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多媒體工程研究所

碩 士 論 文

虛擬科學探究歷程評量與診斷機制

Virtual Scientific Inquiry
Portfolio Assessment and Diagnosis

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Virtual Scientific Inquiry Portfolio Assessment and Diagnosis

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摘　要

科學教育最主要的目的在於培養學生有科學探究之能力。而培養此能力的最佳方式是老師帶領學生進行探究式實驗。由於探究式實驗的進行，需要花費老師大量的時間與精力，但礙於課程的時間有限以及教學進度的壓力下，在實際的課堂中，老師鮮少進行探究實驗教學。因此，開始有許多線上實驗平台的研究，讓學生可以在平台上練習操作與課程相關的科學實驗。可惜的是，鮮少平台會針對學生的操作進行評量與診斷，進而給予學生學習回饋。而本研究提出了線上科學探究能力評量診斷機制，提供學生與老師相關的診斷報告書，進而學生可以根據報告書內容自學，老師也能利用報告書內容有效地瞭解學生科學探究之能力。診斷機制是利用不同的知識表示方式之技術設計而成，同時也採用對話式資料擷取方式設計出讓老師容易倒入知識的方法。由於不同背景的學生所發展出的探究能力也不一，因此本研究也使用了資料探勘的技術找尋高層次的能力表現。根據實驗的結果，學生與老師大都認為此線上評量診斷系統，可以幫助他們瞭解問題與進行改進。

關鍵字：科學探究，線上診斷，檔案評量，知識工程技術

Virtual Scientific Inquiry

Portfolio Assessment and Diagnosis

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Abstract

Training students' scientific inquiry ability is a major learning objective of science education, so teachers require effective assessments to evaluate students' performance of scientific inquiry and offer appropriate supplementary instruction. This ability should be assessed by evaluating students' scientific inquiry processes in real experiments and judging whether the overall operation sequences are reasonable or not. Although many virtual laboratories were proposed to reduce the cost of implementing experiments, this kind of portfolio-based assessment is also difficult to be implemented due to the high cost of monitoring each student's scientific inquiry process and analyzing their operation sequence. In this thesis, an online scientific inquiry diagnosis scheme was proposed to assist teachers in automatically assessing and diagnosing students' scientific inquiry abilities, where diagnostic reports were generated by extracting experiment plans and operation patterns, evaluating skills from these patterns, and inferring the integrated diagnostic results using teacher-designed scientific concept maps and science process skill maps. Appropriate supplementary instructions are provided to students by using model tracing. Because students' backgrounds are different, this study proposed behavior finding by data mining technology. Two experiments were conducted where 30 junior high school students and 30 senior high school students participated in the experiments. The results show that students thought that the diagnostic reports were helpful, and teachers also agreed that the comments in diagnostic reports were reasonable and useful.

Keyword: Scientific inquiry, Online diagnosis, Portfolio assessment, Knowledge-based approach

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Chapter 1 Introduction

Training students' scientific inquiry ability[13][14], including scientific concepts and science process skills[13], is a major learning objective of science education. Thus, teachers require effective assessments to evaluate students' performance of scientific inquiry and offer appropriate supplementary instruction. Traditional paper-and-pencil tests [19] could assess students' scientific concepts but were difficult for teachers to evaluate students' science process skills, because these skills should be assessed by evaluating students' scientific inquiry process [19], including planning and operating in experiments. This kind of assessment, named portfolio-based assessment [23], should not only judge the correctness of each operations in an experiment but also evaluate performance by judging whether the overall operation sequence is reasonable or not. However, a portfolio-based assessment is costly, because teachers must monitor each student's scientific inquiry process and analyze their operation sequence in the process. Some studies proposed virtual experiments [6], where students could implement experiments in virtual laboratories, to effectively reduce the cost of experiments and record students' operation sequences for further analysis. Some studies [24] also proposed approaches to assess students' scientific inquiry abilities by the recorded scientific inquiry process. However, these studies still have some drawbacks for doing online scientific inquiry assessment.

(1) **Manually analyzing**: Scientific inquiry assessments have to realize the ability by the whole experimental operation process and complex relations, so it is hard to do online diagnosis. Furthermore, they also cannot design a systematic way to make teachers provide their assessment knowledge for various experiments.

(2) **Various diagnosis results**: Students may have different learning behaviors according to distinct learning environments and cultures. Teachers cannot know all learning conditions in the beginning. To assist teachers construct related assessment rules more effectively, the assessment mechanism also needs to analyze students' portfolios. However, recently researches seldom discuss about how to analyze portfolios.

This thesis proposed an online scientific inquiry diagnosis scheme to assist teachers in automatically assessing and diagnosing students' scientific inquiry abilities by analyzing the operation sequence. A dialogue-based knowledge acquisition was proposed to acquire teachers' knowledge of diagnosing scientific inquiry abilities. The assessment knowledge could be used to automatically evaluate a student's performance of scientific concepts and science process skills by the student's plan and operations in an experiment. With the teacher-designed concept maps and skill maps, the overall diagnostic results could be inferred by analyzing the performance of the detailed concepts and skills, a diagnostic report could be generated according to these results, and a tutorial which is an adaptive courseware for students by using model tracing[8][9][12][17] could be provided. Besides, the results of the proposed experimental behavior mining could assist teachers in clustering students by their scientific inquiry abilities for supplementary instruction and finding frequent operation patterns for refining their diagnostic knowledge.

The evaluation criteria of this study include student satisfactions of diagnosis reports and the effectiveness of diagnosis results for teachers. This diagnosis scheme is applied in Computerized Interactive Multiple Assessment System[2] and Virtual Physics Experiment System[11]. Computerized Interactive Multiple Assessment System was used in 30 students of Fong-Ping junior high school, and Virtual Physics

Experiment System was used in 30 first grade students of National Nanke International Experimental High School. The experimental results show this diagnosis scheme can really help students in self-learning and assist teachers in students' learning.

Chapter 2 Related Works

2.1 Online Learning Diagnosis

Recent researches in online learning diagnosis almost focused on concepts, such as [3][4][7][10][20]. These researches are almost linear assessment procedures which were using multiple choices items to know those concepts that the student had learning difficulties. Part of studies[4][20] as mentioned before also used some specific relations to realize other related concepts that could be have difficulties on learning. However, the scientific inquiry diagnosis needs to observe sequences of actions, complex rules between experimental actions, and knowledge inference not just consider the concept map. Therefore, possible scientific inquiry diagnosis results need to consider many conditions and complex relations, and cannot be obtained by using these researches.

2.2 Learning Feedback

Another issue which also has been discussed in those researches is how to give appropriate learning tutorials. Although appropriate curriculums could be given, those curriculums' contents were fixed, and could not be dynamic modified by learning conditions. In our study, we can not only provide appropriate different experiments but also offer different degree of the same experiment to assist students on scientific learning.

Open Learner Models researches could provide different learner models and various visualizations of assessment results in order to assist students in better understand their learning.[15][16][18] This is to say, these researches have positive effects of students' metacognition. However, inquiry diagnosis has to realize real problems that students have, and needs to tell students to solve these problems first. Visualization of these results may help students to understand their learning difficulties quickly, but only visualization may result in the increase of students' misconceptions. Therefore, diagnosis reports and learning suggestions are main assistances for students in scientific inquiry learning.

Some researches provide teachers with students' portfolios for obtaining learning feedbacks on the web which can benefit distance education and help students easily understand their problems. But, these researches still focused on concept level.

2.3 virtual experimental systems

According to [5][6][21], we could discover most experimental system that provided virtual experimental environments to make students practice the related experiments. However seldom virtual experimental researches could give students learning feedbacks by their operations. In[5], this researches can design chemistry experiments' contents by teachers, and give some related questions to students in the final. Unfortunately, they only give simply assessment result to students or teachers. As we know, experimental operations may have cause-and-effect relations, so we need to use relations to give students advanced assessment results. Moreover, those virtual experimental systems which have important information for teachers seldom use students' operations to discover new or high level experiment behaviors.

2.4 Scientific Inquiry Assessment in Science Education

In [1], we can know that laboratory activities can help students to understand scientific truths. Students can prove the scientific concepts by operations. Hence, experiments curriculums are better learning ways for science education.

According to researches of science education, the scientific inquiry assessment still depends on teachers' investigation about students' portfolios[22][24]. As we known, there are no assessment standards on scientific inquiry, because assessment rules have been changed by teachers' thinking or different experiments. Moreover, education researchers presently concern the research of high level inquiry ability.

Chapter 3 Development an Online Scientific Inquiry Diagnosis System

The architecture of the scientific inquiry assessment system, as shown in Figure 1, consisted of an online diagnosis phase, a data preprocessing phase, and a data post-processing phase.

The online diagnosis phase analyzed a student's experimental portfolio to generate a diagnostic report for teachers and the student to understand this student's performance in an experiment. After a student implemented an experiment in a virtual lab system, the system received experiment logs and identified experimental operation facts by a portfolio interpreter to extract information from the raw data for diagnosis. Afterward, a scientific inquiry diagnosis used teacher-designed assessment knowledge, including concept maps, skill maps, assessment rules, and explanation templates, to infer the diagnostic results and generate a diagnostic report for the student and teachers.

Assessment rules expressed performance-evaluation knowledge of scientific concepts and science process skills from experimental operation facts. Concept maps and skill maps, expressing the knowledge structure of scientific concepts and science process skills respectively, could be used to infer the summarized diagnostic results from the performance of detailed concepts and science process skills. Explanation templates were text-based templates for the system to generate readable diagnostic reports by the inferred diagnostic results.

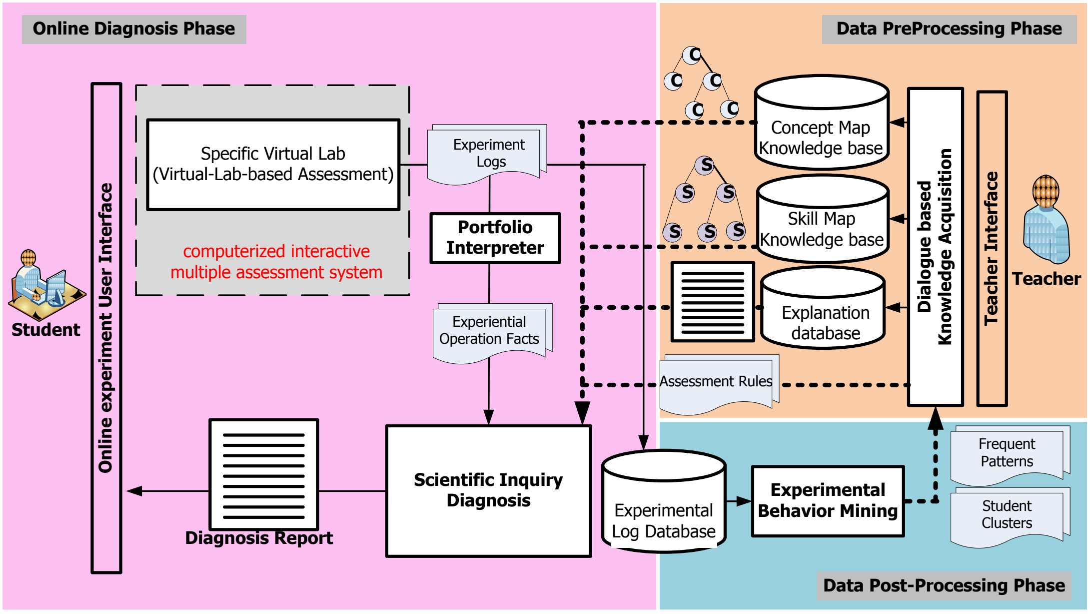


Figure 1 System architecture of Scientific Inquiry Assessment

In the data preprocessing phase, a dialogue-based knowledge acquisition was used to facilitate teachers to provide the necessary assessment knowledge mentioned above.

In the data post-processing phase, an experimental behavior mining was used to discover students' operation frequent patterns and construct student clusters by students' experiment logs. Teachers could modify the assessment rules according to the new identified operation frequent patterns and provide supplementary instruction for each student clusters adaptively.

In this chapter, we introduce assessment knowledge modeling. First of all, we give an example "Biology Transpiration Experiment" from the curriculum of junior high school in order to show the modeling.

In Figure 2, this experiment includes experiment objects such as celeries, a tank, a knife, backers, a ruler, a scale, and so on. Experimental actions which can be operated by users like "cut the root of plants", "dip in the water", "fill the container with red water", "put the plant in the container", "pluck leaves" and so on. Moreover, this experiment can change environments like laboratory and playground where environment variables have different values, such as temperature, would influence the experimental result.

The main idea of this experiment is to discuss about what experimental factors would be inference the transpiration speed of plants by observing the decreasing quantity of red water.

Figure 2 Biology Transpiration Experiment from CIMAS

3.1 Knowledge Structure

In this system, concept and skill ontology was applied to represent concept and skill map to facilitate inference and knowledge sharing. Therefore, this system uses the ontology-based approach to represent these two knowledge structures. Scientific concept map, including a set of concepts, hierarchical relations (*H*), and prerequisite relations (*PR*), is a hierarchy of concepts (*C*). Prerequisite relations could be defined among these concepts to represent the necessary sequences of understanding these concepts.

