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The Development and Preliminary Evaluation of a Chemistry Educational Virtual Reality Game with Authentic Manipulation and Situated Learning

Chih-Chen KUO[a], Shu-Ming WANG[b], Kuang-Chung HAO[c], Chang-Hsin WU[d], Huei-Tse HOU[a]*

[a]*Mini Educational Game Development Group, Graduate Institute of Applied Science and Technology, National Taiwan University of Science and Technology, Taiwan*
[b]*Department of Information Management, Chinese Culture University, Taiwan*
[c]*Department of Computer Simulation and Design, Shih Chien University*
[d]*Daxi Senior High School of Taoyuan City*
*hthou@mail.ntust.edu.tw

Abstract: In recent years, virtual reality educational game has gained much attention and has been applied for learning abstract and complex subject like chemistry. However, the study of the virtual reality educational game integrating authentic manipulation and situated learning assisting chemistry experiment learning is still limited. To improve the understanding of how VR can assist learning. This study developed a VR integrated educational game – *VR Crystal Chamber* for learning chemistry filtration and evaporation procedure. To evaluate the game, thirty students of a senior high school in northern Taiwan participated in this study. Preliminary results suggested that the game could be helpful in enhancing students' learning performance. In addition, students' flow state revealed positive game engagement. In terms of gender differences, the result showed there were no significant gender differences in male and female students' flow state as well as their learning performance. These preliminary findings suggested that *VR Crystal Chamber* could be an effectively tool in learning chemistry experiment procedure.

Keywords: virtual reality, game-based learning, authentic manipulation, situated learning, flow

1. Introduction

Chemistry concepts can be abstract and complex. In addition, to better learn chemistry, authentic experiments in the laboratory and situated learning strategy can improve students' acquisition of procedural knowledge (Brown 1989; Stein, 1998). Nonetheless, real-world laboratory has many limitations. For example, the cost of laboratory experiment can be high as it includes material consumption (Limniou, Papadopoulos, & Whitehead, 2009), equipment maintenance, limited number of laboratories. Moreover, real-world laboratory can of great risk when conducting experiments (i.e. using alcohol burner or handling dangerous chemical compounds) (Koretsky, Amatore, Barnes & Kimura, 2008; Sokoutis, 2003; Yalcin & Vatansever, 2016).

With the assistance of information technology, nowadays, virtual laboratory has been widely applied in teaching experiment operation as pre-lab exercises to deal with the limitations and risks of real-world laboratory (Yalcin & Vatansever, 2016; Heradio, Torre, Galan, Cabrerizo, Herrera-Viedma, & Dormido, 2016; Tüysüz, 2010). Virtual laboratory not only reduces the cost as well as the risks of experiment, but also enables students to better learn the procedure and concepts of the experiments through repeatedly practicing (Yehezkel, Eliahu & Ronen, 2009).

However, repeatedly practicing can sometimes be boring. To promote students' learning motivation, game-based learning has been regarded as an ideal solution in comparison with traditional lecture-based approach (González, Collazos, Guerrero, & Moreno, 2017; McLaren, Adams, Mayer, & Forlizzi, 2017). Positive results of adapting educational games or computer simulation, in terms of learners' motivation and performance have been reported by previous studies (i.e. Antunes, Pacheco, & Giovanela, 2012; Hou, Wang, & Tsai, 2013; Scherer, & Tiemann, 2012; Hou, &Lin, 2017; Wang, Chen, Hou, Li, 2017).

Seeking to promote students' learning motivation and performance, this study developed an educational game – *VR crystal chamber*, which employed virtual reality to create a gamified and real-world simulated environment with authentic VR manipulation for learning chemistry filtration and evaporation procedure. Virtual reality technology was used in the game to increase the degree of authenticity and improve the transfer of learning for students (Bossard, Kermarrec, Buche & Tisseau, 2008).

According, the primary purposes of this preliminary study are what follows:

(1). To evaluate students' learning performance with the support of *VR Crystal Chamber*.

(2). To evaluate students' perceptions toward the game – *VR Crystal Chamber* as well as their gaming experience in terms of flow.

(3). To explore the possible gender differences in students' perceptions toward the game, gaming experience, and their learning performance.

2. Research Methods

2.1 Game design

The game employed in this study was *VR Crystal Chamber*, an educational game developed by National Taiwan University of Science and Technology Mini Educational Game (NTUST-MEG) research group. *VR Crystal Chamber* integrates virtual reality technology with authentic manipulation and situated learning. The game story begins with the player kidnapped in a chamber by alien. The only way to escape the room is to refine Sodium chloride (NaCl) with the material in the room as weapon to defect the monster in 10 minutes. The story provides the learners a scenario and a task as a part of situated learning. In this study, there were three players in each group (figure 1). The whole game kits were consisted of one joystick, one goggle, two instruction sheets, one screen, one computer and a pair of sensors as shown Figure 1. The main purpose of this setting was to promote collaborative discussion and complete the task together as a group. When playing the game, one player (the main player) in the group wore the goggle and joystick, and the rest two players of the group played the observers with joystick instruction sheet to assist the focal player. Joystick allowed the main player to perform certain actions in the game, such as walking around, searching and obtaining the object, looking for game clues as well as manipulating objects to conduct the experiment.

