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Posing Questions during Experimental Operations for Safety Training in University Chemistry Experiments

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Abstract

A classroom lecture-style of safety training is often conducted at the beginning of each semester in university chemistry experiments, where materials such as a textbook and a video are utilized. However, we consider that a gap exists between such learning style and actual practice. In our previous study, we showed the effectiveness of ambiguous presentation to memorize the topic of learning.

By taking a hint from hazard-prediction training, we propose to utilize questioning about a caution in a particular operation as a form of ambiguous presentation. People try to find answer when they are asked, which we expect to facilitate active thinking that contributes learning. An experiment showed the learning with question and answer contributed better than learning with answer only. Thinking time with 5 and 10 seconds were significantly effective in learning compared with answer-only style. Particularly, 10 seconds of thinking time allowed the subjects to look around the objects on an experimental table before being given the answer. We also found that the effect of learning is not direct proportion to the length of thinking time, i.e. 30 seconds of thinking time lost the subjects' eagerness to learn.

Keywords: *On-site safety training, Chemistry experiment, Learning contents, Questioning*

1. Introduction

Traditional safety training in university classes is basically conducted in a classroom lecture-style that utilizes materials such as a textbook and a video at the beginning of a semester. This particular training style can accommodate a large number of students at one time; however, we consider that there is a gap between the lecture-style learning and actual practice. An assistant can support students during an experiment, but, obviously, one assistant cannot take care of students all the time. Of course, a simulation-based learning method is under investigated in the context of virtual or mixed reality [2, 5, 6, 8] however, the reality of the experience between simulation and actual experiment is still irreplaceable.

We have proposed a tangible chemistry experiment support system that helps *on-site safety training* for the beginner to avoid danger [7], in which the most important design issues is to make students independent of the system in the future: if a safety-training system is too suggestive all of the time, it would certainly be helpful for a student during the course of an experiment, but it would deprive him or her of the opportunity to learn to avoid accidents. Here, the core idea is to facilitate *active thinking*, and we have shown the effect of multiple presentations or ambiguities of a message for learning [1].

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In this article, we propose to leverage "questions" as a form of ambiguous message. People try to find answer when they are asked, which we expect to facilitate active thinking that contributes to memorize the topic related to the question. We carry out an experiment to validate the question-thinking style of learning as well as to evaluate the appropriate length of thinking time. The rest of the paper is organized as follows. Section 2 specifies basic chemistry experimental operations that we deal with this study. Then, in Section 3, we propose the learning contents. Section 4 describes a basic experiment to evaluate the effect of the proposed method, which is followed by a more realistic experiment and discussion in Section 5 and Section 6, respectively. Finally, Section 7 concludes the paper.

2. Target Operations

Based on the analysis of an incident report in chemistry experiments for the first and the second grade undergraduate students [9], we specified five major operations as target operations in our study. They are 1) getting out chemical material from a container (25.0 %), 2) inserting a glass tube into a rubber tube (22.5 %), 3) heating chemicals (20.0 %), 4) handling glass apparatuses (18.8 %), and 5) handling a ceramic pot (6.3 %). The numbers in parenthesis indicate the ratios of the number of accidents in a particular operation to the total number of accidents. These five operations are basic ones, but sum up to 93 % of accidents in [9]. This indicates that preparing appropriate learning contents for these five operations can cover almost all the cases of accidents.

3. Designing Learning Contents

In this section, we describe the proposed method that facilitates "active thinking" of students during an experiment from two points of view: leveraging questioning and presenting a failed operation.

3.1. Question and Thinking Phase

Kiken-Yochi Training (KYT) [3] or hazard-prediction training is a method of training investigated in Japan, in which workers discuss unsafe conditions provided as a picture or a video to ensure their safety. By taking a hint from KYT, a hazardous scene is presented to students prior to a particular operation in a chemistry experiment.

