The Development and Evaluation of an Educational Game Integrated with Augmented Reality and Virtual Laboratory for Chemistry Experiment Learning

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***Abstract*—Virtual laboratory helps students' learning of experiment manipulation and scientific concepts before they actually enter the real chemistry laboratory. It also helps reduce the risks in conducting the real chemistry experiments and reduce the cost for chemistry experiment materials. This study developed an educational game "O_2 LAB©", on the mobile device that combined augmented reality and virtual laboratory. It is a game-based learning system integrated with augmented reality, anchored instruction, and virtual laboratory. The game includes two stages (the AR exploration stage and the virtual experiment stage). Fifty-two senior high school students participated in this study. The results show that the students improved their learning significantly after the game and the scores in each dimension of flow and acceptance are both high.**

***Keywords*—game-based learning, flow, virtual laboratory, augmented reality**

I. INTRODUCTION

In a virtual laboratory, students can have preparation and practice before the actual experiment with more confidence in operating it, thus enhancing their practical performance and reducing the possible wastes in materials or time [1]. The students' reflections in learning could also be assisted when the virtual laboratory is integrated with simulated educational games that contain different contextual themes [2]. However, the way how those experimental items are presented in simulation may not be consistent with the students' understanding of how they actually look in the real life. In order to help the students know the real experimental items, we can combine augmented reality (AR) with the virtual laboratory. With the help of AR, where the students explore the necessary items for the experiment in a real laboratory, the students' understanding of how those items look and how they should be used is facilitated, thus leading to learning transfer. The educational theory foundation of the integration of AR technique and contextual tasks could be the anchored instruction where the clues could be anchored in the AR exploration tasks. The students could be placed in a specific story context and be guided to find the problems and solutions, based on the content and clues in the story [3]. Therefore, the present study aims to develop a chemistry experiment educational game O_2 *LAB*©, which integrates AR and virtual laboratory based on anchored instruction theory. The students in the study are grouped for collaborative problem solving, and each group member can share and familiarize the acquired knowledge, helping the students' understanding of chemistry knowledge and operating experiences. The educational game O_2 *LAB*© includes two stages, including the AR exploration stage and the virtual laboratory stage. In the AR exploration stage, the players can use tablet computers or mobile phones to scan the cards in front of experiment items in the laboratory to collect and make the experiment items and the chemistry materials needed. The players also try to solve the security problems in the laboratory (see Figure 1). The immediate feedback and guided clues provided by AR as cognitive scaffolding help the students know the features and appearance of experiment items as well as laboratory security rules. After having collected the experiment items, the players can enter the virtual laboratory. The virtual laboratory system is about a virtual experiment that the players need to make an oxygen supplying equipment in a tablet computer, and they can drag any items based on the clues for a simulated experiment operation (see Figure 2). The system mentioned above is expected to assist the students' chemistry experiment knowledge and skills. This research purpose of this empirical study aims to explore the students' learning effectiveness, flow, and game acceptance.

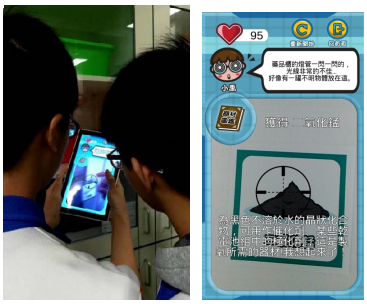

Figure 1. The students use mobile devices to find correct experiment items at the AR stage.

978-1-5386-0621-6/17 $31.00 © 2017 IEEE
DOI 10.1109/IIAI-AAI.2017.14

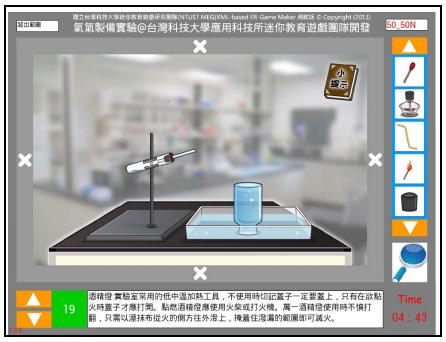

Figure 2. The students can drag items and chemistry materials for experiment operation at the Virtual Lab stage.

II. METHOD

Participants were 52 students from a senior high school in northern Taiwan (42 males and 10 females), and their average age was 17. In this study, the students were divided into groups of 4-5 people for game-based learning with tablet computers. The study used a pre-test and post-test to measure the students' learning effectiveness, and the tests were about knowledge of chemistry items, laboratory security, and the making of oxygen experiment. The students' flow was measured by Kiili's flow scale [4] [5], a five-point Likert scale that included flow antecedent and flow experience, after the experiment. Based on the participants' scores in the study, the internal consistency was Cronbach's α=0.97. The technology acceptance scale was adapted from Davis [6], including perceived usefulness and perceived ease of use. Based on the participants' scores in the study, the internal consistency was Cronbach's α=0.905.

III. RESULTS AND DISCUSSION

In terms of learning effectiveness, the results of the paired t-test are shown in Table 1. After the students used the game developed in the study, their understanding of chemistry items, laboratory security, and the making of oxygen experiment significantly improved (the pre-test score: M=20.98, SD=12.25; the post-test score: M=48.52, SD=16.33; t=18.97, p<0.001). Moreover, the study also measured the students' flow and technology acceptance at the AR exploration stage and the virtual laboratory stage, as shown in Table 2. The results showed that the students' flow and technology acceptance at both stages were above four, higher than the medium three in the five-point scale, suggesting the students' involvement and high acceptance for this game.

TABLE I. SUMMARY OF THE EVALUATION OF LEARNING PERFORMANCE

Variable	Post-test		Pre-test		
	mean	***S.D.***	***Mean***	***S.D.***	***t-statistics***
Learning Performance Post-test – Pre-test	48.42	16.33	20.98	12.25	18.97.***

***: p-value < 0.001

TABLE II. SUMMARY OF THE EVALUATION OF FLOW STATE AND TECHNOLOGY ACCEPTANCE DURING AR AND VIRTUAL LAB STAGES

Dimension	mean	S.D.
AR-stage		
Flow Antecedents	4.28	0.70
Flow Experience	4.24	0.72
Percevied usefulness	4.50	0.57
Perceived ease of use	4.25	0.73
Virtual Lab-stage		
Flow Antecedents	4.35	0.71
Flow Experience	4.28	0.73
Percevied usefulness	4.48	0.57
Perceived ease of use	4.35	0.66

IV. CONCLUSION AND SUGGESTIONS

The research shows that the integration of AR and virtual laboratory improves the students' chemistry experiment learning with their high degree of involvement and acceptance. The game mechanism that integrated AR and virtual laboratory for simulated operations with the given clues based on anchored instruction [3] should help the learning of chemistry and experiment operations. Future studies may add a control group and explore the students' behaviors in operation and reflection in this integrated environment (e.g. [2]) to further understand learning process.

ACKNOWLEDGMENT

This research was supported by the projects from the Ministry of Science and Technology, Republic of China, under contract number MOST- 104-2511-S-011 -003 -MY3, MOST- 105-2511-S-011 -006 -MY3 and MOST-105-2511-S-034-001.

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