

Constructing Intelligent Virtual Laboratory for High School Chemistry to support learners' consideration

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Abstract: In this paper, we describe construction of Intelligent Virtual Laboratory for high school chemistry. We construct a system that can grasp the current state of a learner's experiment and give well-timed questions or messages to let him/her consider essential factors in experiments. Moreover, we propose methods for expanding the system to help learners acquire investigative ability by planning the procedures of experiments.

Keywords: Intelligent Educational System, Interactive Learning Environment, Virtual Laboratory, High School Chemistry

Introduction

The purpose of our research is to construct Intelligent Virtual Laboratories (IVL) for high school chemistry. There are many virtual laboratories for chemistry, however, most of conventional ones only show simulated process of chemical reactions or structure of materials [1-2]. We think virtual laboratories should perform more adaptive supports based on diagnosis of learners' plans.

According to MEXT (Ministry of Education, Culture, Sports, Science and Technology) in Japan, there are two aims in chemical learning.

- To deepen essential understanding of phenomena.
- To promote interests in and *investigative ability* of the chemistry.

We think that chemical experiments in high school have the following important roles:

- (1) By observing chemical phenomena and considering both of the process and the results using the knowledge learnt from lectures, learners will understand the phenomena more deeply.
- (2) We think *the investigative ability* means a skill to imagine experimental procedures taking into account a given goal, available instruments, reagents and so on, and to select the most effective procedure from the candidate procedures. By planning experiments, learners will acquire *the investigative ability*. Trial-and-error process will make such learning more effective.
- (3) By watching chemical materials or phenomena in actual experiments, learners can feel reality of the knowledge they have learnt. It will promote their interest in chemistry.

The role (3) can be better performed by actual laboratories than virtual ones. In this paper, we propose the methods to make our virtual laboratory capable for performing the roles (1) and (2).

In usual textbooks of high school chemistry, standard procedures of most experiments are given. Many learners achieve the goals of the experiments by only tracing the given procedures. However, such learners cannot learn effectively, because they finish the experiment without consideration. To let learners make consideration, teachers should observe their actions, recognize how their experiments are performed, and give them well-timed triggers for

consideration by asking questions or suggesting focus of attention. In addition, teachers should help learners who fail to trace the given procedures. However, only one teacher is usually in charge of teaching many learners. Thus it is difficult for teachers to give all learners such well-timed triggers and helps. So we have designed our first version of IVL (IVL1), which has the following functions:

- (a) IVL1 grasps the current state of a learner's experiment by comparing the learner's behavior with the standard plan of the experiment.
- (b) IVL1 gives well-timed trigger for learners' considerations, in the form of question or suggestion.
- (c) If necessary, IVL1 advises learners how to resolve an impasse.

However, IVL1 is not well capable of performing the role (2), because it can cope with experiments only if the standard procedures are given; in other words, it can't support experiments with many alternative procedures for achieving the goals. In such experiments, learners have to choose the best procedure from them. We call experiments with their standard procedures and experiments with many alternative procedures "*simple experiments*" and "*complex experiments*", respectively. As mentioned above, the complex experiments are very important for learners to acquire *the investigative ability*. The system treating *complex experiments* should have ability to generate valid procedures of experiments in order to suggest to learners that there are better procedures than the learners'. Such suggestion has an effect to make learners repeat trials and errors. Moreover, the system should be able to diagnose the causes of learners' invalid procedures, such as lack of knowledge on chemistry or lack of skill for logical thinking. Therefore, we extend IVL1 to the second version (IVL2) that has the following additional functions:

- (d) IVL2 generates valid plans to achieve the goal of an experiment.
- (e) IVL2 diagnoses knowledge or strategy that learners cannot use, based on their plans.

1. IVL1

1.1 Supporting methods by IVL1

In order to find effective strategies for the function (b), We analyzed experiments in a textbook of high school chemistry [3] and classified suggestions and questions in the textbook into the following groups:

- (1) To let learners consider the meaning and purpose of operations
 - (1-1) To ask about the result of an operation
 - To let learners predict the result if it is visible
 - To let learners predict or guess the result after the operation if the result is invisible
 - (1-2) To ask about important factors in the result of an operation
- (2) To let learners check their knowledge concerning the experiment
 - (2-1) To ask about knowledge on material/phenomena (name, definition, class, property, etc.)
 - (2-2) To ask about knowledge on a phenomenon that causes the current state
- (3) To direct learners' attention to *keypoints* (important concepts in an experiment, such as material, phenomena, status, etc.) in the experiment
 - (3-1) To suggest that learners should take note of key points of a phenomenon that will happen subsequently
 - (3-2) To suggest that learners should take note of key points of the state after a phenomenon.