In the context of our *on-site safety training*, a student participates to the training activity during an experiment to narrow the gap between the time of learning and the time of doing. So, a computer system poses questions to individual student through a computer display on the experimental table instead of a traditional face-to-face discussion style of KYT. The left part of Figure 1 shows an example of the question presentation. The answer to a question and related information is then provided after a certain period of "thinking time" (Figure 1-right). We will evaluate the effectiveness of this method by comparing with a more direct approach that just presents a note of caution without a question during an experiment. Also, the tradeoff between the length of the thinking time and the memorability is examined in later section.

3.2. Getting Answer and Caution Phase

The answer to the posed question is designed so that a student can learn the key point of a certain operation and actual correct operation. The actual correct operation may be provided as video contents (Figure 1-c) while the key point can be simply presented a still picture with a short textual message (Figure 1-b). Additionally, a failed operation is included to help a student to have a concrete image of "what should not do" (Figure 1-d). The severity of an accident caused by a failed operation depends on the material of experimental apparatuses and chemicals. To increase the shareability of the learning contents, we intentionally removed the information about the *result* of the accident with an exception in case that the result is apparent, *e.g.*, heat injury by touching heated material. Instead, just the causal operation is presented.

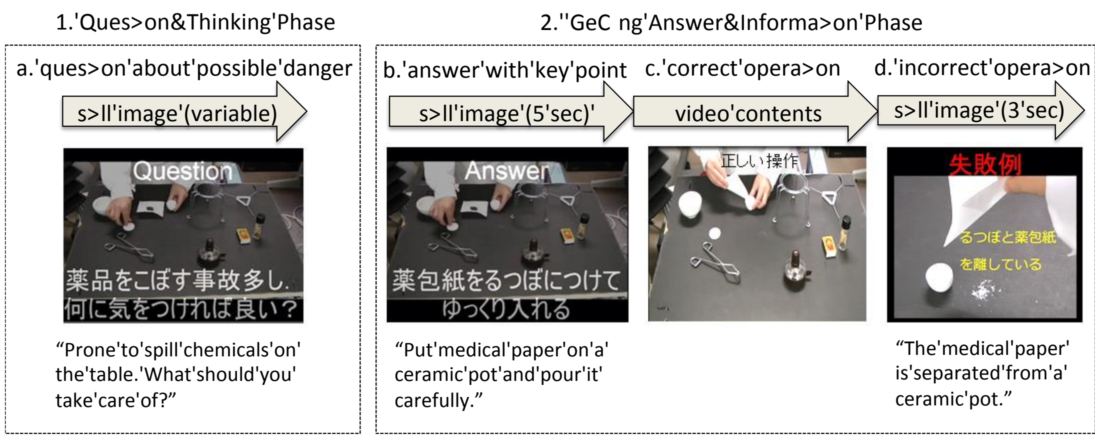

Figure 1. A flow of learning contents

4. Experiment on the Effect of Learning with Question-Thinking

We carried out a basic experiment to evaluate the effect of the learning style with *question-thinking*. In order to focus on the proposed learning style, the subjects just learn by watching presented information in a computer screen, *i.e.*, the contents are provided during a chemistry experiment, which is similar to traditional e-Learning. We will examine the possibility of on-site training in Section 5.

4.1. Methodology

The experimental procedure consisted of two phases and five components as shown in Figure 2. The first phase is intended to be a *learning period*, while the second is a *test period*. The experimental skills from safety aspects were evaluated in both phases to assess the effect of proposed learning style.

The learning period is further divided into three components. In Step 1, each subject conducted three types of simulated basic chemistry experiments that contained the five types of operations as shown in Figure 3. The description of the chemistry experiments is summarized in Table 1. Step 1 was aimed at obtaining safe experimental skill of each subject as a baseline, in which the subjects followed specific experimental instructions. Step 2 comes every after Step 1, in which the subjects watched learning contents as shown in Figure 2 and Figure 3-b). During the thinking time, the subjects were asked to tell the answer in words to ensure that they actually tried to find the answer and the appropriateness of the duration of thinking time. As Step 3, the subjects filled out questionnaire survey to obtain subjective opinions on their experiences.