Definition of Scientific concept map

- $C = \{c_1, c_2, \ldots\}$ is a set of scientific concepts.
- $H = C \times C$ is a set of hierarchical relations.
- $PR = C \times C$ is a set of prerequisite relations

Relations of this map do not allow the loop between nodes, so the map is the tree architecture.

As shown in Figure 3, the concept *plant* has two sub concepts, and the prerequisite concept of *transpiration* is *water transportation*.

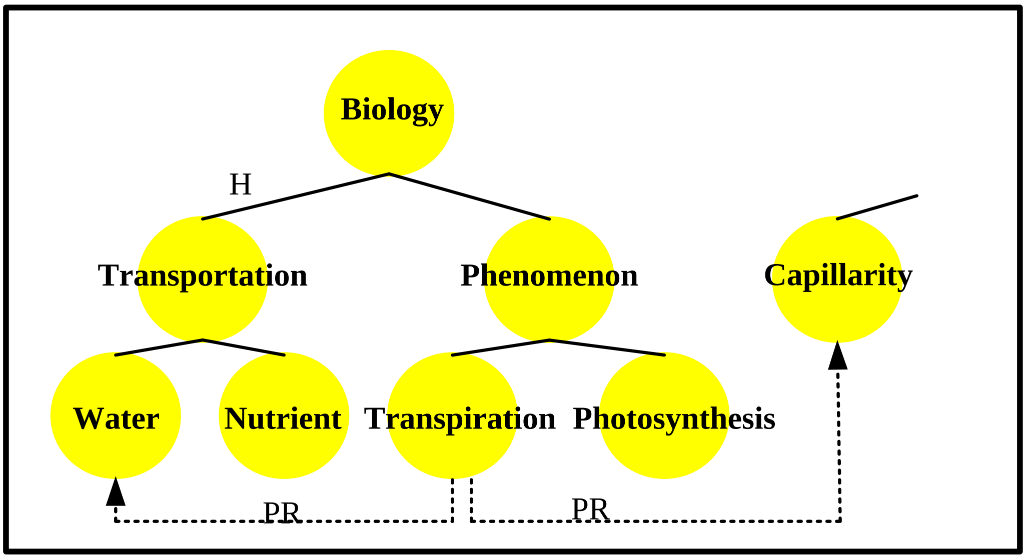


Figure 3 Concept map of Biology Transpiration Experiment

Definition of Scientific process skill map

Scientific process skill map, including skills, hierarchical relations (*H*), and dependence relations (*D*), is a hierarchy of scientific process skills. Dependence relations could be defined to represent the cause-and-effect relations between two skills.

- $S = \{s_1, s_2, \ldots\}$ is a set of scientific process skills.
- $H = S \times S$ is a set of hierarchical relations among skills.
- $D = S \times S$ is a set of dependence relations among skills.

Relations of this map do not allow the loop between nodes, so the map is the tree architecture.

For instance, *"making the hypothesis"* and *"setting variables"* mean the high level skill *"Experiment planning"*, and the skill *"experiment independent variable"* have error may be affected by the skill *"experimental operations"*.

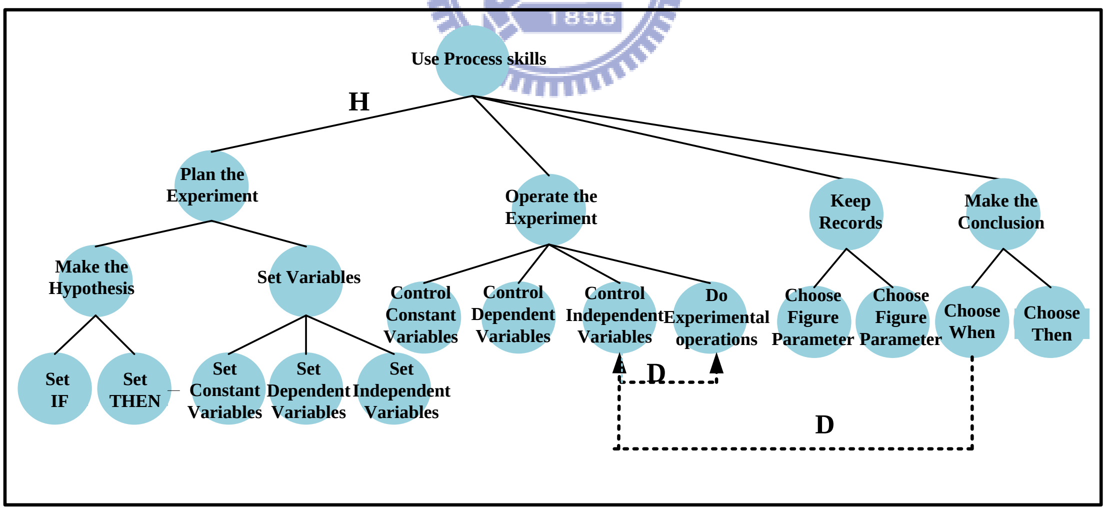


Figure 4 An example of Scientific Process skill map

3.2 Experimental Assessment Information

This section discussed about key points of assessments for various experiments. According to researches, inquiry process has experimental operations. Besides, it could include stages of making the hypothesis, setting experiment variables or making the conclusion and so on. Therefore, inquiry experiments have to assess two kinds of data.

This system also proposed two assessment formats for teachers. One is called *experimental action assessment* which described experimental actions. Another is called *experimental planning assessment* which is used in other stages. Moreover, relations of each format would be used to do assessment patterns. Finally, this system provides relations to construct experimental assessment rules which could represent and tag process skills or concepts.

Raw data

For diagnosis, CIMAS provides information as shown in Table 1 and Table 2. Table 1 shows experiment planning logs, which include students' decisions in each planning stage and doing time. Table 2 represents action logs, which include experiment action name, related experimental objects, observed experiment objects, environment variables and doing time.

Table 1 Planning logs

Attribute: Value	**Time**
Name: Hypothesis-IF, Object: Celery, State: Leaves , Comparison: More	20100515 130510
Name: Hypothesis-THEN, Object: Backer, State: Decreasing quantity of red water , Comparison: More	20100515 130510
Name: Independent-Variable, Object: Celery, State: Leaves	20100515 130708
Name: Dependent-Variable, Object: Backer , State: Decreasing quantity of red water	20100515 130708

Table 2 Action logs

Experiment-Variable	**Object**	**Action-Name**	**Target-Object**	**Time**
Temperature, 25℃, Light, Yes, Humility, 60%	Knife, Celery	Cut the root of plants	Celery	2010051 5130940
Temperature, 25℃, Light, Yes, Humility, 60%	Tank, Celery	Dip in the water	Celery	2010051 5131052
Temperature, 25℃, Light, Yes, Humility, 60%	Celery	Pluck leaves	Celery	2010051 5131120

Definition of experimental planning assessment

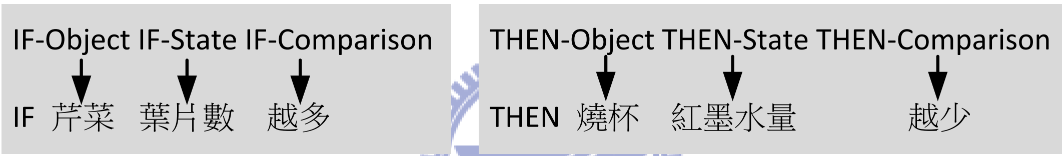
$$Experimental\ planning\ assessment = EP(\{Attribute\})$$

Example 3.1:

EP({Hypothesis-IF , IF-Object, IF-State , IF-Comparison})

EP({ Hypothesis-THEN , THEN-Object, THEN-State , THEN-Comparison})

Making the hypothesis is one stage of experiment planning after the student read the experiment question. It assists students in designing their experiments. This example shows the hypothesis that includes IF and THEN. Take the biology transpiration experiment for example.



Relations of experimental planning assessment

$$Consistency = CS(EP_i,\ EP_j\ \{EP_i.Attribute_m = EP_j.Attribute_n\})$$

This relation means that part of attributes' values have to be the same between two different EP.

Example 3.2:

CS(EP(Hypothesis-IF , {IF-Object , IF-State, IF-Comparison}),

EP(Independent Variable , {Object , State}),

{IF-Object = Object, IF-State = State} **)**

"IF" means what factor the student attempts to prove that would affect the experiment result. This is to say, this factor is the independent variable which would be set by the student in the setting variables stage. Hence, it has the consistency relation between them.

Definition of experimental action assessment

Experimental action assessment = EA(Name,{Operated-Object}, {Target-Object})

Name - The action's name

{Operated-Object} - The set represents experiment devices which used in this action

{Target-Object} - The set shows experiment devices whose attributes have been changed.

Example 3.3:

EA(dip in water,{Celery, Tank},{ Celery})

EA(cut the root of plants,{ Celery, Knife},{ Celery})

"Dip in water" means the celery dip in the tank, so the celery's attribute has to change. The next action "cut the root of plants" is used the knife to cut the celery, and the celery's attribute is changed again.

Relations of experimental action assessment

Key Action = KA(EA)

"Key Action" means the single action could indicate certain meanings.

Example 3.4:

KA(EA(fill the container with red water,{ backer with scale, red water } ,{backer with scale}) **)**

This key action means the measurement skill is used in the experiment.

Action Sequence = AS({EA})

Action Sequence" shows these actions should be done in a particular time period.

Example 3.5:

AS({EA(dip in water,{Celery, Tank},{ Celery})

EA(cut the root of plants,{ Celery, Knife},{ Celery})

EA(put the plant in the container,{ Celery, backer with scale },{ Celery})

EA(wait ,{ },{backer with scale})**})**

This sequence represents the main concept “transpiration of plants” to be used correctly in the experiment.

Action Continuity = AC({EA})

“Action Continuity” expresses these actions that need to be done continuously, and there is no action can be done in the middle of this process.

Object Continuity = OC({EA})

“Object Continuity” represents, for one object, these actions that need to be done continuously. Namely, it could do actions that change other objects’ attributes.

Example 3.6:

OC({EA(dip in water,{Celery, Tank},{ Celery})

EA(cut the root of plants,{ Celery, Knife},{ Celery})**})**

If the celery does not do these actions continuously, it would mean the student does not have the concept “capillarity”.

Relations of experimental assessment rules

Input: Assessment patterns (ASP) with types like that Experiment Planning (EP), Consistency(CS), Key Action (KA), Action Sequence (AS), Action Continuity (AC) and Object Continuity (OC).

Output: Assessment rules with concepts or skills.

Number = NUM(ASP, Count)

“Number” means this assessment pattern has a certain meaning when doing specific time.

Example 3.7:

Num(EP(Independent Variable , {Object, State}) , 1)

$$X = null$$

Single assessment pattern reveals some of assessment information as shown in **Examples 3.4~3.6.**

$$OR = OR(\{ASP\})$$

Doing one of actions in this set reaches this assessment rule.

$$AND = AND(\{ASP\})$$

If all assessment patterns in this set could be found in the experiment, we would show some meaning.

Example 3.8:

AND(

{ KA(EA(fill the container with red water,{ backer with scale, red water } ,{backer with scale}) **)**,

Num(AS({EA(dip in water,{Celery, Tank},{ Celery})

EA(cut the root of plants,{ Celery, Knife},{ Celery})

EA(put the plant in the container,{ Celery, backer with scale },{ Celery})

EA(wait ,{ },{backer with scale})}), 2 **) })**

This meaning is that the student could understand the domain knowledge of this experiment and use the skill “recheck”.

3.3 Portfolio Interpreter

This diagnosis system needs **Portfolio Interpreter** to translate raw data from different virtual experiment systems into diagnosis formats. As mentioned before, for diagnosis, this system also provides two kinds of portfolio diagnosis formats. We give a real case shown in Example 3.9.