IVL1 observes learners' behavior and generates suggestions and questions by using rules which are triggered according to the combination of the key points, the current state of learner's experiment, and each learner's level of understanding on specific knowledge. IVL1 gives questions to learners, but it doesn't correct the answers even if they are incorrect. It is because

the purpose of questioning isn't the correction of their misunderstanding, but the goal is to let them consider the key points by giving timely triggers. IVL1 judges that learners are at an impasse when they repeat incorrect operations. In such a case, IVL1 suggests an operation that should be done next, based on the standard plan.

1.2 Outline of functions

Fig. 1 shows the structure of IVL1. In *Experiment Plan Base*, plans for standard chemical experiments are prepared. First of all, a teacher selects one of the plans in *Experiment Plan Base*. The selected plan is called a "standard plan". Some steps in a standard plan are marked as the step when the system should give a question or suggestion in order to let learners consider keypoints (we call such steps "points for interruption"). Teachers can modify the prepared points for interruption based on their pedagogical intention. Then a learner inputs an operation to *Interface*. *Interface* sends the operation to both *Simulator* and *Plan Recognizer*. *Simulator* reproduces chemical reactions. IVL1 uses *Domain Knowledge Base* [4] and *Simulator* [5] that have been developed for our practice system of high school chemistry. *Plan recognizer* judges whether a learner's action is valid by comparing the learner's plan with the standard plan. At the same time *Plan Recognizer* discovers whether learners are at an impasse. When *Plan Recognizer* finds that the experiment reaches a point for interruption, *Support Controller* generates a suggestion or a question by referring to both *Support Rule Base* and *Learner Model*. *Support Controller* also generates messages for helping learners when *Plan Recognizer* finds the learners are at an impasse.

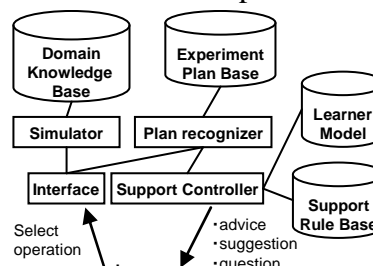


Fig1. Structure of IVL1

1.3 Algorithm of IVL1

1.3.1 Plan Recognizer

Plans are represented in a tree structure involving the goal, operations to achieve the purpose, and the execution order. Some (sub)goals can be achieved by a set of operations regardless of their execution order. We call such order "random order". *Plan Recognizer* executes the following processes.

(1) It extracts operations that can be executed in the next step from the standard plan. If the plan includes a subgoal to be achieved by operations "in random order", then plural operations may be extracted.

(2) It judges validity of learners' operations. When a learner selects an operation, *Plan Recognizer* matches the operation with the list of valid operations. If the operation is included in the list, it is judged as valid. Then it is linked to the operation in the standard plan, and *Plan Recognizer* repeats (1) and (2) as long as the learner's operation is valid. Invalid operations can be classified into two types: "redundant operations" and "malignant operations". The latter means operations that have an effect to spoil the status reached through the previous operations. In our current system, we adopt a simple method to detect malignant operations; if a material generated by the previous valid operation is lost by a new operation, it is judged as malignant. When a malignant operation is recognized, our current teaching strategy makes the learner restart the experiment from the initial step. *Plan Recognizer* counts continuous execution of invalid operations. When a learner repeats invalid operations three times, *Plan Recognizer* judges the learner reach an impasse. Then *Support Controller* generates advices on the operation to be executed next.

1.3.2 Support Controller

Support Rules are composed of the condition part and the result part. The condition part has two conditions: the point for interruption and the grade of a learner's understanding on knowledge. The result part has templates for generating messages. Whenever the experiment reaches the next step by an operation, IVL1 searches for rules that have the step as the point for interruption in the condition part. If the grade of the learner's understanding satisfies the other conditions of the found rule, IVL1 generates messages by using the result part.