Step 4 in the second phase was carried out in one week, in which the subject conducted the same experiments as in Step 1. We set the duration of one week because a class of chemistry experiment is usually scheduled once a week. In both Step 1 and 4, the subjects' operational skills were assessed based on a checklist for safe experiment. Examples are shown in Table 2. Note that the checklist was developed under the supervision of an expert of chemistry experiments. The number of unsafe operations in Step 1 was subtracted by that of Step 4 to obtain the net effect of the learning contents (Step 5).

We tested with three different length of thinking time, *i.e.*, 5, 10 and 30 seconds. The length of 10 seconds was determined based on our finding in [1] that it took about 10 seconds to comprehend message. The length of 5 and 30 seconds were specified as the ones that were shorter than and longer than 10 seconds, respectively.

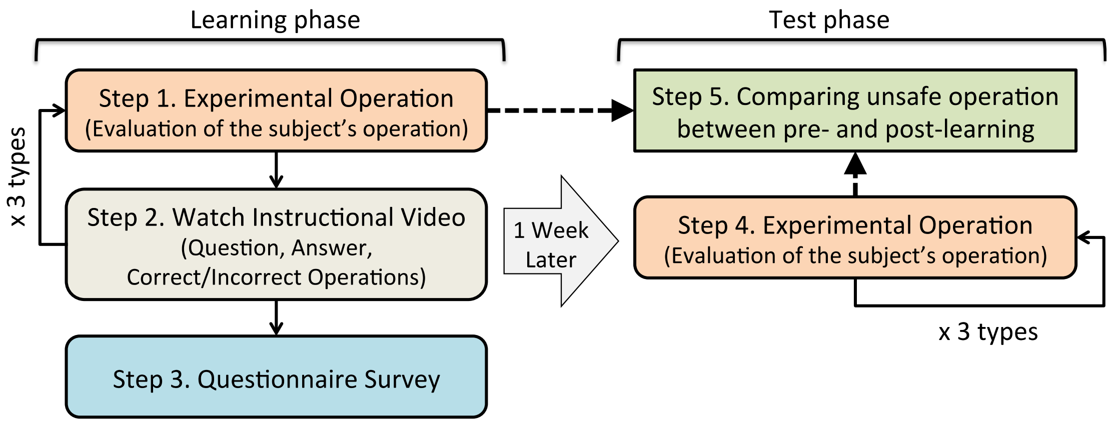

Figure 2. Experimental procedure

a) conducting chemistry experiment

b) watching the learning contents

Figure 3. Scenes of experiments: a) experimental operation for evaluation of subject's skill (Step 1 and 4) and b) watching learning contents (Step 2)

Table 1. Description of chemistry experiments applied in the experiment

ID	Topic of experiment (upper) and operations (lower)	Type of operation	Number of check points
E1	Picking and heating solid reagent		14
	1. Pick solid reagent on medical paper, and put it into a ceramic pot	1	
	2. Put a triangular support and the pot on a tripod, and heat the pot	3	
	3. Remove the cover of the pot and put the pot on a wire cloth	5	
E2	Picking and heating liquid reagent		20
	1. Pour liquid reagent into a beaker from a liquid bottle	1	
	2. Attach a dropper on a pipette, and suck 1 *ml* from the beaker	1, 2	
	3. Tap the sucked liquid into a test tube	4	
	4. Hold the test tube by a clipper, and heat the tube	3	

E3	Mixing solid and liquid reagent and heating the mixture		15
	1. Put solid reagent into a test tube from a mortar using a spoon 2. Pour liquid reagent into a test tube from a liquid bottle 3. Hold the test tube by a clipper, and heat the tube	1 1 3	

Type of operation: 1) getting out chemical material from a container, 2) inserting a glass tube into a rubber tube, 3) heating chemicals, 4) handling glass apparatuses, and 5) handling a ceramic pot

