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Inorganic Chemistry Learning Support System using AR-based Virtual Environment and Question Recommendation Method

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Abstract: In this paper, we proposed AR-based learning support system for inorganic chemistry that uses the historical information of each participant. To perform experiments in a virtual environment, markers and a USB camera are utilized as the input interface. By using this interface, a learner can perform chemical experiments in the virtual environment. Our proposed system presents the learner with a number of questions, which are selected on the basis of the leaner's historical information within the system. This selection algorithm helps a learner perform experiments that correspond to questions suitable for his/her level of understanding. Each learner's historical information is obtained from his/her examination results by paper tests. By this selection method, a learner can repeatedly learn about inorganic chemistry in the virtual environment.

Keywords: Augmented Reality, Experiment-based Learning, Selection of suitable Questions, Inorganic Chemistry

1. Introduction

In Japanese high schools, chemical education consists of the following three components: theoretical chemistry; organic chemistry; and inorganic chemistry. To learn inorganic chemistry, it is crucial for learners to perform various chemical experiments in the classroom. Based on these experimental results, learners gain knowledge of chemical reactions and learn inorganic chemistry; however, it is difficult for them to obtain complete knowledge about chemical reactions in a single experiment, and it is impossible for all experiments to be repeatedly performed until all students memorize all chemical reactions. To address these problems, learning support systems using virtual experiments have been developed (Konishi *et al.* (2010) and Nanko *et al.* (2008)).

For example, Konishi developed an Intelligent Practice Support System (IPSS) for high school chemistry (Nanko *et al.* (2008)); however, IPSS does not take inorganic chemistry into consideration. In the inorganic chemistry field, it is important for learners to observe experimental results and the experimental methods in Japanese high school education. To learn inorganic chemistry based on virtual experiments, we previously developed an AR-based learning support system (Sumida *et al.* (2012)). AR is helpful in that it provides a natural user interface that integrates VR and the real world (Asai *et al.* (2011), Iwasaki *et al.* (2010) and Sano *et al.* (2010)). Using this approach, a virtual experimental environment is constructed without actual equipment. To perform experiments in the virtual environment, markers printed on papers are utilized as the control interface, and the virtual environment is created using AR technology. By operating such markers, users perform various experiments, such as the flame test. In addition, the system presents questions and hints, enabling users to acquire knowledge of chemical reactions by solving these questions in a virtual environment; however, for learning inorganic chemistry using only this system, learners have to select questions regarding inorganic chemical reactions that they does not yet remember. If the system can present suitable questions to learners, we expect that they can learn more effectively. Most of the learning content for chemistry does not have this function (Ikuo *et al.* (2012)). The content only enables learners to confirm the chemical reaction or information.

Figure 1: The overview of the proposed system.

In this paper, we proposed AR-based learning support system using user's learning historical information for inorganic chemistry. In the proposed system, AR-based virtual environment for inorganic chemical experiments is utilized in order to make learners find a questions answer. And the given questions are determined by each learner's historical information corresponding to the learner's percentage of given questions already answered correctly. This information is calculated from results of paper tests about inorganic chemical reactions. By using this information, the proposed system can determine the set of questions given to learner. The determined set of questions corresponds to the chemical reactions that the learner has not yet answered or mastered. By learning repeatedly using this system, it is expected that the learner can memorize all chemical reactions corresponding to prepared questions.