VR Crystal Chamber included three types of scaffolding for the learners. First of all, players' movement would receive instant feedbacks. For example, when a player put the alcohol burner in the right place or angle, green shades would show up indicating that the player have put the burner to the right position (figure 2). Before the green shades showed, the player can freely try to put the alcohol burner in any position or angle as many times as s/he would like to. Second, the whole experiment procedures were shown in a poster on the wall in the chamber in the VR game (figure 3), player could check the poster whenever they needed. Third, when players performed correct steps of the experiment procedure, sounds would be played as feedbacks.

With the support of virtual reality, the game – *VR Crystal Chamber* was able to simulate each step of the chemistry filtration and evaporation procedure, such as obtaining the water, lighting the alcohol burner, put on filter papers, and so on, with authentic manipulation and situated learning. In this manner, *VR Crystal Chamber* was expected to improve the transfer of learning and served as a pre-lab learning activity for students.

Figure 1. Game kits of *VR Crystal Chamber*

Figure 2. Screen capture of experiment manipulation

Figure 3. Part of scaffolding of refine the NaCl

2.2 Participants

The participants of this study were 30 students including 19 males and 11 females from a senior high school in northern Taiwan. The 30 participants involved in the study were grouped into ten groups of three members for the learning activity. All students had not yet participated this chemistry course before, and played games similar to the one employed in this study.

2.3 Measurement

To evaluate *VR Crystal Chamber*, this study adapted flow scale for game (Kiili, 2006) to measure learners' perceptions toward the game as well as their game experience while playing the game.

Flow scale for game was consisted of two dimensions, namely the flow antecedents and flow experiences. The flow scale was consisted of 22 items. Flow antecedents involves five sub-dimensions, which were challenge, goal, feedback, control, and playability. These sub-dimensions were to measure learners' perceptions toward the game. Learners' in-game experience was measured by the four sub-dimensions of flow experience, which were concentration, time distortion, autotelic experience, and loss of self-consciousness, respectively. All items were measured using five-point Likert scale with 1 for strongly disagree and 5 for strongly agree. The higher score of a dimension (sub-dimension) suggested the more positive evaluation or experience. The flow scale was of high reliability for flow scale (chronbach's α=0.786).

To evaluate learners' learning performance, a learning assessment for pretest and posttest was employed. The assessment was firstly developed by an experienced chemistry teacher in high school. There were two parts of the learning assessment. The first part was a sorting question. Students were asked to sort the chemical experiment equipment for filtration and evaporation of saline. Each answer of correct order was given one point. There were 9 points in total for sorting question. The second part was two illustration question. Students were asked to illustrate the whole filtration and evaporation of saline process with drawing and description. In this part, students had to employ high level of memory retrieval in order to correctly answer the assembling sequence and operating procedure. Each correct answer would be given 12 points. The total score of the learning assessment was 33 points.

2.4 Procedure

To evaluate the game VR Crystal Chamber, a 45 minutes learning activity was employed. The procedure was shown in Table 1. Each group with three students were given one set of game kits including one joystick one goggle, two instruction sheets, one screen and one computer. Due to the time constraint and limited sets of VR game kits (three sets in total), ten groups took turns to play the game. In specific, three groups played the game at each turn. After all groups completed playing the game, all students then took posttest and flow scale for gaming experience survey.

Table 1

Research procedure

Procedure	Session time	Description
Pretest	15 minutes	Students were grouped and asked to complete the pretest.
Playing game	10 minutes	Each group was allowed for 10 minutes to play the game.
Posttest	10 minutes	After playing the game, students were asked to complete the posttest.
Administering survey	10 minutes	Flow scale for game was administered in this session.

3. Results

Table 2 – 5 summarized the results of this study. As for learning performance, results shown in Table 2 indicated that students' learning performance has been greatly improved after the game-based learning activity. This finding suggested the effectiveness of employing the game – VR Crystal Chamber to help students to learn chemistry filtration and evaporation procedure.

Table 2

Learning performance of pretest and posttest

	Posttest (n = 30)		Pretest (n = 30)		
	Mean	S.D.	Mean	S.D.	t-stat.
Posttest - pretest	14.66	4.02	20.10	5.92	-4.834***

*** $p<.001$

Regarding the student's perceptions toward and their gaming experiences of *VR Crystal Chamber*, Table 3 summarized the means and standard deviation of the flow scale for game. As Table 3 showed, students positively evaluated the game – *VR Crystal Chamber* in general (Average of flow antecedents exceeded 3.5).

To further test the plausible gender differences of learning performance, perceptions of game as well as gaming experience, Mann-Whitney U test was conducted considering the small sample size of different gender group. As shown in Table 4, there was no significant gender differences in pretest, suggesting there was no differences in prior knowledge between male and female. As for posttest, result showed no significant difference as well. This finding suggested the game – *VR Crystal Chamber* had no particular preference on specific gender.