Table 2. Examples of check points for the five representative operations

ID	Op.	Check point
E1	1	1. Picking solid reagent slowly to avoid spilling it 2. Putting material/objects on a stable objects, e.g. a ceramic pot 3. Not putting reagent on the edge of an experimental table 4. Not spilling solid reagent on the table
	2	1. Putting a triangular support on the center of a tripod 2. Putting a ceramic pot on the center of a triangular support 3. Lighting a match safely 4. The distance between a match and a spirit lamp is not too close. 5. A flammable object is not near a spirit lamp. 6. Being careful of not touching flame of a spirit lamp
	3	1. Extinguishing a fire of a spirit lamp safely 2. Grabbing a ceramic pot firmly with a pot-clipper 3. Putting the pot on a wire cloth without upsetting 4. Being careful of handling heated objects, e.g. a ceramic pot, a tripod
E2	2	1. The distance between a dropper and a hand holding a pipette is not too far. 2. Not exerting extra power in attaching a dropper on a pipette 3. The pipette does not contact with a beaker to avoid breaking of the head of the pipette. 4. Obtaining precise amount of liquid by sucking slightly more than necessary and draining with the glass tube perpendicularly till required amount 5. Not sucking liquid to the dropper 6. Not holding the dropper when sucking the liquid
	3	1. The pipette does not contact with a beaker to avoid breaking of the head of the pipette. 2. Tapping the sucked liquid to a container with stable conditions, e.g. a glass object is not on the edge of a table, a glass object is not on some unstable objects. 3. Tapping the very last drop by heating the center of a pipette

4.2. Subjects

The subjects were 32 undergraduate and graduate students who were majoring in science and engineering. To equalize the knowledge of chemistry experiments, we excluded those who majored in chemistry; however, all subjects had experiences of chemistry experiments in high school. As shown in Table 3, the 32 subjects were divided into four groups (8 subjects in each group), and they conducted three types of chemistry experiments with different length of thinking time. Here, “N/A” indicates that the first phase of the learning contents, *i.e.* question and thinking phase, was skipped and that only the second phase contents were provided. So, the case acts as a control group.

Table 3. Thinking time [sec] and subjects’ grouping

	Group A	Group B	Group C	Group D
E1	5	10	30	N/A
E2	10	30	N/A	5
E3	30	N/A	5	10

4.3. Results

The bar chart in Figure 4 shows the relationship between the length of thinking time and the number of improved points (NIPs) in experimental operations. NIP indicates the net effect of the learning contents as proposed in Step 5 of Figure 2. One-way ANOVA showed significant difference in NIPs against thinking time ($F(3, 73)=2.96614$, $p < 0.05$). Then, the Dunnett multiple comparison between "N/A" and other three thinking time showed that there were significant differences ($p < 0.05$) in 5 and 10 [sec].

The preferences on the thinking time in terms of comprehending presented information are shown in the line chart of Figure 4, in which thinking time of 10 and 30 seconds were preferred. Furthermore, the subjects' ratings on the presentation of failure examples showed expectation and affirmative impression as shown in Figure 5.

Some of the subjects' opinions are summarized in Table 3. These results sustain the effectiveness of the question-based learning and presentation of failure examples from the user's point of view. Regarding the length of thinking time, the impression on 5 seconds was agreed on being too short; however, their opinions were divided in terms of 30 seconds.