2. Inorganic chemistry learning management system using AR-based virtual laboratory

2.1 System Structure

Figure 1 shows the overview and structure of the proposed system respectively. As shown in Figure 1, this system has three devices (1: USB camera, 2: computer and display, 3: markers for input interface). USB camera records image of user's operation in order to create the virtual environment for experiments based on real image and CGs. Simulation of experiments and creation of virtual environment are carried out by computer, and in display virtual environment (processes and results of experiments) is displayed (shown in Figure 1). In order to construct the virtual laboratory from real image recorded by USB camera, user's operation must be recognized from real image. Then various markers are utilized for recognition of user's operation. By putting and moving markers in recorded area, user's operation of items, used for performing experiments, are easily recognized by the system. For recognition of markers from image recorded by USB camera, ARToolKit library and markers are utilized. Table 1 shows examples of markers used in the virtual environment. A set of multiple markers is used as marker corresponding to equipment (such as burner and beaker). By putting these markers in recorded area, this system understand that user utilize the corresponding instruments. In addition, corresponding CGs are displayed near the marker in virtual environment (shown in Figure 1). Then, solutes and water solutions have to be selected for performing experiments which user wants to conduct. For selection of the solutes and water solutions, 17 solute markers and 6 water solution markers are used. In order to perform experiments in virtual laboratory, markers corresponding to operation have to be prepared. The operation markers shown in Table 2 are used for showing user's intention of operation.

When a learner wishes to learn about inorganic chemistry reactions using this system, the system displays questions about chemical reactions over the virtual laboratory to describe the purpose of experiments to learners. By answering a question by performing experiments in the virtual laboratory, learners can acquire knowledge about inorganic chemistry. For performing such learning effectively, the system has to present suitable questions to learners. Then, the proposed system selects the question displayed over the virtual laboratory based on the learner's learning historical information. By using such information, the system can give some suitable questions corresponding to the chemical reactions that learner have yet to learn.

Table 1: Examples of Markers Corresponding to Instruments and Item for Experiment.

	Instruments	Solutes	Water solutions
An Example Image of Markers			

Table 2: Examples of Markers Corresponding to Operation by Learner.

	Operation for water solutions	Adjustment of Solutes' parameters	Checking answer
An Example Image of Markers			

(a) Preparation of water solution which contain ferric ion

(b) Adding the precipitating agent for making precipitation of ion

Figure 2: Example of Experimental Process of Precipitation of Ion.

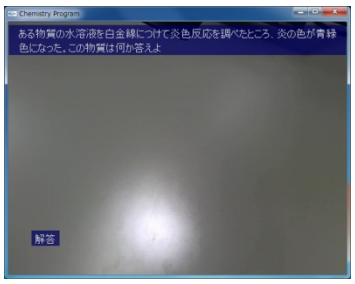
In the next subsection, the details of the virtual laboratory are described.

2.2 AR-based Virtual Environment with Giving Questions Function

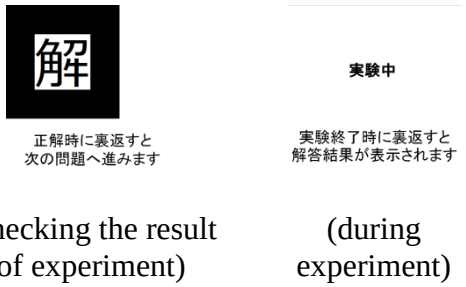
In this system, in order to perform the chemical experiments, the virtual environment [4] is utilized. By using this environment, learner can perform three chemical experiments (1: flame color test, 2: precipitation of ion, 3: positive ion analysis). The system understands the type of experiments which learner wants to conduct from the arrangement of the instruments markers. Next, detail of precipitation of ion experiment is described as example of virtual experiment.

Precipitation of ion experiment is shown in Figure 2. In this experiment, user has to investigate the phenomenon about the color precipitation of ion, used precipitating agent and so on. In order to conduct this experiment in virtual environment, user should use the three kinds of marker (instruments marker, solutes marker and water solutions marker). In the example of experiment shown in Figure 2, at first, water solution that contains the ferric ion is prepared in beaker (Figure 2(a)). For this preparation, ferric ion marker is put and moved near the beaker marker. In next process, by adding the precipitating agent into the beaker, user can check the precipitation of ion. Then a water solution maker is put and moved near a beaker marker (Figure 2(b)). By this operation, corresponding water solution (hydrogen sulfide solution) is added into prepared solution in virtual environment. Although test tube is generally used for this process, since the quantity of solution is not considered in learning in this paper using proposed system, a solution marker is moved near the beaker marker directly. By conducting the experiment corresponding to phenomena which can indicate the

information that user wants to know, user can learn about precipitation phenomena through the experiments.