Experiment Action Log

Experiment Action Log = (Order, Action-Name, {Operate-Object}, {Target-Object} , {Experiment-Variable} , Doing-Time)

Experiment Planning Log

Experiment Planning Log = (Order,{Attribute: Value}, Doing-Time)

Example 3.9:

Table 3 An example of Experiment Action Log

Order	Action-Name	Operate-Object	Target-Object	Experiment-Variable	Doing-Time
10	fill the container with red water	Backer with scale, red water	Backer with scale	Temperature: 25℃,Light: Yes, Humility: 60%	12
11	Cut the root	Knife , Celery	Celery	Temperature: 25℃,Light: Yes, Humility: 60%	5
12	Pluck leaves	Celery	Celery	Temperature: 25℃,Light: Yes, Humility: 60%	10
13	Dip in the water	Tank, Celery	Celery	Temperature: 25℃,Light: Yes, Humility: 60%	12
14	Move out	Tank, Celery	Celery	Temperature: 25℃,Light: Yes, Humility: 60%	5
15	put the plant in the container	Backer with scale, Celery	Celery	Temperature: 25℃,Light: Yes, Humility: 60%	5
16	Waiting		Backer with scale	Temperature: 25℃,Light: Yes, Humility: 60%	30
17	Waiting		Backer with scale	Temperature: 25℃,Light: Yes, Humility: 60%	24
18	Pluck leaves	Celery	Celery	Temperature: 25℃,Light: Yes, Humility: 60%	7
19	Pluck leaves	Celery	Celery	Temperature: 25℃,Light: Yes, Humility: 60%	2
20	fill the container with red water	Backer with scale, red water	Backer with scale	Temperature: 25℃,Light: Yes, Humility: 60%	8
21	Waiting		Backer with scale	Temperature: 25℃,Light: Yes, Humility: 60%	37

Table 4 An example of Experiment Planning Log

Order	Attribute: Value	Doing-Time
1	Name: Hypothesis-IF, Object: Celery, State: leaves, Comparison: More	40
2	Name: Hypothesis-THEN, Object: Backer, State: Decreasing quantity of red water, Comparison: More	40
3	Name: Independent-Variable, Object: Celery, State: leaves	22
4	Name: Dependent-Variable, Object: Backer, State: Decreasing quantity of red water	22
5	Name: Constant-Variable, Object: Celery, State: length of the stem	22
6	Name: Constant-Variable, Object: Celery, State: area of the stem	22
30	Name: Experiment-Independent-Variable, Object: Celery, State: leaves	124
31	Name: Experiment-Independent-Variable, Object: Celery, State: area of the stem	124
32	Name: Experiment-Constant-Variable, Object: Celery, State: length of the stem	124
33	Name: Experiment-Dependent-Variable, Object: Backer, State: Decreasing quantity of red water	124
34	Name: Drawing, Object1: Celery, State1: leaves, Object2: Backer, State2: Decreasing quantity of red water	37
35	Name: Conclusion-When, Object: Celery, State: leaves, Comparison: More	49
36	Name: Conclusion-Then, Object: Backer, State: Decreasing quantity of red water, Comparison: No effect	49

Chapter 4 Diagnosis Algorithm

Figure 5 shows the diagnosis architecture and the method is shown in Table 5.

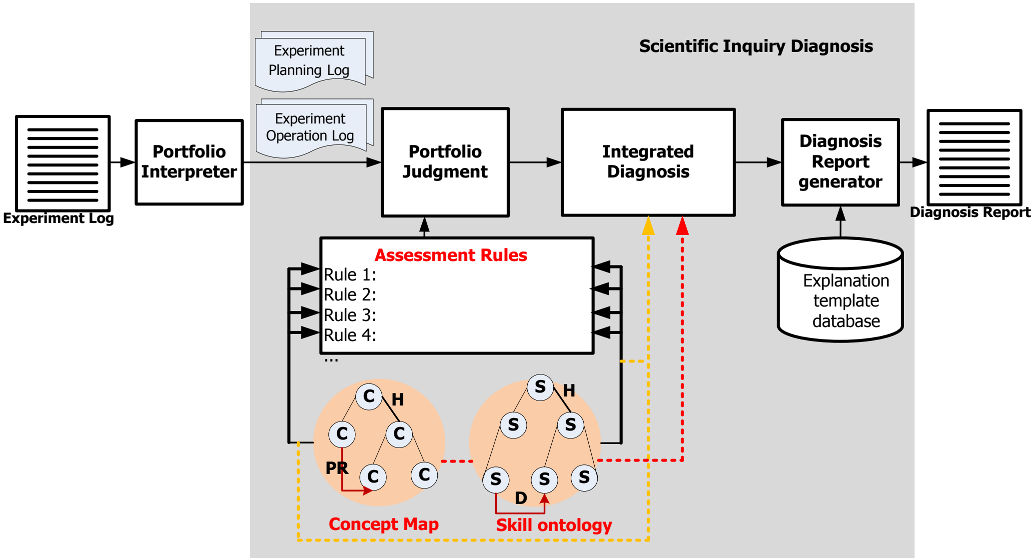


Figure 5 System architecture of Scientific Inquiry Diagnosis

Table 5 Scientific Inquiry Diagnosis Algorithm

Diagnosis Algorithm

Input: experiment planning logs, experiment operation logs

Output: diagnosis report

Step 1: After experiment planning logs and experiment operation logs passes **Portfolio Judgment**, we know that assessment rules which could be matched or not.

Step 2: In **Integrated Diagnosis**, according to the representation of assessment rules, it used relations between the rule and domain knowledge to discover what elementary concepts or skills may have difficulty.

Step 3: Use relations of the concept map or the skill map find out real problems and the entire representation in **Integrated Diagnosis**.

Step 4: Find corresponding explanations in **Diagnosis Report Generator**.

Step 5: Give the diagnosis report to the student.

Step 6: Find an adaptive experiment for the student by using tutorial model tracing.

We used an example to explain this diagnosis algorithm.

Example 4.1:

Input: Example 3.9

After **Step 1**, we discovered some assessment rules that the student did not do, and it reflected concepts "capillarity", "transpiration" and skills " independent variable in operation", "operated flow", "making the conclusion" could have problems at **Step 2**.

Table 6 Assessment rules

Rule	Concept (Rule-Num,Concept)	Skill(Rule-Num,Skill)
Rule 1 : ES({8,9,10,11})	Rule-Concept(1, transpiration)	Rule-Skill(1,Experimental operations)
Rule 2 : OC({8,9})	Rule-Concept(2, capillarity)	Rule-Skill (2, Experimental operations)
Rule 3 : NUM(3, 1)	X	Rule-Skill (3,Independent Variable)
Rule 5 : NUM(7,1)		Rule-Skill (5, Independent Variable in Experiment)

"PR" is used to find prior concepts "water transportation", "capillarity" could have problem, too.

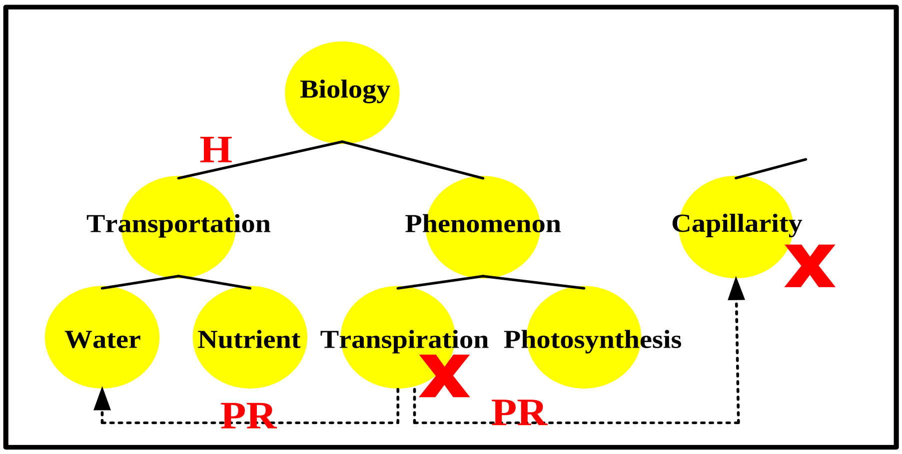


Figure 6 Concept map with error marks

By using the relation "Dependence", the main problem in skills is that students operated actions error.

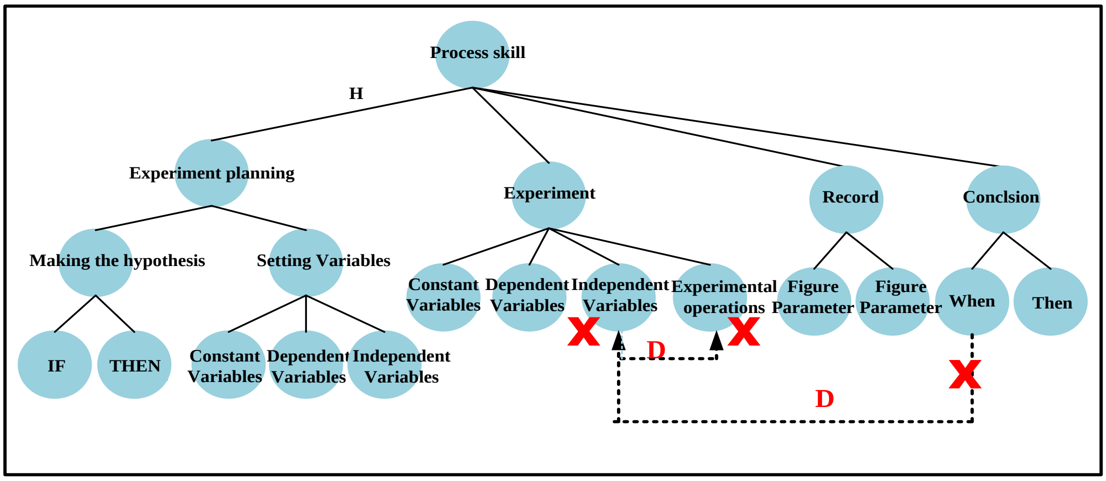


Figure 7 Skill map with error marks

Finally, the diagnosis report shows error operations, possible error reasons and the learning suggestion to the student. The suggestion represented that concepts "water transportation", "capillarity" and "transpiration" have to be learned again.

Table 7 Diagnosis report

診斷報告書
分項報告
[問題]:您在操作實驗動作時有誤。 [對應技能]:實驗流程控制。 [現象]:因為您在實驗中對於 **[芹菜]** 的實驗操作-- **[浸水][切根][插入植物][等待]**,推測您在操作 **[浸水][切根]** 的前後順序有誤。 [可能原因]:可能是因為你對於生物學科的 **[植物的蒸散作用][毛細現象]** 尚未完全了解。
[問題]:在操作實驗時有誤 [對應技能]:實驗變因控制、實驗流程控制。 [現象]:因為您可能是想觀察 **[芹菜葉子][芹菜莖的截面積]** 對於 **[紅墨水體積減少量]** 的影響。 [建議]: 以本類型實驗來說,請選擇一個實驗變因來進行實驗觀察!
整體報告:
[問題]:您在下結論並沒有將問題解決,可能是因為在實驗中同時對 **[芹菜葉子][芹菜莖的截面積]** 多個實驗項目改變數值, 也可能是由於你在控制動作順序操作有誤,才不小心在實驗中改變多組變因。 [技能建議]:在操作實驗時除了您在設定變因所設定 **[芹菜葉子數]** 改動數值以外,其他項目請保持定值。 [學科概念建議]:在學科概念中,建議您對於 **[植物的蒸散作用]][毛細現象]** 的相關概念進行學習。 [學科概念-先備知識建議]:在學科概念中,建議您參考先備知識 **[植物的水分運輸][毛細現象]** 進行學習。

Tutorial Model Tracing

According to diagnosis results, we can find out students' learning problems. Our leaning suggestions include not only concept curriculums but also adaptive experiments. This is to say, for specific learning goals, teachers can design various experiments, such as different degrees of the same experiment or different experiments using the same theorems.

Teachers can use assessment rules to define this tutorial model. We give a simple example as below.

Example 4.2: Biology Transpiration Experiment

Table 8 assessment rules

Rule	Concept (Rule-Num,Concept)	Skill(Rule-Num,Skill)
Rule 1 : ES({8,9,10,11})	Rule-Concept(1, transpiration)	Rule-Skill(1, Experimental operations)
Rule 2 : OC({8,9})	Rule-Concept(2, capillarity)	Rule-Skill (2, Experimental operations)

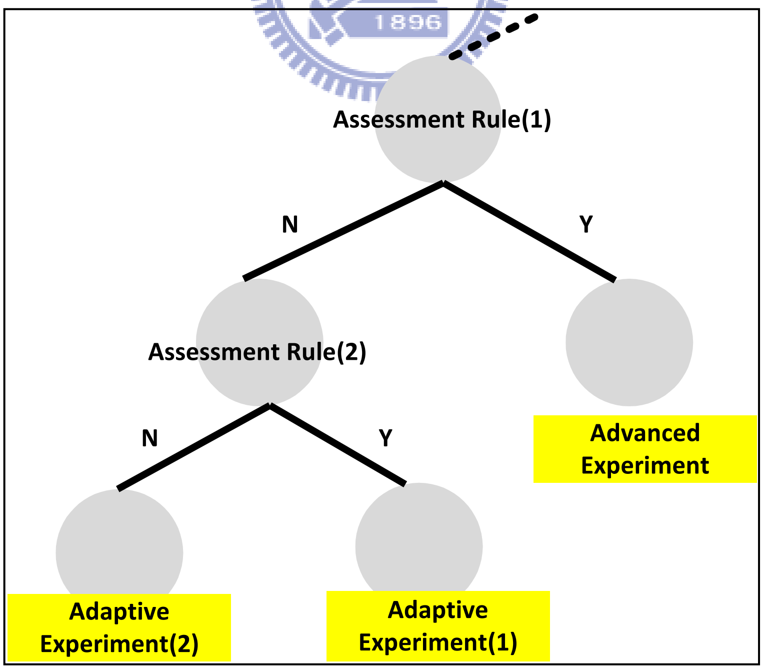


Figure 8 Tutorial model for Biology Transpiration Experiment

The advanced experiment is given to students when students achieve the assessment rule 1. It means that students understand main theorems of this experiment.

Therefore, teachers design another experiment which uses the same theorems and totally different experiment environment as shown in Figure 9.

Figure 9 Advanced experiment described in Figure 8

Adaptive experiment (2) is provided when students do not achieve assessment rule 1 and 2. Teachers would fix some experiment actions as shown in Figure 10 in order to reduce the difficulty of this experiment.