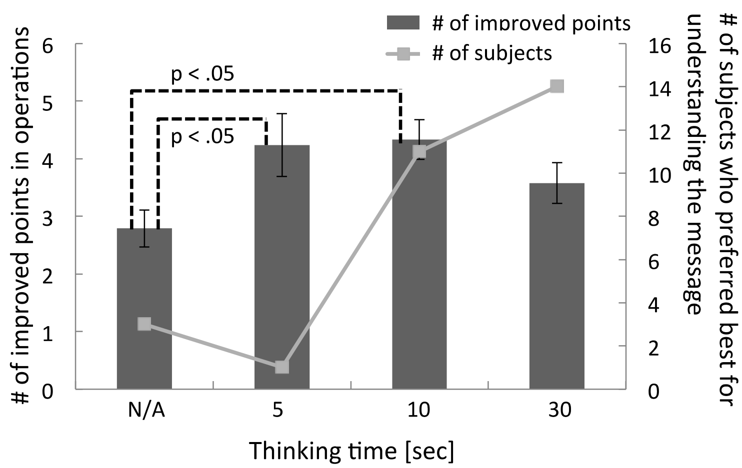

Figure 4. The relationship between the length of thinking time and the number of improved points in operations (left axis) and the number of subjects who preferred the length best for understanding the message (right axis). "N/A" indicates that thinking time is not given

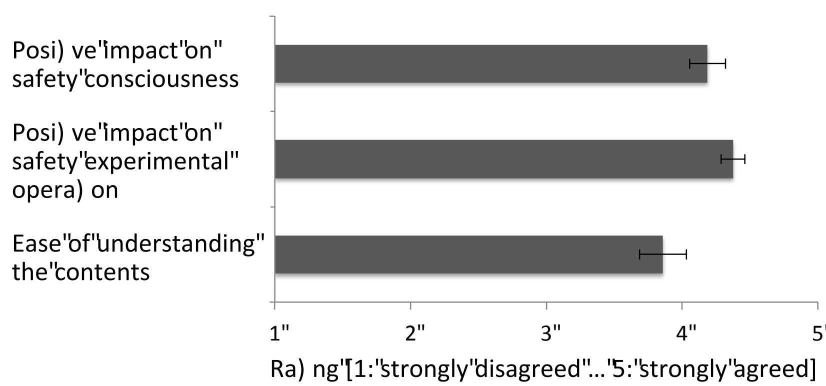

Figure 5. The subjects' ratings on the presentation of failure examples with 5-points Likert scale

Table 3. Major opinions of the subjects collected in the interview session

No.	Opinion
1	Safety consciousness would change once I try to find the answer to the question.
2	I think that presenting points of caution after questions made more impression.
3	I felt 30 seconds of thinking time was too long and annoying.
4	I like 30 seconds because I could have enough time to find answers.
5	Five seconds was too short to find answer. I could just understand the question.
6	I think the failure examples contribute to increase the safety consciousness.
7	Some failure examples are hard to understand by a still image.

5. Experiment on On-site Safety Training

We conducted another experiment to validate the proposed method in the context of *on-site safety training*, our final goal. As shown in Section 4.1, the learning activity in the previous experiment is not on-site, but the subjects carried out experiments in their heads by watching videos. Since a chemistry experiment is conducted by hand operation on a flat surface, there might be some difference, which is to be shown in this experiment.

5.1. Methodology and Subjects

A Wizard-of-Oz (WOz) method [4] was applied to remove the uncertainty of recognition of experimental operation at an early stage of prototyping, in which subjects carried out actual chemistry experiments, while an experimenter directed a system to present learning contents based on observation of the subject's operation. We tested with three chemistry experiments and three levels of thinking time, *i.e.*, N/A (answer only), 5 seconds and 10 seconds. The reason why we excluded 30 seconds is that we considered that it might be dangerous to interrupt into a subject's operation for 30 seconds. Also, there was no significant effect on learning with 30 seconds of thinking time in the previous experiment. The experimental scene is shown in Figure 6. Here, learning contents are provided through a computer display installed in front of a subject. In order to observe the eye-movement during an experiment, a subject wore an eye-tracker. Additionally, a questionnaire survey was conducted to obtain subjective opinions.

Nine undergraduate and graduate students participated to this experiment. They were grouped into three groups and experienced the three types of chemistry experiments with different levels of thinking time to avoid biases on experimental operations and thinking time while conducting the (original) experiment efficiently.

