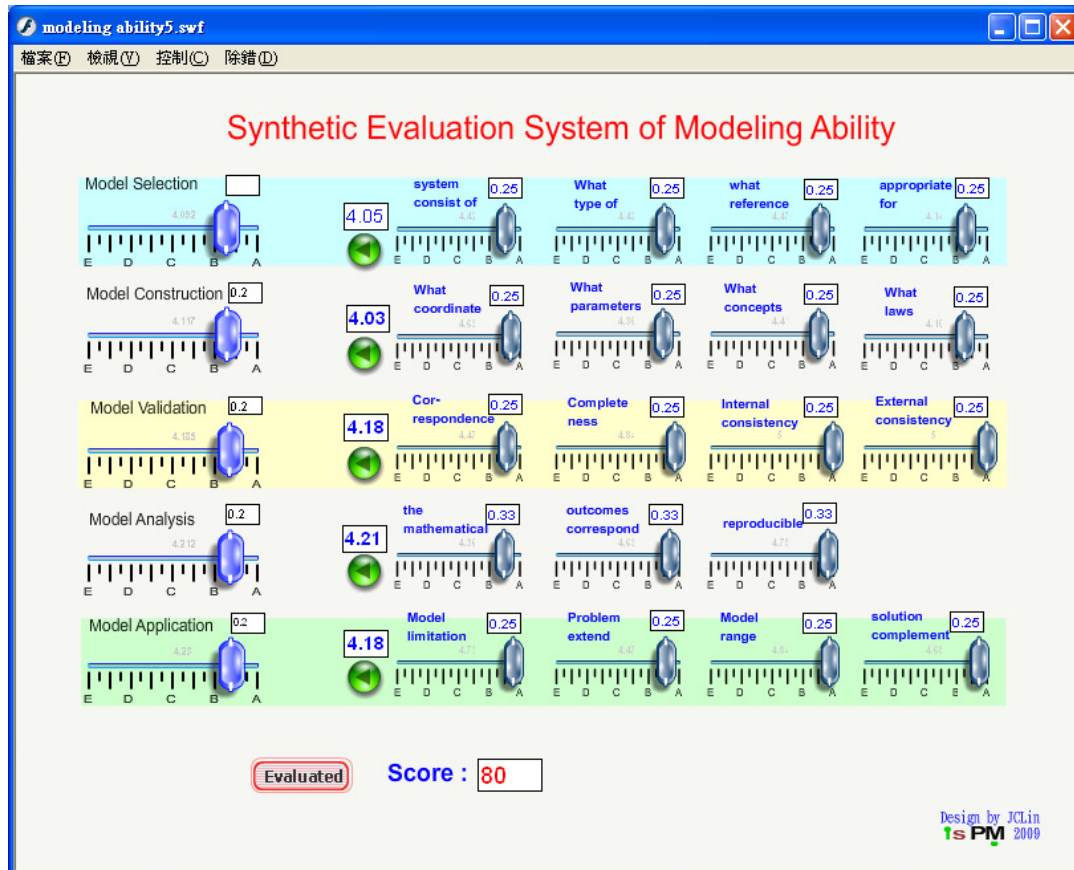


Figure 8. Modeling ability fuzzy synthetic evaluation

Furthermore, in this stage, the researcher also found that students formed the initial mental model in the experiment, they applied limited reasons to think; namely they didn't make the detail thought experiment as scientists did; they only simply reasoned according to the listed variables instead.

From the line graph on the right of figure 9, which shows the relationship between length and period, shows that the case-students had correct model in length variable. With the correct model, the student can predict and explain the characteristics of pendulum. For example, different periods can be predicted by the line graph in their experiments, which indicate that the students really understand the characteristic of

pendulum. Simultaneously, they can also learn how to control the variables and conduct the scientific verity.