Figure 10 Adaptive experiment (2) described in Figure 8

Chapter 5 Scientific Inquiry Knowledge Acquisition

5.1 Dialogue Based Knowledge Acquisition

Acquiring teachers' assessment knowledge becomes a challenging issue due to heterogeneous and multi-dimensional knowledge used in scientific inquiry diagnosis. In this thesis, a dialogue-based knowledge acquisition, as shown in Figure 11, was proposed to facilitate teachers to provide assessment knowledge step by step.

The knowledge acquisition method includes constructing Map, defining experiment assessment information, modifying assessment rules, and refining feedback. Maps and assessment patterns pass through dot-lines in order to make teachers construct relations between them. Detailed descriptions of process are offered in the following section.

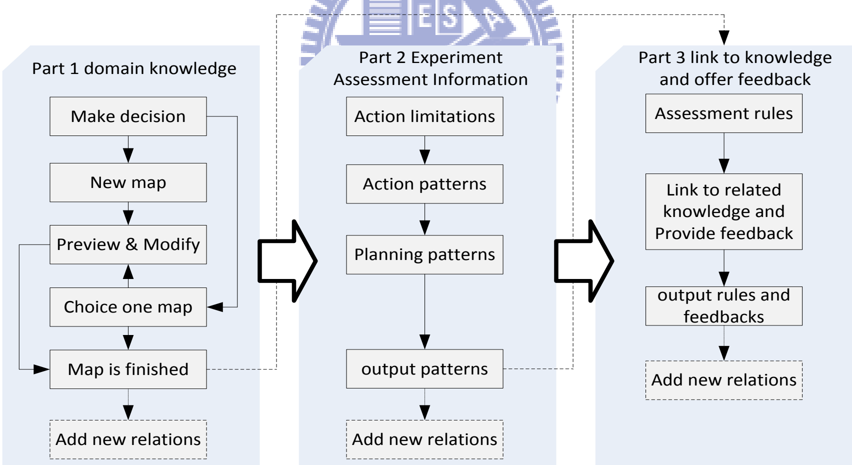


Figure 11 Dialogue Based Knowledge Acquisition Algorithm

As we know, similar concepts and science process skills have been substantially used in various experiments, so sharing and reusing concept and skill maps which could reduce much construction cost is our idea.

Teachers can modify or construct relations of existing maps or a newly constructed map. Moreover, teachers can provide new relations by offering a real example. The algorithm was shown as follows:

Table 9 Dialogue-Based Knowledge Acquisition Algorithm(1)

Dialogue-Based Knowledge Acquisition Algorithm for Domain knowledge
Output: Maps
Step 1: Preview previous concept and skill maps to find the required map.
Step 2: If a required map could not be found, create a new map.
Step 3: Modify or extend concepts and relations in the map for current requirements.
Step 4: Return a new or modified map.
Step 5: The map is finished.
Step 6: Provide new relations and its example.

An authoring interface of concept maps and skill maps was shown in Figure 12, where teachers could preview and edit a map at the left part and modify information for a concept, including a name of the concept or skill, the parent of the concept or skill, prerequisite concepts or skills, and their weights, at the right part.

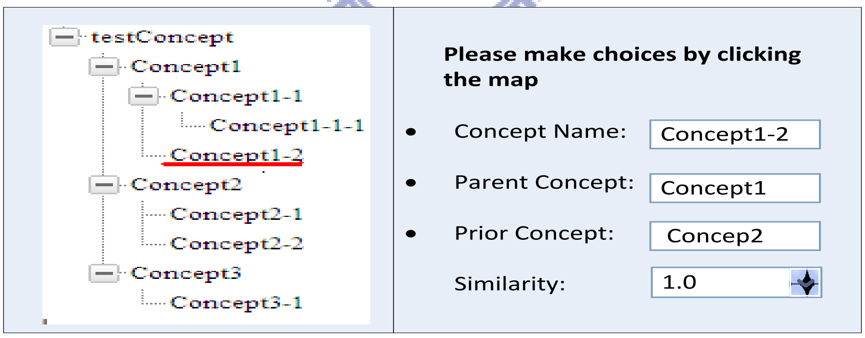


Figure 12 An authoring interface for editing concept and skill maps

The authoring interface can help teachers set limitations for each action, such as time limitation and environment limitations and so on. Moreover, it can also create assessment patterns by using relations “Single Key Action”, “Action Sequence”, “Action Continuity” and “Object Continuity”. Correct planning patterns are also setting in this part. Therefore, after this part, we can obtain assessment patterns. Teachers can provide new relations to describe action patterns by using an example. The algorithm was shown as follows:

Table 10 Dialogue-Based Knowledge Acquisition Algorithm(2)

Dialogue Based Knowledge Acquisition Algorithm
Part 2 Experiment Assessment Information
Input: All experiment actions and planning actions in this experiment from CIMAS.
Output: Experiment action patterns Experiment planning patterns.
Step 1: Set the related limitation of actions to know actions doing right or not.
Step 2: Do action assessment patterns with the following relations:
Single Key Action, Action Sequence, Action Continuity and Object Continuity.
Step 3: Set the correct values of planning patterns.
Step 4: Output patterns.
Step 5: Provide new relations and its example.

However, a lot of patterns may be extracted from many actions. In order to reduce the construction cost, our designs are as below.

(1) At first, a checkbox table which lists all experiment actions from CIMAS is given, and then teachers can choose desirable actions which could be used in the assessment by checkbox.

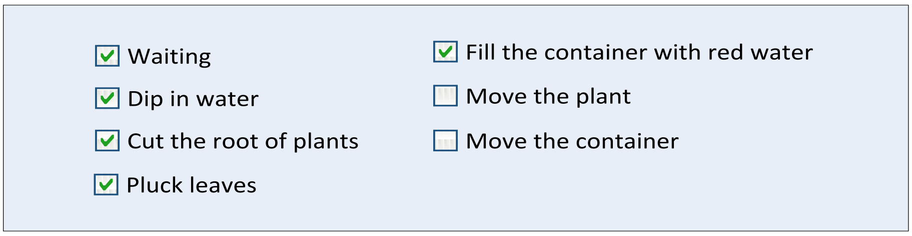


Figure 13 Interface design of setting actions' limitation

(2) **Setting limitations**. This part provides default environment variables, such as "temperature", "humility", "atmosphere", and so on. It also offer default values for each environment variable. For instance, "temperature" includes "normal temperature", "high temperature" and "low temperature", but teachers also can set value by themselves. Besides, in general, actions usually do in some certain values of environment variables, such as doing in the "normal temperature". Therefore we would choose some default value beforehand, in order to reduce teachers loading.

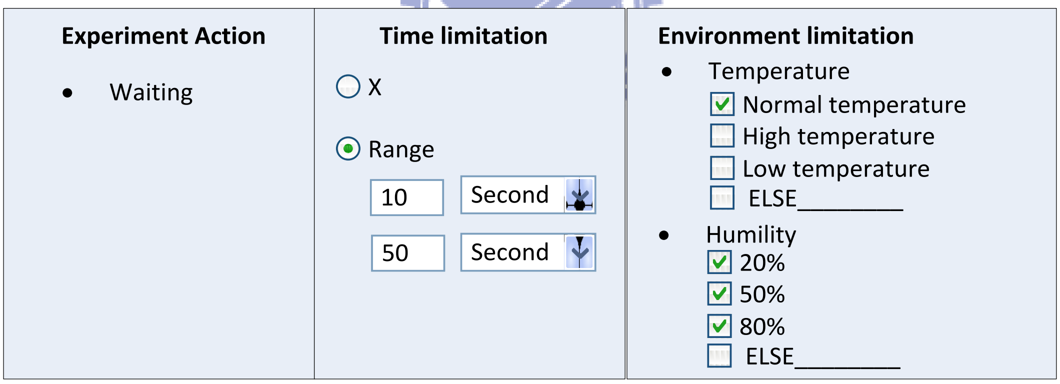


Figure 14 Interface design of setting actions' limitation

The purpose of this part is to assist teachers to do assessment rules using outputs from Part 2, link these rules to maps and do learning feedbacks. It provides relations "Num", "OR" and "AND" to help teachers create assessment rules.

Table 11 Dialogue-Based Knowledge Acquisition Algorithm(3)

Dialogue Based Knowledge Acquisition Algorithm
Part 3 Experiment Assessment Information link to domain knowledge and offer appropriate feedbacks
Input: Experiment action patterns, experiment planning patterns and maps
Output: Assessment rules and its feedbacks.
Step 1: Compose actions patterns to be assessment rules.
Step 2: Link to related knowledge and provide its feedback for each rule.
Step 3: Output rules and feedbacks.
Step 4: Provide new relations and its example.

Each assessment rule needs to have their learning feedback, so teachers also have to offer these feedbacks. In order to reduce the cost, it provides some feedback templates to help teachers do feedback easier, such as Figure 15.

Feedback template

- _(Action Name)_ is doing wrong, Because you spent _(Time)_ in this action , it is too long (or short). It is possible that you do not understand concepts (or skills) completely.
- _(Action Name)_ is doing wrong, Because you did this action in (Environment variables). It is possible that you do not understand concepts (or skills) completely.

Figure 15 Feedback templates

Detailed design is shown in appendix.

There are some relations that have not been provided in this study. Finally, we ask teachers whether they have new relations. If yes, we would request the teacher to provide this relation information which will be added at offline.

.

5.2 Experiential Behavior Pattern Mining

Teachers can get elementary understandings of students from assessment rules. However, students usually have different learning behaviors because their learning environment or their backgrounds have distinctions, but actually teachers do not know some learning behaviors of students which probably belong to abstract behaviors.

As mentioned before, science education researches indicate sequence of experiment actions that could means specific behaviors. According to these characters, this study applies sequential pattern mining technology to design a method to discover new inquiry behaviors as shown in Figure 16.

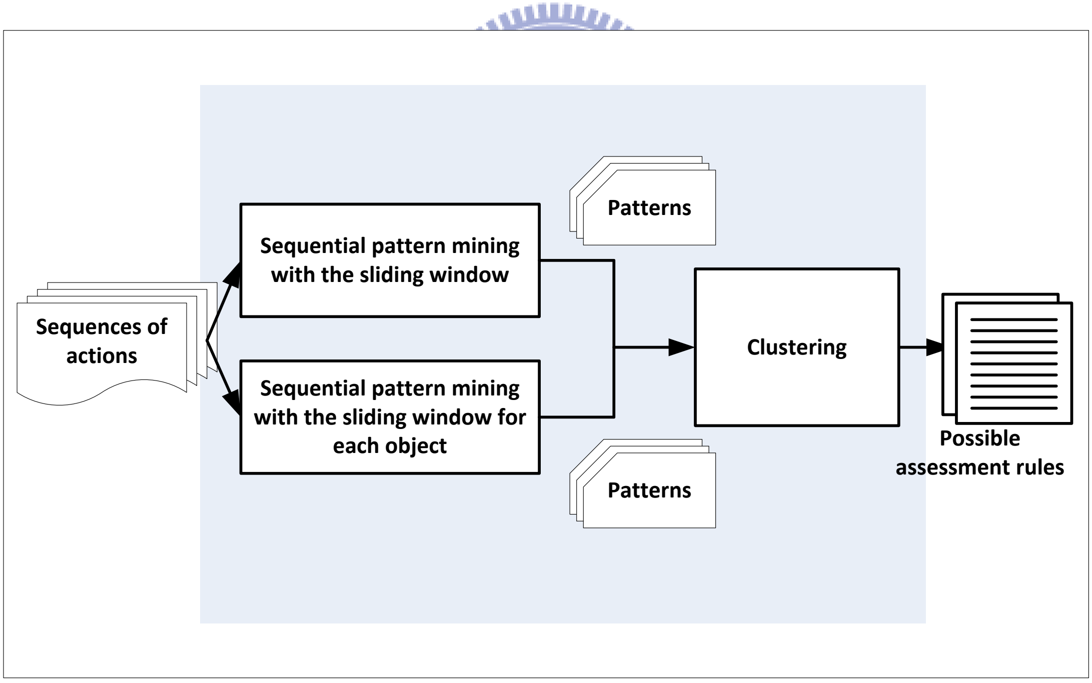


Figure 16 Behavior Finding Method

Transaction

First of all, mining transactions are the sequences of actions that students operated.

Transaction = {action1, action2, action3,…}

Pattern finding

As mentioned in Chapter3, action assessments relations include "Sequence", "Continuity" and "Object Continuity", so sequential patterns mining is an appropriate way to find new patterns that teachers do not know for this study. Therefore, we provide some changes to this way.

The advantages include reducing many nonuse patterns. Useful patterns much response students' intentions, because these patterns are operated continually.

But, the sliding window may lose useful patterns if the window size is not appropriate. Hence, this study uses "Sequential pattern mining with the sliding window" in each experiment object. For instance, in Biology Transpiration Experiment, we get all actions of the celery to do continuity pattern mining.