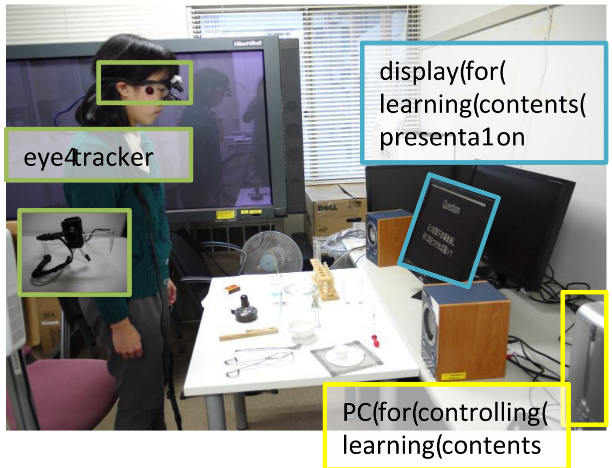

Figure 6. Configuration of the second experiment

5.3. Result

As a result of analysis of eye-tracking during the experiment, we found clear difference in the subject's attention among the three levels of thinking time. As shown in Figure 7, the subjects with thinking time of 10 seconds tended to pay more attention to the experimental table compared with other two levels. Also, we observed that the way of paying attention differed by the level of thinking time. That is, the subjects with "N/A" case watched the display just after a message was presented and started an experimental operation. In case of thinking time of 5 seconds, the answer was presented while the subjects were watching the PC display to understand the question, and they started an experimental operation after confirming the answer. By contrast, the subjects who experienced 10 seconds tried to find an answer while looking at objects on the table after checking a question on the display, and sometimes looked at the display to reconfirm the question. They started an experimental operation after looking at the presented answer. Regarding the subjective opinions, some subjects worried if 10 seconds of thinking time would make them danger because they had to look aside from their hands in operation.

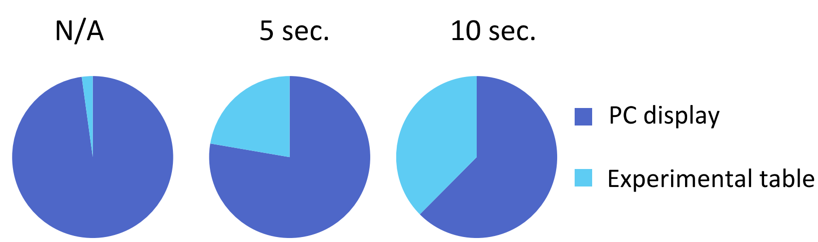

Figure 7. Ratio of subject's attention on a PC display and an experimental table

6. Discussion

6.1. Improvement of experimental operations by questioning

As described in Section 4, the presence and the length of thinking time has an impact on the improvement of experimental operations. More specifically, thinking time of 5 and 10 seconds performed effectively in acquiring the knowledge of safe experimental operations.

Our observation of the subjects throughout the experiment revealed that the subjects were looking forward the answer from the system, *i.e.*, correct operation and failure examples, and became happy or sad when they were given the answer. This implies that the reason for the ineffectiveness of 30 seconds exists in the low eagerness for the answer from the system. That is, only one subject among 24 tried to find answers by the end of thinking time (30 seconds), and others dropped by the wayside and looked boring. Instead, thinking time of 5 and 10 seconds are short enough to make a user's answer clear if it is correct or not, and a user can accept the result without being boring. We consider that providing answers from the system at the peak of their eagerness contribute to maximize the memorization of the information.

As described in Section 5.3, the comparison in the ratio of attention on a PC display and an experimental table showed difference in both quantitative (ratio) and qualitative senses. An interesting point is that thinking time of 10 seconds allowed subjects to have time to find answer to a presented question by switching attention on the display and the experimental table back and forth. We expect this would produce the effect expected from the question-thinking method. Furthermore, their eye traces went around whole the surface of the table. Fujinami and Sokan suggested that presentation with high level of spatial ambiguity enhances learning effects by facilitating to find the target of presented information on an experimental table [1]. We consider that thinking time of 10 seconds had similar effect.