(a) An example of presentation of a question in virtual environment



(checking the result of experiment) (during experiment)

(b) Checking marker

Figure 3: Question and Marker for Checking Answer.

2.3 Giving Questions Function

The question is displayed on the upper part of virtual environment. Figure 3(a) shows an example of presentation of question in virtual environment. In this question, "What is ion which can change the color of flame into blue-green?" is written in Japanese. By presenting a question, user perform experiment in order to find answer about presented question. In proposed system, user's answer corresponds to results of experiment. User can show his/her situation (experiment is finished or not) by checking marker (Figure 3(b)). This marker is printed on both sides. When this marker is turned over, the system evaluates the answer (result of experiment). If user makes mistake, hint is displayed on the underside of virtual environment and user perform experiment again based on given hint. After attaining a correct answer, by turning this marker over again, the next question is given for user.

2.4 Selecting Questions from the Results of Learner's Paper Test

In the proposed system, a set of question is given to each learner for leaning the chemical reactions through answering process. In order to performing learning effectively, suitable questions have to be selected. By find answers of given questions through experiments in the virtual environment, the leaner can acquire the knowledge corresponding to given questions. Algorithm for selecting the set of questions given to a learner for learning process described above is shown below. Then, in this algorithm, the number of questions in one set is equal to n.

1. As an initial set of questions, seven questions are given.
2. A learner performs experiments in the virtual environment to answer the given questions.
3. A few days later (within four days), a learner takes a paper test. This paper test includes all given questions in the virtual environment before now.
4. The number of incorrect answers from Step 3 is set as $I(t)$. The number of given questions in Step 3 is set as $Q(t)$: where t is the number of times of a repetition of a test in Step 3.
5. Immediately after a test, if $I(t)$ is smaller than n, the questions corresponding to incorrect answer are set as the set of questions given in the virtual environment. New questions are added into the set of questions until the number of questions in a set is equal to n. Immediately after a test, if $I(t)$ becomes in more than n, n questions are selected from the questions corresponding to incorrect questions at random, and the selected questions are

set as the set of given questions in the virtual environment. Return to the Step 2 after the above process in Step 5.

In Step4, when $I(t)$ is equal to 0 and all prepared questions are given to a learner, this learning algorithm is completed. By giving the set of question to a learner for learning in the virtual environment, a leaner acquires knowledge of inorganic chemistry reactions by the performing experiments in the virtual environment. Moreover, this repetition learning

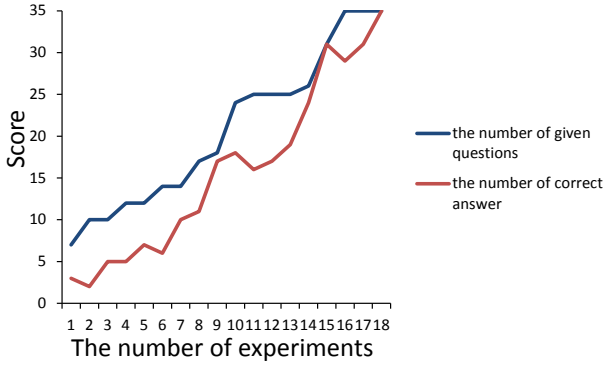


Figure 4: Experimental Results of Subject A in Paper Test.