Clustering

The next step is to cluster students based upon patterns. We organize logs as fixed-length records shown in Table 12, where the vector value is 1 if the student did this pattern in this experiment, and is 0, otherwise. The fixed-length record of each student

Table 12 clustering process

	Patten 1	Patten 2	Patten 3	Patten 4	Patten5	Patten 6	…	Patten N
Student1	1	1	1	1	1	1	…	1
Student2	1	0	0	0	1	0		0
…								

Using k-means algorithm divides students into some groups. In the same group, students' behaviors are similar. This is to say, every group may represent one learning behavior. We provide these clustering results to teachers, and teachers can consider them to add new assessment rules.

Chapter 6 Implementation and Experiment

The proposed online diagnosis scheme was implemented and applied to two virtual laboratory systems, named Computerized Interactive Multiple Assessment System and Virtual Physics Experiment System[8], to evaluate the effectiveness of experiment diagnosis in biology and physics, respectively

6.1 System Implementation

Computerized Interactive Multiple Assessment System(CIMAS)

Based on the proposed model, a CIMAS is developed. CIMAS provides a virtual experiment environment for students to plan and operate in a teacher-designed virtual experiment. In the assessment flow as shown in Figure 17, a student chooses a hypothesis according to a description of an assessment problem. Afterward, this student chooses independent variables, dependent variables, and constant variables to describe the plan of the assessment experiment. Then, the student operates in the virtual experiment environment to gather experimental data for proofing the hypothesis, as shown in Figure 18. Finally, the student gives a conclusion according to the experimental records.

Figure 17 Computerized Interactive Multiple Assessment System

Figure 18 Operate actions in CIMAS

After experiencing in CIMAS, each student will obtain a diagnostic report, which records error operations in this assessment experiment, main possible reasons of these error operations, and learning suggestions for the diagnostic results. An example of a diagnostic report is shown in Figure 19.

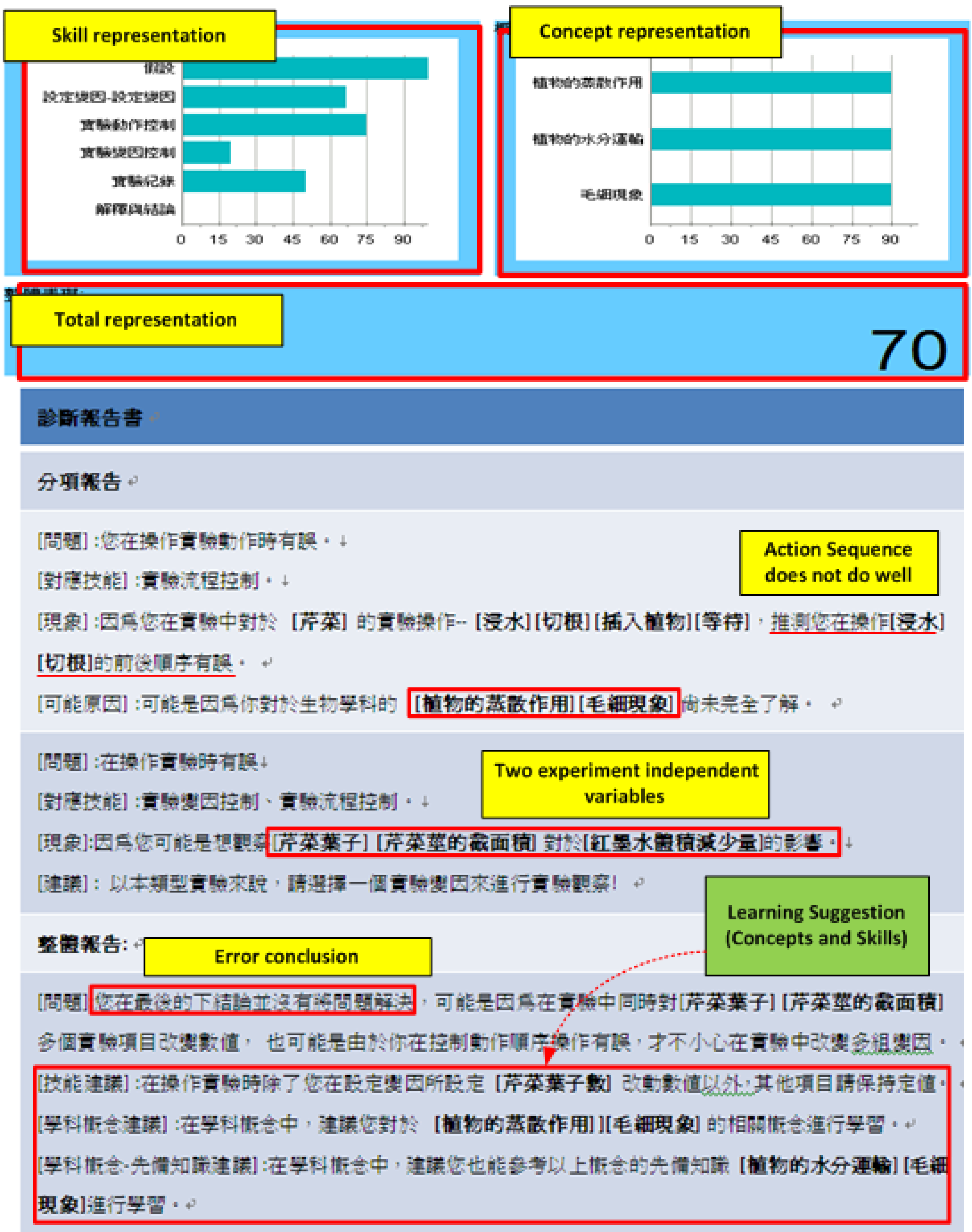


Figure 19 Diagnosis Report (1)

Virtual Physics Experiment System

A Virtual Physics Experiment System provides experiments of senior high school physics curriculum. As shown in Figure 20, in the beginning of an assessment experiment, the student chooses a scenario and a corresponding hypothesis for a given assessment problem. Then, the student chooses an animation of physical phenomenon to match the chosen scenario, and map the objects in the animation to the chosen scenario. According to this animation and the hypothesis, the student sets experiment variables for the further experiment. In this virtual experiment system, the student could vary values of experiment variables to observe the simulated physical phenomenon and record the experimental data for automatically drawing a figure. This figure could assist the student in understanding the trend of variables' values. In the last step, the student chooses a conclusion and tells whether the conclusion could answer the problem in the chosen scenario or not.

The Diagnosis report is shown in Figure 21.

Figure 20 Virtual Physics Experiment System

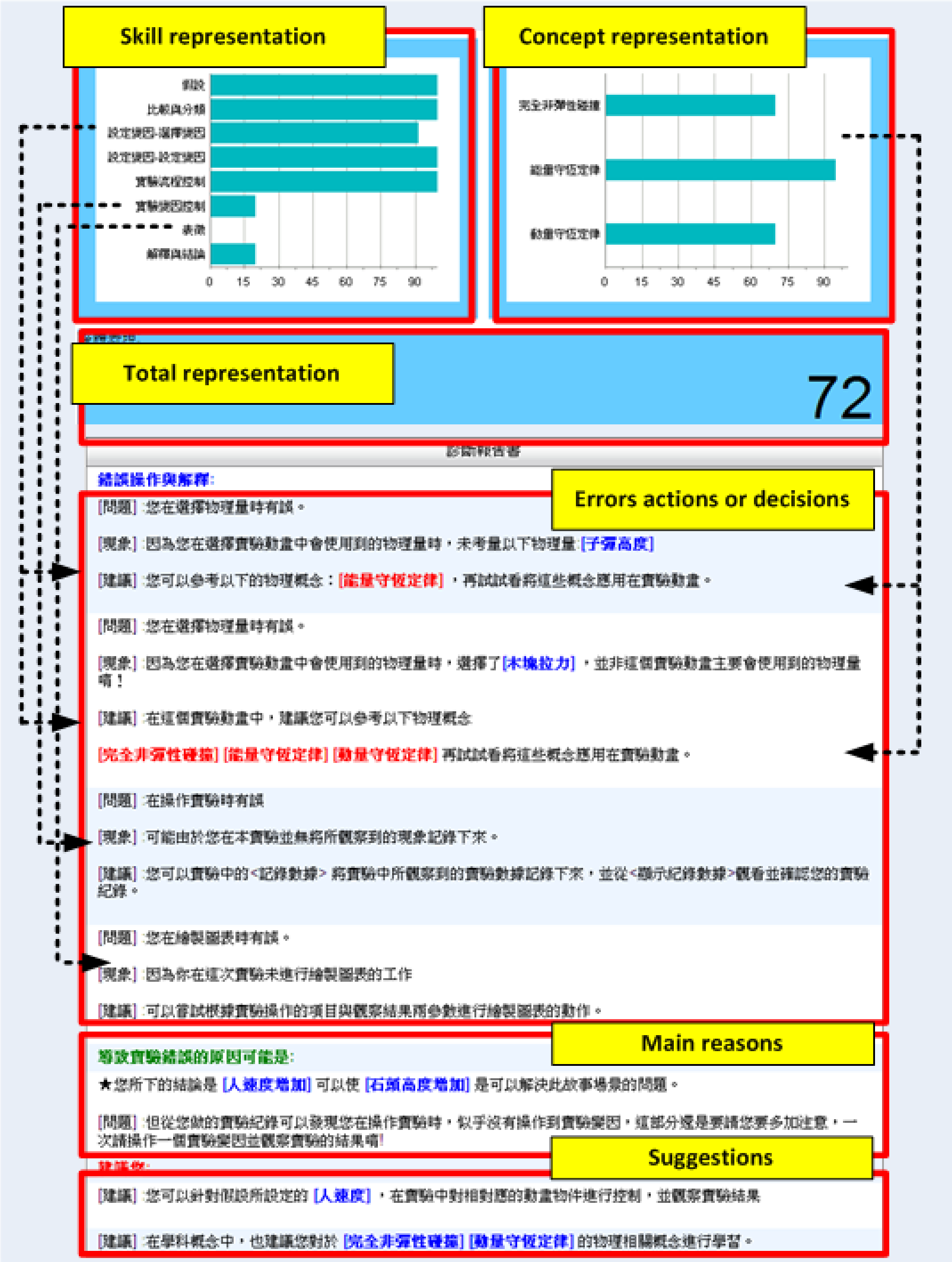


Figure 21 Diagnosis Report (2)

6.2 Experiment Result

Computerized Interactive Multiple Assessment System

An experiment with Computerized Interactive Multiple Assessment System was conducted for 30 third-grade students of Fong-Ping junior high school in a remote district of Taiwan.

Student Satisfaction

Student Questionnaire is shown in Table 13 Student Questionnaire. There are five questions that we want to understand from students. The first one is to know that personal analyses and learning suggestions whether can help students realize their learning condition after the assessment or experiment. The next three questions are to realize each part of the diagnosis report whether can have different help to students. The last question is whether the whole diagnosis report can assist students in self-learning. The questionnaire result is shown in Figure 22

Table 13 Student Questionnaire

		1	2	3	4	5
Q1	Assessment systems could provide personal analysis and learning suggestions after you operate experiments whether it could help you on learning.	☐	☐	☐	☐	☐
Q2	In diagnosis reports, whether the skill representation, the concept representation and the total representation could help you to understand the assessment result rapidly.	☐	☐	☐	☐	☐
Q3	In diagnosis reports, whether the section which shows error action or decisions could help you to understand problems during the assessment time.	☐	☐	☐	☐	☐
Q4	In diagnosis reports, whether main reasons and suggestions could help you to improve your learning.	☐	☐	☐	☐	☐
Q5	Whether this diagnosis report could help you to understand and improve your problems.	☐	☐	☐	☐	☐

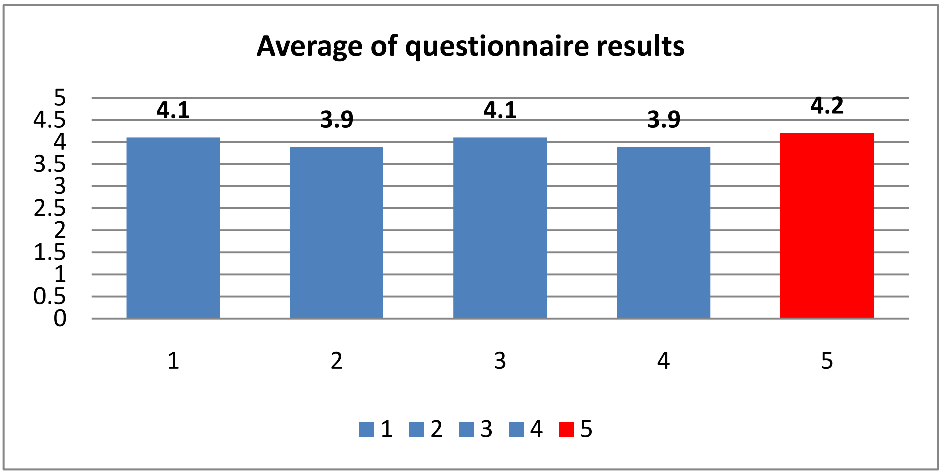


Figure 22 Average of questionnaire results

As shown in Figure 22, the student satisfaction degrees are all about four, so this kind of diagnosis report was really helpful for students.