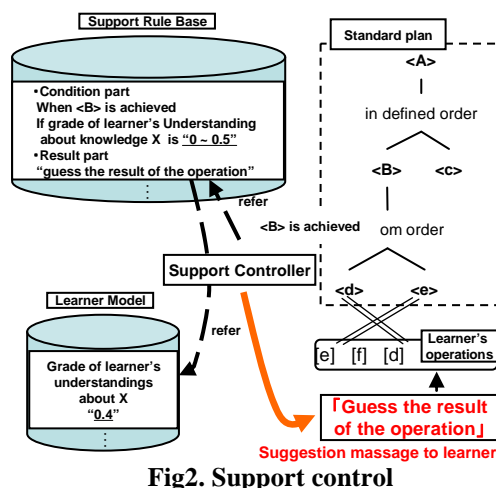


Fig2. Support control

1.3.3 Example of performance of IVL1

Our existing Experiment Plan Base has 10 kinds of experiments. Teachers and learners can edit materials appearing in the experiment and their parameters like mass, volume, etc. Fig. 3 shows performance of IVL1: oxidation of copper. The pedagogical purpose of this experiment is to have learners become aware that copper becomes copper oxide by heat. Therefore, a point for interruption is set to the operation heating copper. When this operation is executed, IVL1 directs learner's attention to the color of the generated material. Moreover, if IVL1 judges that the learner doesn't understand oxides well, it asks which color copper oxide has.

Name	Mass (g)	Concentration (mol/l)	Volume (ml)	Color	State
Generated material	Unknown			black	solid

Fig3. Performance of IVL1

2. IVL2

2.1 Expand IVL1 and its functions

We are constructing IVL2 to support complex experiments whose standard plan cannot be defined. We treat systematic separation of metal as an example of complex experiment. The purpose of this experiment is to separate each metal ion, by using reagents, from solution in which several ions are mixed. Such experiment has the learning effect that the learners can learn chemical reaction, and that they have experiences to determine effective procedure by logical thinking. An example of systematic separation goes as follows. At first, solution containing Cu, Ag, and Pb ions is given. Learners select reagents from candidates. Suppose that a learner first selects H₂SO₄, and then choose HCl. In this case, he/she will successfully separate all ions. Learners may fail by selecting invalid reagent that makes all ions precipitate (e.g., H₂CO₃).

As mentioned in the introduction, the following functions are necessary.

(I) Generating valid plans of experiments.

We add *Experiment Planner* to IVL2. It generates a list of all executable operations, and simulates each operation, giving the result of each operation. If all ions are separated in one of

the results, it judges the process to the result as a valid plan. If the goal will never be achieved after a certain stage, the process to the stage is judged as invalid. Otherwise, it grades each result by another additional unit: “*Status Evaluator*”. Status Evaluator refers to strategies in *Experiment Strategy Base*, in which heuristics for scoring statuses is stored. Experiment Planner executes this process recursively for each result in order of the score.

(II) Diagnosing the causes of invalid procedures, such as lack of knowledge on chemistry or lack of skill for logical thinking.

When a learner inputs an operation, IVL2 generates a valid plan using Experiment Planner. By referring to the generated plans, IVL2 suggests a better procedure than the learner’s after the learner finishes his/her experiment. IVL2 recognizes lack of skill for logical thinking if a learner doesn’t apply an experiment strategy that Experiment Planner has used. Moreover, Status Evaluator grades both of states before and after a learner’s operation. If the score is the same as or lower than the one before the operation, IVL2 doubts whether the learner misunderstands chemical reactions caused by the operation. It gives a question to confirm his/her understanding.

2.2 Outline of IVL2 and experiment example

Fig. 4 shows the structure of IVL2. Additional units are Experiment Planner, Status Evaluator and Experiment Strategy Base. The function of Experiment Planner is mentioned in 2.1. Experiment strategies are heuristics to evaluate a status based on the distance from the goal of the experiment. Our current strategy base has the following heuristics for systematic separation: “when only one metal precipitates and it can be separated by filtering, the score is the max point”, “when two kinds of precipitation exist and both of them cannot become complex ion, the score is the minimum point (= separation will fail)”, etc. Status Evaluator grades a status by using these strategies.

IVL2 is under construction. Now we are designing support rules for complex experiments. We have to decide pedagogical policy about when IVL2 should interrupt learners’ experiments.

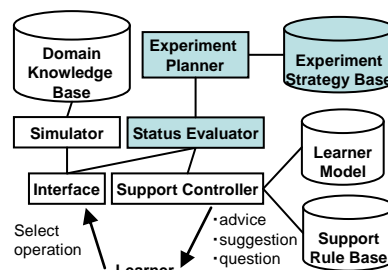


Fig4. Structure of IVL2

3. Conclusion

We have constructed IVL1 and proposed method to construct IVL2. Our future work will be the implementation of IVL2 and experimental evaluation of both IVL1 and IVL2. Effective pedagogical strategies for chemistry should also be developed. We are planning to interview several high-school teachers to reflect their experiences in our system.

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