Although there was significant improvement of experimental operation with 5 seconds of thinking time, the subjects did not prefer the length because they did not feel that they had reached to the conclusion of the question and thus felt frustrated.

6.2. Presentation of failure examples

As shown in the third topic of Figure 5 ("Ease of understanding the failure examples"), the presentation of failure example was mostly preferred by the subjects. The subjects might be able to connect the scene in the picture with anticipated accident in the operation, which might emphasize their interests in safe experiment. Also, the failure example provides the information on the wrong way of operation, which means that the subjects could understand "what should not do". Such information would have allowed the subjects to check their operation if it was ok in an instant manner.

6.3. Towards safe experiment

The subjective opinions from the second experiment imply that 10 seconds of thinking time would make students danger due to interruption to their experimental operations. Let us consider lighting a spirit lamp by a match. Finding an answer to a question posed prior to lighting a match or picking up a matchbox in hand might have low possibility of burn injury; however, a student would get into danger when a question is posed while lit match is in his/her hand. The timing of posing a question should take into account the risk of an accident.

7. Conclusion

In this article, we adopted *questioning about a caution in a particular experimental operation* to learn safe ways of experimental operations in university basic chemistry during experiments, in which a user is given information of correct operations as well as failure operations after a certain period of "thinking time". The findings from off-site and on-site experiments are as follows:

- Learning with question and answer contributed better than learning with answer only.

- The effect of learning is not direct proportion to the length of thinking time. Too long duration of thinking time, i.e. 30 seconds, weaken a user's capability of acquiring presented answers.
- Thinking time with 5 and 10 seconds were significantly effective in learning compared with answer-only style. Particularly, 10 seconds of thinking time allowed the subjects to look around the objects on an experimental table before being given the answer.
- The presentation of failure example is expected to increase the consciousness of safety operations.

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References

[1] K. Fujinami and A. Sokan, "Nondirective Information Presentation for On-Site Safety Training in Chemistry Experiments", In Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI'12), **(2012)** May, pp. 308-311.
[2] T. Gläser, J. Franke, G. Wintergerst and R. Jagodzinski, "Chemieraum: Tangible Chemistry in Exhibition Space", In Proceedings of the 3rd International Conference on Tangible and Embedded Interaction (TEI '09), **(2009)** February, pp. 285-288.
[3] Japan International Center for Occupational Safety and Health (JICOSH), Publication of the main points to hazard prediction activities (KYT), http://www.jniosh.go.jp/icpro/jicosh-old/english/zero-sai/.
[4] J. F. Kelley, "An iterative design methodology for user-friendly natural language office information applications", ACM Transactions on Office Information Systems, vol. 2, no. 1, (**1984**), pp. 26-41.
[5] D. Nishihama, T. Takeuchi, Y. Horiuchi, T. Inoue and K. Okada, "AR Chemistry: Bulidling up augmented reality for learning chemical experiment", International Journal of Informatics Society, vol. 2, no. 2, (**2010**), pp. 43-48.
[6] M. Sakamoto and M. Matsuishi, "Hands-on training for chemistry laboratory in a ubiquitous computing environment", In Proceedings of International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC'08), **(2008)** June, pp. 561-563.
[7] A. Sokan, M. Hou, N. Shinagawa, H. Egi and K. Fujinami, "A Tangible Experiment Support System with Presentation Ambiguity for Safe and Independent Chemistry Experiments", Journal of Ambient Intelligence and Humanized Computing, vol. 3, no. 2, **(2012)** February, pp. 125-139.
[8] K. Song, G. Kim, I. Han, J. Lee, J. -H. Park and S. Ha. "CheMO: mixed object instruments and interactions for tangible chemistry experiments", In Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems, (**2011**), pp. 2305-2310.
[9] A. Usui, "Incidents and Safety Guideline in Chemistry Experiments (Originally, only Japanese title is given", English title was given by the authors, http://www.eng.tottori-u.ac.jp/~www_tec/doc/safety.xls, **(2004)** March.

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