According to the observation during this experiment time, students' attentions usually arose from diagnostic scores and the bar charts of scores, and then these virtualized representations could encourage students to understand the further diagnostic results. Some students tried the assessment experiment for many times to modify their mistakes after reading their diagnosis reports. Moreover, the mistakes described in the diagnostic reports could push students to actively discuss with teachers.

Teacher' Feedback

After experiment, a teacher of Fong Ping Junior High School observed students behaviors, and gave feedbacks described as follows:

"Students of Fong Ping Junior High School are not interested in book learning, and most students always get low scores on tests. Before this experiment, I thought that these students might not know how to use this system, or interested in the assessment. Unexpectedly, it was a successful experiment. No matter what the reason is, this system can really attract students' interests. In the diagnosis system, students felt their tests and diagnosis were unique, and spent more time to understand their problems. Although the system is still developed, this system can not only help students but teachers.”

Behavior Analysis

After Behavior Finding, we found behavior patterns and clustering results, and students’ portfolios shows in appendix.

Table 14 Behavior patterns

	action		**action**
A	Pluck leaves of celery 1	**B**	Pluck leaves of celery 2
C	Cut the root of celery 1	**D**	Cut the root of celery 2
E	Measure the stem of celery 1	**F**	Measure the stem of celery 2
G	Fill the backer 1 with red water	**H**	Fill the backer 2 with red water
I	Dip in the water and Cut the root of celery 1	**J**	Dip in the water and Cut the root of celery 2
K	Put celery 1 in the container and Waiting	**L**	Put celery 2 in the container and Waiting
M	Waiting and Waiting		

Table 15 Clustering Results

NO.	**Students’ ID**	**Central of the cluster {A,B,C,D,E,F,G,H,I,J,K,L,M}**
1	<1,5,8,10,11,20,21,22>	{0,1,1,1,1,1,1,1,1,1,1,1,0}
2	<2,3,4,6,7,13,14,19,23,24>	{0,1,1,1,1,0,1,1,0,0,1,1,1}
3	<12,15,16,17,18, 26,27,29,30>	{0,1,0,1,0,0,0,1,0,0,0,1,0}
4	<9, 25,28>	{0,0,0,1,1,0,0,1,0,0,1,1,0}

Cluster 1 means the typical operation of this experiment. Students operated different leaves' counts in order to observe whether leave's counts affect the transpiration speed of celeries. To control the count of leaves is usually taught by teachers in the class. Students of this cluster have the inquiry skill of using the control group and the experimental group, and they can use tools to measure the stem of celery. Moreover, they had a good using of related concepts.

Students of cluster 2 attempted to control the count of leaves, but they made some mistakes during experimental time. They could have the bad concept "capillarity" so that they were not to operate "Dip in the water" and "Cut the root of the celery" continually. However, they had good behaviors in doing experiment. For example, they operated "Waiting" one more time to observe that the transpiration phenomenon of the same celery.

Students of cluster 3 had some misconceptions of this experiment. They observed one of celeries. This is to say, they were not to control attributes of celeries, so they did not know which attributes would affect the transpiration speed of celeries. The possible reason is that students did not have a good reading ability to understand this problem.

Students of cluster 4 attempted to control stems of celeries. They thought different lengths of stems which can affect the transpiration speed of celeries, and they also used the control group and the experimental group. This is good inquiry behaviors, but they also learned the concept "capillarity".

Evaluation of Virtual Physics Experiment System

Diagnosis of Virtual Physics Experiment System has been applied to 30 first grade students of National Nanke International Experimental High School in Taiwan. This experimental result is to verify that the diagnosis scheme can really help teachers and students to know difficulties effectively.

Student Satisfaction

Student Questionnaire is also shown in Table 13 Student Questionnaire, and the questionnaire result is shown in Figure 23. Figure 23 shows students almost think diagnosis reports can help them on their learning.

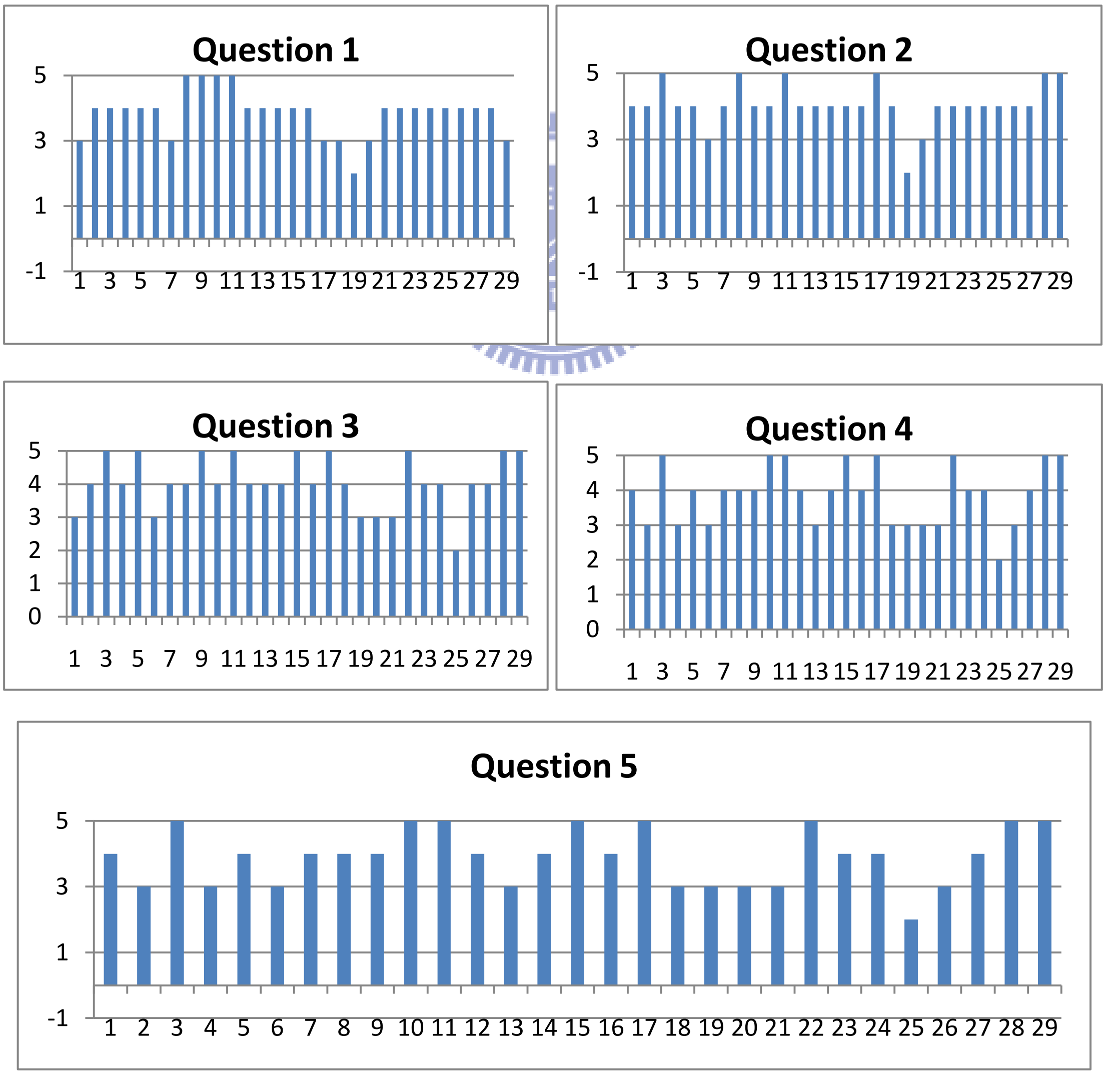


Figure 23 Result of questionnaire

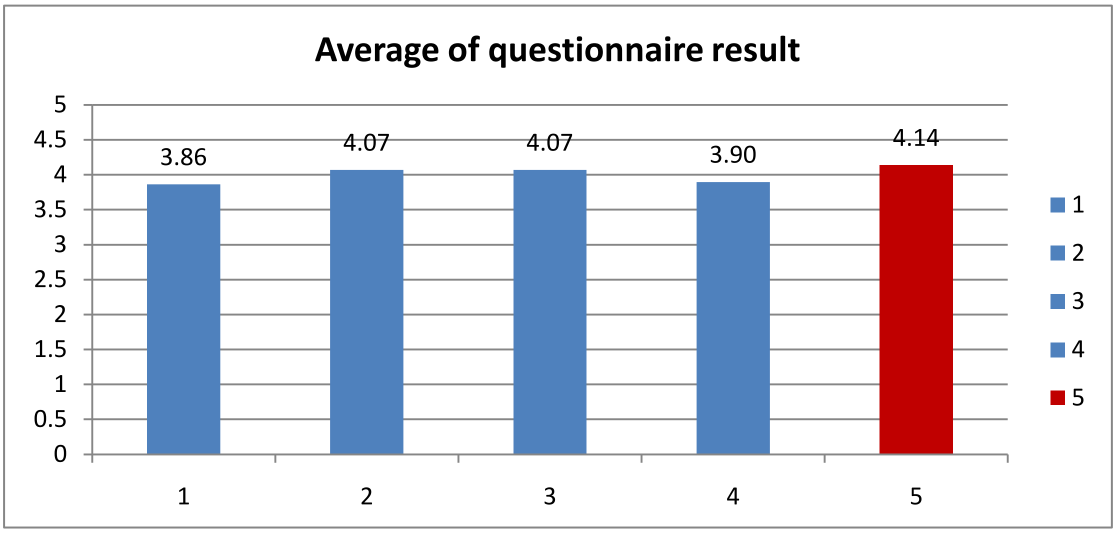


Figure 24 Average of questionnaire result

In Figure 24, the average students' satisfaction of experiment diagnosis report is near eighty percent. This result shows that the diagnosis report can help students to understand their problems or difficulties on experiment assessments and main possible reasons for all mistakes. Moreover, learning suggestions of concepts or skills also help them to improve their background knowledge. In short, this diagnosis report of scientific inquiry experiment assessment can really assist students in self-learning.

Teacher Satisfaction

We wanted to understand the diagnosis result whether matches the thinking of the teacher. Therefore, we designed the teacher feedback interface to help the teacher give she/he suggestions as shown in Figure 25.

First, we provided students' portfolios which were obtained by Virtual Physics Experiment System. The teacher observed these portfolios to judge each item of diagnosis reports correct or not by choosing the degree of matching, and give suggestions.

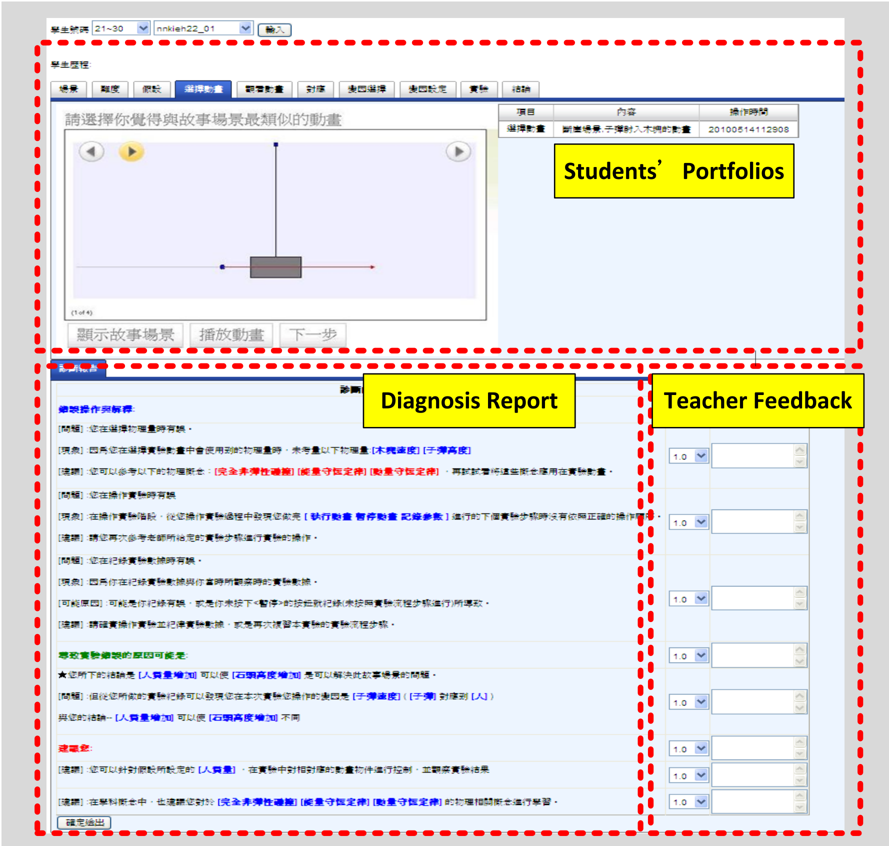


Figure 25 Teacher feedback interface

Figure 26 shows the correct degree of each item on the diagnosis report. There are three different experiment contents, and we chose ten students portfolios for each experiment. Therefore, the teacher gave evaluations by 30 students' portfolios. As shown in Figure 26 and Figure 27, the teacher scarification is 85%. Teacher suggestions focus on the virtual physic system. For example, experiment objects should be detailed to describe in order to avoid students making misunderstanding.

In addition, the teacher indicated diagnosis reports can really assist teachers to realize students' inquiry ability, and it is actually not easy to do this diagnosis result in the develop stage.