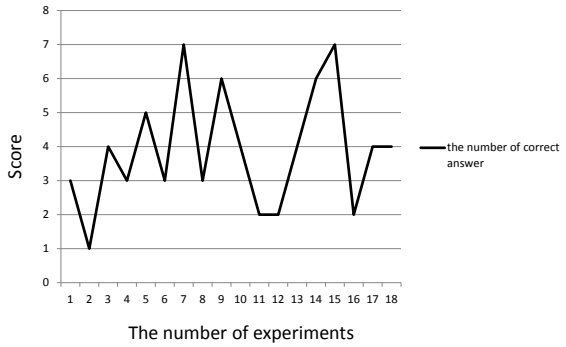


Figure 5: The Number of Correct Answer of Subject B for given Questions in each Experiment.

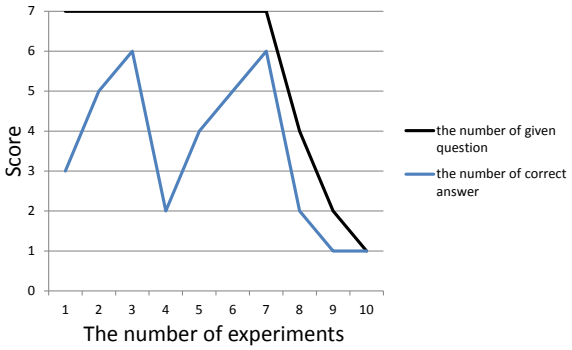


Figure 6: Experimental Results of Subject B in Paper Test.

continues until a leaner acquires the knowledge corresponding to all the questions. If a learner forgets the knowledge about the questions which a learner has answered correctly before, the system can give the corresponding questions to a leaner once again by the check of Step 4 using paper test.

3. Evaluation Experiment

In order to evaluate the effectiveness of proposed selection of given questions and learning process using a virtual environment, learning experiments about chemical reactions were conducted. Two subjects (A and B) participated in the experiments.

Subject A learned the knowledge of chemical reactions using the proposed system. As a candidate for comparison, subject B used different systems for learning. The proposed system was modified as a system which subject B uses. In the system for subject B, the algorithm of selecting a set of questions given to a learner differs from the algorithm of the proposal system. In order to confirm the validity of repeated learning, a paper test has only n questions used by prior learning using the virtual environment in comparative algorithm (in the proposed system, a test has all question in the virtual environment before now). In the

experiments, the total number of questions is 35. 35 questions correspond to the inorganic chemical reactions that Japanese high school students study. Further, *n* was set to 7.

The experimental results of subject A are shown in Figure 4. By repeated learning, in the 18th experiment, subject A has acquired all the knowledge of chemical reactions corresponding to all questions given to subject A in the virtual environment. Figure 5 shows the number of correct answers in each experiment. From this figure, it is indicated that subject A was unable to acquire all seven knowledge in an experiment once. However, by performing learning repeatedly, finally subject A has acquired all the knowledge of chemical reaction through learning using the proposed system. Next, in order to compare with a proposed system, the subject B's experimental result is shown in Figure 6. As shown in this figure, the subject B's learning experiment is ended by 10 times. And the total of correct answers in paper test is 35 corresponding to given questions because modified system for subject B does not set repeatedly the problem which the learner was able to solve. After these experiments shown in Figure 6, subject B challenged answering to all questions about chemical reactions by a paper test. The percentage of correct answers of the subject B in this test was 45.8% (He can answer 17 questions). Conversely, subject A can get all the answers right after this experiment.

From these results, by repeated learning using proposed questions selection algorithm and virtual environment, there is possibility that a learner can get all knowledge of inorganic chemical reaction which the Japanese high school students have to study.

4. Conclusions

This paper proposes a learning support system using AR-based virtual environment and question recommendation method based on a learner's learning history. For chemical experiments, the proposed system gives some questions to a learner. These questions are selected based on a leaner's learning history information. The determined set of questions corresponds to the chemical reaction which a learner cannot answer. By learning repeatedly using this system, it is expected that the learner can memorize all chemical reactions corresponding to prepared questions. From experimental results, there is possibility that a learner can get all knowledge of inorganic chemical reaction which the Japanese high school students have to study, by using the proposed system.

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