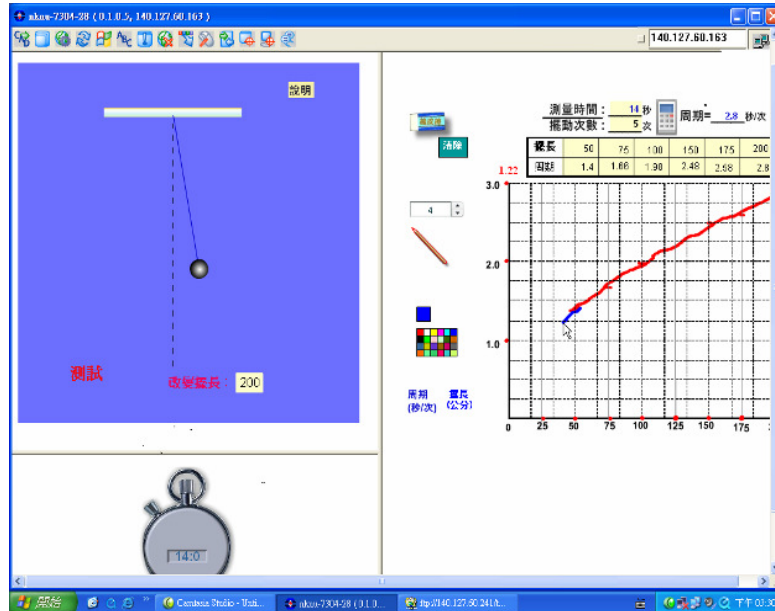


Figure 9. The pendulum simulation software

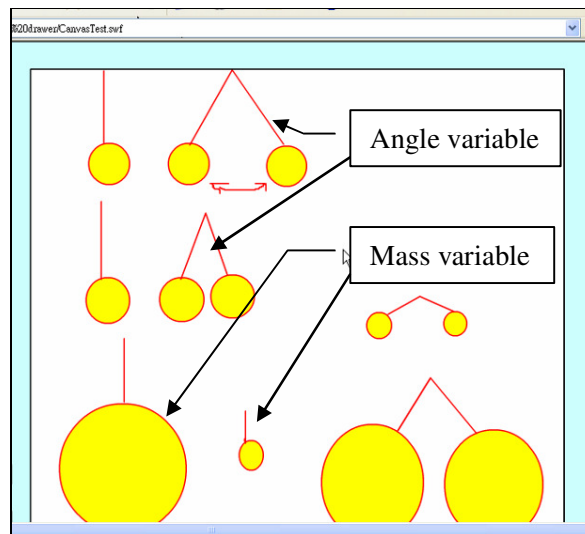


Figure 10. The St205 did prediction and inference in thought experiment

As mentioned above, students combined experiences with personal intuitive observances to infer various variables that influence the swinging period.

Furthermore, the chief intermediary variable is the swinging range. Although the program, which helps student to infer in the thought experiment, to draw the designed experiment was

offered in this research; yet, it is difficult for students to change their original misconceptions. That is show in the following the Figure 10.

The researcher wanted to summarize the results of 3 different types of questionnaires with the Likert’s five-points scale, whose full mark is 5. The result of this software in the mean of “Subject Content” was 4.62 and the mean of “Media Interface” was 4.78, which revealed the experts’ great sense of satisfaction. The dimension “User Attitude” was divided into the usefulness and the ease to use, both accessible as well as usable. The mean of the former was 4.09; the mean of the later was 3.93. All the statistic numbers were shown in Table 1.

Table1. Summary for the results of 3 types in the questionnaire

No.	Type	participant		mean
(1)	Subject Content	5		4.62
(2)	Media Interface	5		4.78
(3)	User Attitude	Usefulness	15	4.09
		Ease to use		3.93

The result of this whole evaluation of software is suitable for the pendulum modeling simulation software of eighth or ninth-grade junior high students.

4. Conclusion and suggestion

This research mainly discusses how the researchers manipulated both computer simulation pendulum and pendulum simulation software evaluation to realize characteristics of modeling process of junior high students.

1. Six kinds of simulation pendulum variables: (1) mass, (2) length, (3) angle, (4) force, (5) air-force, and (6) width of string were constructed. It is significant to develop relevant software tools to help students' modeling according to the systematic modeling software, such as the mentioned Drawing Design, the film of Galileo's history of science, and so on.

2. The research implemented the synthetic fuzzy evaluative modeling ability system, there are five aspects, totally 19 sub items together, can be regarded as teacher evaluation to student's modeling ability.

3. Via the evaluation in subject content, media interface and the user attitude, etc., this simulation software is suitable for the stage of junior high student pendulum modeling under the movement law, $f = m a$.

The researcher thinks this system may help teachers understand students’ various characteristics in modeling process, such as abstracting and refining their experiment variables according to the results of the study. On the other hand, researcher developed the isPM software to enhance instructors’ understanding of students’ thinking process.

According to the students’ modeling process, teachers may discover and realize students’ different mental models with a view to enhancing their efficacy of teaching. Moreover, the researcher suggests aggrandizing larger samples for experiments in the follow-up researches to understand the more unrevealed characteristics of students’ mental models.

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