Experiment 1

實驗場景-斷崖場景												
過程技能	實驗階段	13_01	15_01	19_01	24_03	28_01	25_02	26_01	29_01	18_01	22_01	平均
假設	假設	X	X	X	X	X	X	X	X	X	X	X
比較分類	選擇動畫	X	X	X	X	X	X	X	X	X	X	X
比較分類	物件對應	X	X	1	1	X	X	X	X	X	X	1
設定變因 選擇變因	選擇變因	0.5	X	X	1	0.7	1	X	0.7	1	0.6	0.78
設定變因 設定變因	設定變因	X	1	1	0.6	0.85	0.5	1	X	1	X	0.85
實驗流程控制	實驗	0.9	1	1	0.7	1	0.8	1	0.9	0.9	0.8	0.9
實驗變因控制	實驗	0.7	1	1	0.7	1	X	1	1	0.7	X	0.88
表徵	繪圖圖表	1	0.7	1	0.85	1	1	X	1	0.95	0.7	0.91
各別解釋												0.86
主因與建議		0.7	0.95	0.9	1	0.8	0.7	0.8	0.8	0.9	0.9	0.84

Experiment 2

實驗場景-馬車場景												
過程技能	實驗階段	13_05	16_02	18_05	19_03	24_02	27_02	26_03	29_02	23_03	22_04	平均
假設	假設	X	X	X	X	X	X	X	X	X	X	X
比較分類	選擇動畫	X	1	X	X	X	X	X	X	X	X	1
比較分類	物件對應	X	1	1	X	X	X	X	X	X	X	1
設定變因 選擇變因	選擇變因	1	0.3	X	X	0.7	1	0.3	0.8	0.7	0.8	0.7
設定變因 設定變因	設定變因	0.9	0.6	1	X	1	1	0.8	1	1	0.8	0.9
實驗流程控制	實驗	1	1	1	1	0.8	1	1	1	0.8	0.9	0.95
實驗變因控制	實驗	0.8	1	0.9	0.9	0.8	X	0.8	X	0.7	1	0.86
表徵	繪圖圖表	0.9	1	0.9	0.9	0.9	1	0.9	0.8	0.95	0.95	0.92
各別解釋												0.86
主因與建議		0.8	1	0.9	0.7	0.8	0.7	0.8	0.9	1	0.9	0.85

Experiment 3

實驗場景-滅火場景												
過程技能	實驗階段	13_04	15_02	16_01	19_02	17_03	22_03	26_02	25_03	28_04	24_01	平均
假設	假設	X	X	X	X	X	X	X	X	X	X	X
比較分類	選擇動畫	X	X	1	X	X	X	X	X	X	X	1
比較分類	物件對應	X	X	1	X	X	X	X	X	X	X	1
設定變因 選擇變因	選擇變因	1	X	0.3	1	1	1	1	1	1	1	0.92
設定變因 設定變因	設定變因	X	0.1	0.3	X	1	0.9	1	X	X	X	0.66
實驗流程控制	實驗	X	X	1	1	X	0.9	1	X	1	0.7	0.94
實驗變因控制	實驗	0.9	X	0.9	1	0.9	X	1	0.9	1	0.3	0.74
表徵	繪圖圖表	0.9	0.7	1	1	0.8	1	1	1	1	0.7	0.91
各別解釋												0.87
主因與建議		0.9	0.8	0.7	1	0.8	0.8	0.8	1	1	0.8	0.86

X: 沒有錯誤

Figure 26 Teacher feedback result

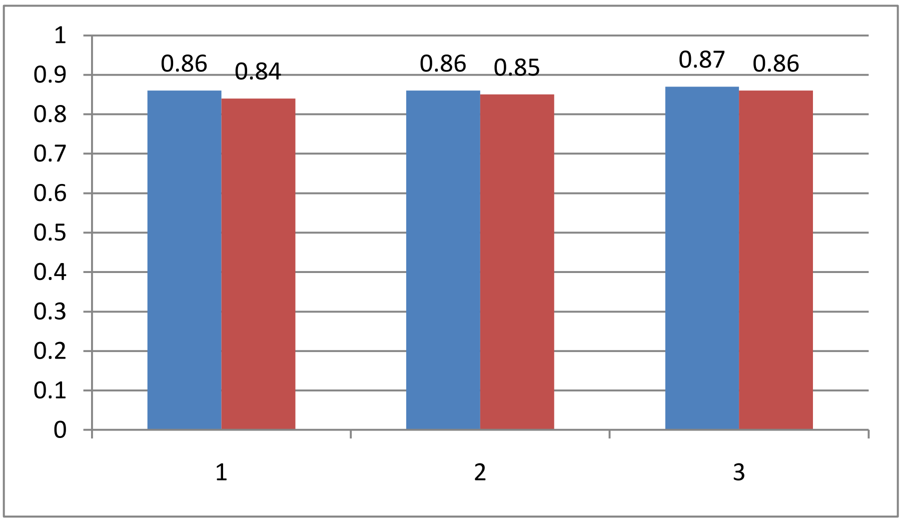


Figure 27 Teacher Satisfaction

Chapter 7 Conclusion

This research attempts to assist teachers or students to know students' logical thinking about this inquiry topic. Therefore, this diagnosis scheme focused on operation processes assessments, and it cannot be used to assess proficient degree of experiment objects.

Experiment Results shows the scientific inquiry diagnosis system which can really help students and teachers in scientific inquiry learning. The diagnosis report provides useful information such as error operations and decisions, learning difficulties, learning suggestions. Moreover, this diagnosis result also includes adaptive experiments to assist students in inquiry learning by dynamic adjusting experiments' contents from CIMAS. Besides, behavior pattern mining can discover some new or high level inquiry behaviors.

In the future, this study will focus on doing another behavior mining researches to discover various and possible experimental behaviors. Learning suggestions will also be concerned in this study, such as how to automatic offer appropriate curriculums and construct adaptive experiments.

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Appendix

Assessment Knowledge Acquisition Algorithm

(目標說明)針對蒸散速率實驗。請老師建立相關知識與實驗評量標準，分三部份。

Part 1： 知識建立

此部份請依循步驟建立與蒸散速率實驗相關的概念圖與技能圖

Step 1： 關於蒸散速率實驗是否新建立相關的學科概念圖?

IF(YES)　Step 2 else Step 4

Step 2： 新增概念圖

Step 2.1： 請先列出本次實驗所涵蓋的所有概念？(可多次增加)

概念名稱: 輸入文字 新增

Step 2.2： 請列出 Step 3.1 概念中的先備概念？

概念名稱: 輸入文字

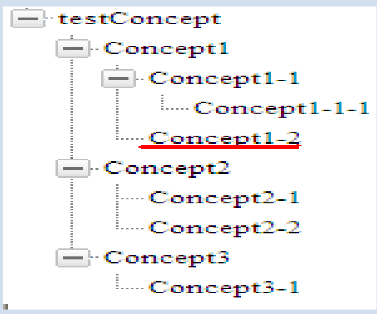
上層概念名稱: 輸入文字 新增

Step 2.3： 請列出列表中概念中的上層概念？

概念名稱: 輸入文字

上層概念名稱: 輸入文字 新增

Step 2.4 :預覽與調整概念圖



概念資料

概念名稱: Concept1-2-1　[請選擇]

父概念:Concept1-2　[請選擇]

先備概念: Concept2-2　[請選擇]

IF(step 2 FINISH) Step 4

Step 3:請選擇蒸散速率實驗相關的學科概念圖?(可複選)

Step 3.1 概念圖名稱: 輸入文字

Step 3.2 是否要重新調整概念間關係？

IF(YES) Step 2.4 ELSE Step 4

Step 4：關於蒸散速率實驗是否新建立相關的過程技能圖?

IF(YES)　Step 5 else Step 6

Step 5：新增概念圖

Step 5.1：請先列出本次實驗所涵蓋的所有過程技能？(可多次增加)

概念名稱: [輸入文字] [新增]

Step 5.2：請列出 Step 5.1 過程技能中的先備過程技能？

過程技能名稱: [輸入文字]

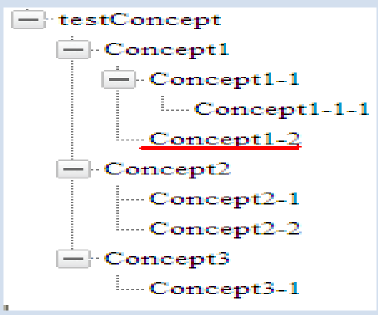
上層過程技能名稱: [輸入文字] [新增]

Step 5.3：請列出列表中過程技能中的上層過程技能？

過程技能名稱: [輸入文字]

上層過程技能名稱: [輸入文字] [新增]

Step 5.4 :預覽與調整過程技能圖



過程技能資料

過程技能名稱: Skill1-2-1　[請選擇]

父過程技能: Skill1-2　[請選擇]

先備過程技能: Skill2-2　[請選擇]

IF(step 5 FINISH) Part2

Step 6 :請選擇蒸散速率實驗相關的過程技能圖?(可複選)

Step 7.1 過程技能圖名稱: [輸入文字]

Step 7.2 是否要重新調整過程技能間關係？

IF(YES) Step 5.4 ELSE Part2

Part 2.1： 實驗動作評量規則建立

Step 1: 在蒸散速率實驗中，有哪些動作需有以下評量標準？

請選擇動作 **[從 CIMAS 實驗動作倒入]**
☑ 等待 ☐ 摘葉 ☑ 浸水 ☐ 切根 ☐ 倒紅墨水 ☐ 插入植物

是否有環境參數上的限制？

環境參數選擇 **[從 CIMAS 實驗設定環境參數倒入]**
☑ 溫度 ☑ 濕度 ☐ 壓力 ☑ 日照 ☐ 風速

IF(Environment Variable Count==0) (Column 3) Disable

是否有時間上的限制？ IF(NO) (Column 2) Disable

動作 **(Column 1)**	**動作時間限制型態** **(Column 2)**	**環境參數** **(Column 3)**
浸水	◉ X ○ 範圍 [ ] [秒] 以上 [ ] [秒] 以下	➢ 日照 ☑ 是 ☑ 否 ➢ 溫度 ☑ 常溫 ☐ 低溫 ☐ 高溫 ➢ 濕度 ☐ 0% ☐ 50% ☑ 80%
等待	○ X ◉ 範圍 [10] [秒] 以上 [50] [秒] 以下	➢ 日照 ☑ 是 ☑ 否 ➢ 溫度 ☑ 常溫 ☐ 低溫 ☐ 高溫 ➢ 濕度 ☑ 0% ☑ 50% ☑ 80%

Step 2：除了以上動作評量方式以外，是否有其他訊息要加入評量動作?

名稱: [輸入文字]

單位: [輸入文字]

Step3：

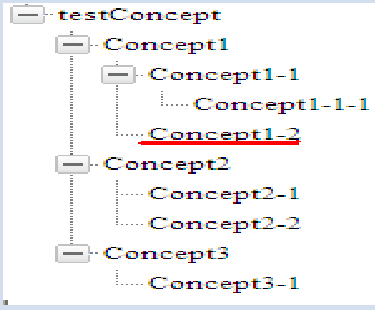
有哪些單一實驗動作，表達哪些概念或是過程技能知識，表達程度又是多少？

請選擇動作　**[從 CIMAS 實驗動作倒入]**

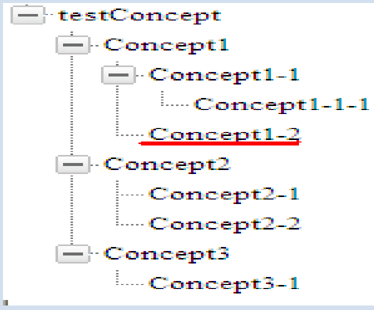
等待 摘葉 浸水 切根 倒紅墨水 插入植物

請選擇此動作相關的概念與技能

概念圖



技能圖



動作	學科概念	概念程度	過程技能	技能程度
等待	Concept1-2	0.8	Skill1-2	0.7

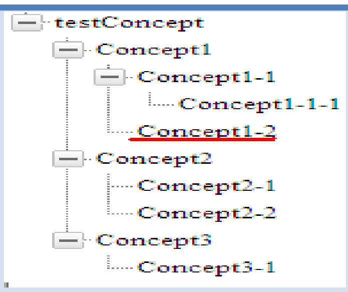
Step4：**順序性動作**(存在操作先後順序，若無依序操作，可能會導致實驗誤差。(中間可穿插其他動作))，是可以表達哪些概念或是技能知識，表達程度又是多少？