Table 3

Means and standard deviations of flow scale for game

Dimension	Mean	S.D.
Flow antecedents	3.65	0.566
Challenge	3.86	0.753
Goal	4.10	0.802
Feedback	3.62	0.690
Control	3.48	0.885
Playability	3.18	0.824
Flow experience	4.07	0.662
Concentration	4.22	0.758
Time distortion	4.05	0.994
Autotelic experience	4.20	0.830
Loss of self-consciousness	3.51	0.835
Flow	3.88	0.559

Table 4

Mann-Whitney U test for pretest and posttest scores of male and female

Dimension	Male (n = 19)		Female (n = 11)			
	Mean	S.D.	Mean	S.D.	U	P
Pretest	14.88	3.92	14.27	4.33	96.50	0.742
Posttest	19.43	5.89	21.27	6.08	84.50	0.398

Table 5 summarized the differences test for each sub-dimensions of flow scale for game. Results suggested there were no gender differences among students' overall flow state. As males were regards as typical gamer and generally have better performance in playing games than females. Our results showed no significant difference between male and female students in terms of flow antecedents (perceptions of the game) and flow experience (gaming experience). These findings suggested that the game – *VR Crystal Chamber* could be employed in a learning activity without serious concern for gender difference

Table 5

Mann-Whitney U test for flow scale for game

Dimension	Male (n = 19)		Female (n = 11)			
	Mean	S.D.	Mean	S.D.	U	P
Flow antecedents	3.71	0.51	3.53	0.64	79.00	0.281
Challenge	3.96	0.67	3.68	0.87	82.50	0.344
Goal	4.16	0.81	4.00	0.80	88.00	0.480
Feedback	3.61	0.67	3.63	0.74	103.00	0.958
Control	3.55	0.88	3.36	0.92	92.50	0.614
Playability	3.29	0.78	3.00	0.89	82.00	0.326
Flow experience	4.08	0.70	4.05	0.61	96.00	0.727
Concentration	4.19	0.85	4.27	0.59	104.50	1.000
Time distortion	3.89	1.11	4.31	0.71	86.00	0.426
Autotelic experience	4.26	0.87	4.11	0.77	96.00	0.723
Loss of self-consciousness	3.68	0.83	3.22	0.78	69.50	0.131
Flow	3.91	0.56	3.81	0.57	90.50	0.559

* $p<.05$ ** $p<.001$

4. Discussion and conclusion

4.1 Discussions

This study developed a virtual reality educational game – *VR Crystal Chamber* for chemistry learning. The game was to assist students to learn chemistry experiment procedures, the filtration and evaporation in this study to be specific. To evaluate the game, this study adapted the flow scale for game (Kiili, 2006). Meanwhile, a learning assessment for measuring students' learning performance was developed by an experience senior high school chemistry teacher and the researchers. Discussions on the findings are as follows.

As for flow scale for game, students in general positively evaluated the game – VR Crystal Chamber as challenging, provided clear goals and feedback, having a sense of control and playable. These positive perceptions of flow antecedents revealed that students' positive gaming engagement. From the positive result of feedback, one of the flow antecedents, indicated that authentic manipulation and its instant feedback helped students immerse to the virtual environment in that game. One thing to note is that among all *flow antecedents*, *playability* and *control* were relatively lower. This finding might be attributed to the nature of educational game. Students perceive educational game as less enjoyable, or less playable, after they were aware of the learning subject. Furthermore, *loss of self-consciousness* was relatively lower than other sub-dimensions of *flow experience*. This finding might also be attributed to the *flow antecedents, playability* and *control*. As far as students are concerned, they still were literally having a learning activity after all, even they did experience *time distortion*, fully *concentration*, or *autotelic experience*.

As for effectiveness of the game – VR Crystal Chamber, results showed there was a significant difference between pretest and posttest. After manipulating the experimental procedure through the game, learner had better understanding and were more familiar with the experiment procedure. The finding suggested the effectiveness of the game – VR Crystal Chamber in supporting students to learn chemistry evaporation and filtration procedure.

In conclusion, VR Crystal Chamber could be considered as an educational game that promotes authentic manipulation and situated learning. The game took the benefits of novel technology to enhance the degree of authenticity, which further enabled student being more immersed in the situation and environment to promote transfer of learning. In this preliminary study, we showed the effectiveness and students' positive evaluation and gaming engagement.

4.2 Research limitation and future research

The small sample size exerted the first limitation of this preliminary study and thus the results of this study should be interpreted with cautious. Future research is suggested to conduct research with a larger sample size to improve our understand of how VR could improve students' learning performance. Moreover, this study did not analyze the behavioral patterns of students' interaction to explore how scaffolding in the game might help student to learn better (Bakeman & Gottman, 1997; Hou, 2015). In addition, what kind of gaming strategy was employed while students playing the game. Lastly, for now, virtual reality equipment can still be relatively expensive, which impose limitation for conducting a larger scale research. In this study, we were only able to employ the learning activity with three sets of VR equipment. Students thus had to play the game turn by turn. Future research is encouraged to conduct the research with more sets of VR equipment when possible and have all the students play the game concurrently.

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