請依序選擇動作　**[從 CIMAS 實驗動作倒入]**

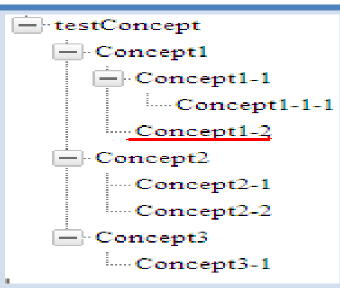
等待 摘葉 浸水 切根 倒紅墨水 插入植物

請選擇此動作相關的概念與技能

概念圖



技能圖



動作	學科概念	概念程度	過程技能	技能程度
1. 芹菜浸水	C1	1	P2	1
2. 切根	C3	1	P4	1
3. 插入紅墨水				
4. 等待				

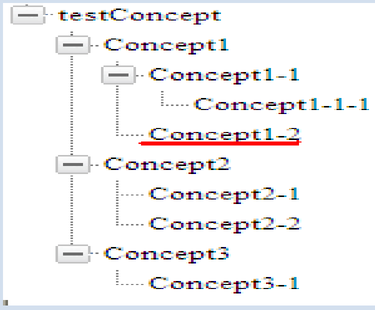
Step5 :有哪些**評量連續性動作**(實驗的操作動作必須是接連操作，才能達到設定效果，才算完成操作)，是可以表達哪些概念或是技能知識，表達程度又是多少？

請依序選擇動作 **[從 CIMAS 實驗動作倒入]**

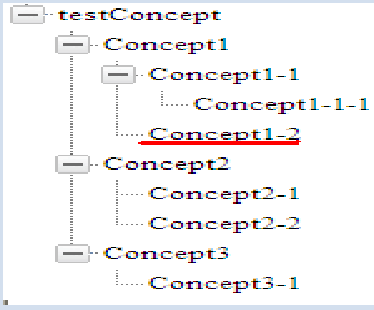
等待 摘葉 浸水 切根 倒紅墨水 插入植物

請選擇此動作相關的概念與技能

概念圖



技能圖



動作	學科概念	概念程度	過程技能	技能程度

Step6 :**物件連續性動作**(針對同一物件所操作兩動作間，必須是連續的。但可以對其他物件進行操作。)，表達哪些概念或是技能知識，表達程度又是多少？

請選擇動作 **[從 CIMAS 實驗動作倒入]**

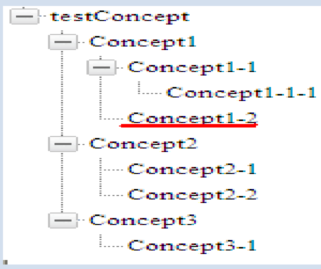
☑ 芹菜 ☐ 燒杯 ☐ 水盆 ☐ 紅墨水 ☐ 美工刀

請依序選擇動作 **[從 CIMAS 實驗動作倒入]**

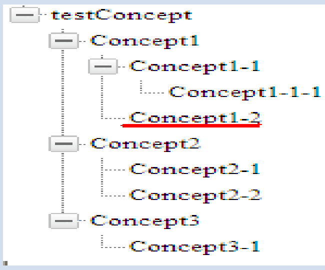
摘葉 浸水 切根 插入植物

請選擇此動作相關的概念與技能

概念圖



技能圖



實驗器材	動作	學科概念	概念程度	過程技能	技能程度
芹菜	1. 芹菜浸水 2. 切根	C2	1	P1	1
		C4	1	P1	1

Step7：除了以上實驗動作規則以外，還有哪些操作動作的評量規則，請在以下作描述並舉例?

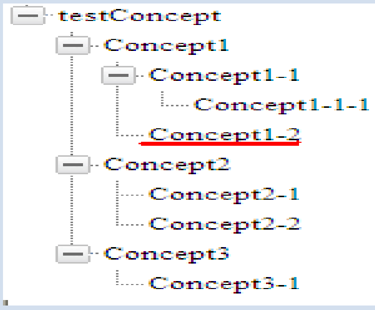
規則 ： 輸入文字

例子(請以本實驗可以操作的動作表示)： 輸入文字

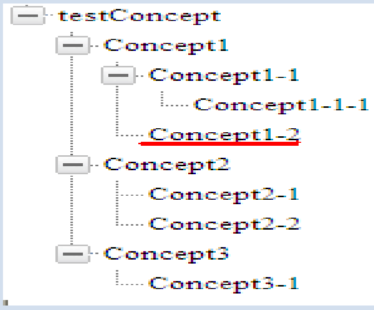
Part 2.2： 實驗規劃評量規則建立

請選擇此動作相關的概念與技能

技能圖



概念圖



規劃訊息	技能	程度	概念	程度	訊息屬性	屬性值
假設_若	假設_若	1			若_物件	芹菜
					若_物件屬性	葉數;莖切面積
					若_比較值	增加;減少
假設_則	假設_則	1			則_物件	紅墨水燒杯
					則_物件屬性	紅墨水量
					則_比較值	增加;減少

Part3： 實驗動作與實驗規畫 知識與背景知識整合，給予學生回饋

實驗共通性的問題:

Step1： 填寫"實驗動作正確與否"回饋? (操作動作時間與環境的影響)

選擇實驗動作名稱(選項從 **Part2 Step1** 的答案來): 輸入文字 (可多選)

(1) 套用系統回饋樣板

回饋樣板
(1)-1 **[問題]**: 您在操作實驗動作有誤。 **[可能原因]**： 由於您在於___________等動作，操作時間為___________，時間太短(過久)，造成實驗誤差。 **[建議]**： 此動作背後與 __________ 學科概念 _________ 過程技能有關，建議您先對於以上相關背景知識進行學習。
(1)-2 **[問題]**: 您在操作實驗動作有誤。 **[可能原因]** :由於您在於___________ 等動作，操作環境是___________，由於環境中的（環境參數），會使得___________的動作產生誤差。 **[建議]**： 此動作背後與 __________ 學科概念 _________ 過程技能有關，建議您先對於以上相關背景知識進行學習。

(2) 套用系統回饋樣板並作修改

(3) 重新填寫

Step2： 填寫" 實驗動作中實驗器材操作正確與否"回饋? (器材操作影響)

選擇實驗動作:(選項從 **Part2** 答案來): 輸入文字

(1) 套用系統回饋樣板

回饋樣板
(1)-1 **[問題]**: 您在操作實驗器材有誤。 **[可能原因]**： 由於您在於___________等動作操作有誤，表示你對於___________實驗器材的操作不熟悉，表示你在___________學科概念有不瞭解的地方。 **[建議]**： 此動作背後與 __________ 學科概念 _________ 過程技能有關，建議您先對於以上相關背景知識進行學習。

(2) 套用系統回饋樣板並作修改

(3) 重新填寫

<u>實驗特殊性的問題</u>： 運用 **"且"(AND)**，**"或"(OR)**，**"數量"(Number)**或不使用，建立蒸散速率實驗整體評量規則

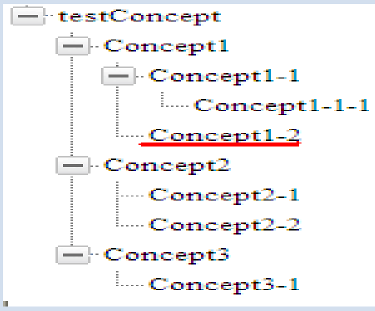
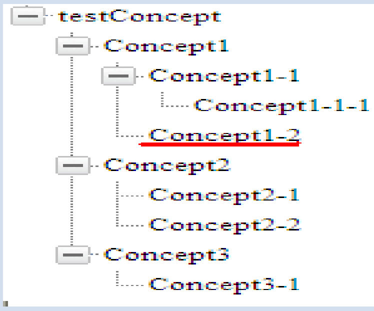
1. 規則一： ⦿X ○且 ○或

2. 規則二： ⦿數量 (若無選擇初始值=1)

3. 規則三： ⦿考量整體操作動作類型個數

4. 選擇實驗動作(選項從問題 **Part2** 的答案來): 輸入文字 **("且" "或"請選擇兩個以上)**

5.

請選擇實驗動作相關的概念與技能	
概念圖 	技能圖 

[若是選擇的實驗動作在前步驟已有設定相關知識與程度，會一併在此先行倒入，且在此步驟仍可修改]

規則一	動作	規則二	規則三	概念	程度	技能	程度	回饋
X	**1.** 芹菜浸水 **2.** 切根 **3.** 插入紅墨水 **4.** 等待	0	X	C1 C3	1 1	P2 P4	1 1	⦿ 使用系統回饋樣版 **[問題]:** 您在操作實驗有誤。 **[對應技能] : P2 P4** **[現象] :**因為您在實驗中對於**[芹菜]** 的實驗操作-- **[浸水] [切根] [插入植物] [等待]** ，推測您在操作[**浸水] [切根]**的前後順序有誤。 **[可能原因] :**可能是因為你對於生物學科的 **C1 C2** 尚未完全了解。 ○ 自行建立

Students' portfolios from CIMAS

Action List

	action		action
1	芹菜 1,裝水的水盆,浸水	**16**	芹菜 1,紅墨水燒杯 2,插入植物
2	芹菜 2,裝水的水盆,浸水	**17**	芹菜 2,紅墨水燒杯 2,插入植物
3	紅墨水燒杯 1,紅墨水燒杯 2,倒紅墨水	**18**	芹菜 1,紅墨水燒杯 3,插入植物
4	紅墨水燒杯 1,紅墨水燒杯 3,倒紅墨水	**19**	芹菜 2,紅墨水燒杯 3,插入植物
5	紅墨水燒杯 2,紅墨水燒杯 1,倒紅墨水	**20**	芹菜 1,NULL,摘葉子
6	紅墨水燒杯 2,紅墨水燒杯 3,倒紅墨水	**21**	芹菜 2,NULL,摘葉子
7	紅墨水燒杯 3,紅墨水燒杯 1,倒紅墨水	**22**	尺,芹菜 2,量長度
8	紅墨水燒杯 3,紅墨水燒杯 2,倒紅墨水	**23**	尺,芹菜 1,量長度
9	美工刀,芹菜 1,切根	**24**	芹菜 2,磅秤,秤重
10	美工刀,芹菜 2,切根	**25**	芹菜 1,磅秤,秤重
11	NULL,NULL,等待	**26**	插著植物的燒杯,磅秤,秤重
12	芹菜 2,NULL,移出水盆	**27**	紅墨水燒杯 1,磅秤,秤重
13	芹菜 1,NULL,移出水盆	**28**	紅墨水燒杯 2,磅秤,秤重
14	芹菜 1,紅墨水燒杯 1,插入植物	**29**	紅墨水燒杯 3,磅秤,秤重
15	芹菜 2,紅墨水燒杯 1,插入植物		

Students' Portfolios

	Sequence of actions
1	2,2,6,6,6,6,10,12,23,19,11,20,20,1,9,5,5,5,5,5,13, 11,15,11,14,11
2	6,6,6,6,6,10,12,21,21,19,9,20,5,5,5,5,14,11,11,22,23
3	21,10,9,6,6,6,6,6,7,5,5,5,5,19,1,13,1,13,14,11,23,23,14
4	6,6,6,6,6,8,10,2,12,10,21,21,22,9,20,20,1,13,18,11,11,11
5	1,9,2,10,22,20,6,6,6,6,6,5,5,5,5,5,12,15,18,11,11
6	10,6,6,6,6,6,5,5,5,5,5,9,15,18,11,11,11,23,22
7	1,13,1,9,10,13,20,21,6,6,6,6,6,5,5,5,5,5,22,19,11,11
8	6,6,6,6,10,21,19,11,11,22
9	21,2,10,12,1,9,13,6,6,6,6,6,5,5,5,5,5,19,14,11,23,23,22
10	1,9,13,6,6,6,6,6,5,5,5,5,5,14,11,2, 21,10, 12,19,11
11	10,6,6,6,6,6,6,21,8,21,19,11,19,11,11,11,11,23,23,23,23
12	21,21,10,6,6,6,6,6,6,6,19,11,11,22
13	6,6,6,6,6,5,5,5,5,5,10,21,23,23,19,11,11,14,11
14	6,6,6,6,6,5,5,5,5,5,10,10,21,21,19,11,11,1,13,27,1,13,9,14,11,22

15	21,21,10,6,6,6,6,6,10,10,19,11,19,11,11
16	10,6,6,6,6,6,21,2,12,17,21,9,18,17,11,11,23
17	10,2,12,21,6,6,6,6,6,22, 9,9,21,21,16, 19,11
18	21,21,6,6,6,6,6,5,5,5,5,5, 14,11,11,22,22,22,22
19	6,6,6,6,6,10,21,14,19,11,11,22
20	2,12,21,2,10,12,1,9,13,6,6,6,6,6,5,5,5,5,5,14,19,11,23,14,22
21	21,1,9,21,2,10,5,5,5,6,6,6,6,14,19,11
22	6,6,6,5,5,5,7,7,10,21,1,9,14,14,19,11,2,10,6,6,6,6,6,21,17,12,19,11,22,23
23	6,6,6,6,6,6,6,10,21,19,11,11,11,6,6,6,6,6,10,17,21,20,9,18,11,11
24	10,10,19,21,21,6,6,6,6,6,6,6,6,6,8,6,14,19,11,11,22,31,1
25	2,12,6,6,6,6,6,10,10,10,14,19,11,11,22,2,12,13,2,2,12
26	10,10,21,6,6,6,6,6,21,19,11,11,21,21,10,10,6,6,6,6,6,19,11
27	21,10,10,6,6,6,6,6,5,5,5,5,19,11,22
28	6,6,6,6,6,6,8,1010,14,19,11,22
29	10,21,6,6,6,6,6,21,19,11,11,11,22
30	21,10,10,6,6,6,6,6,19,11,22