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A science history educational board game with augmented reality integrating collaborative problem solving and scaffolding strategies

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Abstract: While numerous studies have adapted computer simulation or digital games to support chemistry learning, these previous approaches were generally used to support learning the procedural knowledge of chemistry, such as experiment procedure. Nonetheless, chemistry history is mostly of declarative knowledge. Different approach should be taken to support learning chemistry history. Game-based learning was considered as an ideal vehicle to support history education. Previous studies have pointed out that students' learning motivation and comprehension could be improved with the support of educational games. In this manner, this study proposed a novel gaming approach, which combines the board game and augmented reality technology to support learning chemistry history. In the game - *AR chemistry history*, the board game mechanisms were to enable learners to collaboratively learn together and from each other, while augmented reality was used to provide cognitive scaffoldings. To evaluate the game, thirty-five senior high school students were invited to participate in this study. Preliminary results suggested that the game - *AR chemistry history* could be helpful in improving students' learning performance. In addition, students generally reported positive evaluations toward the game as well as positive gaming experience. A further test on plausible gender differences showed there were no significant gender differences in male and female students' perception toward the game, gaming experience as well as their learning performance. These preliminary findings suggested that *AR chemistry history* could be used to effectively support chemist history learning. Future research is encouraged further explore students' behavioral patterns to better depict a more comprehensive picture of the adapting educational games to support learning.

Keywords: Augmented reality, board game, game-based learning, collaborative problem solving, flow

1. Introduction

Traditionally, the teaching of chemistry history was mostly lecture-based. To prepare for the test, students have to memorized the materials that teachers lectured. Nonetheless, this learning approach doesn't encourage students to think actively, nor does it promote students' learning motivation. With the support of information technology, learning chemistry could be more interactive and student-centered. Game-based learning has been regarded as an ideal way to improve students' learning performance as well as their learning motivation in comparison with traditional teaching approach (González, Collazos, Guerrero, & Moreno, 2017; McLaren, Adams, Mayer, & Forlizzi, 2017).

Previous studies have developed computer simulation applications or educational games to support chemistry learning. These studies also reported positive results in terms of learners' motivation and performance with novel IT applications (i.e. Antunes, Pacheco, & Giovanela, 2012; Hou, Wang, , & Tsai, 2013; Scherer, & Tiemann, 2012). Previous studies mostly used computer simulation or educational games to support students' learning of procedural knowledge, such as chemistry experiment procedure. Nonetheless, chemistry history is declarative knowledge, which required a different design to promote students' learning motivation and performance. Integrating games to learning activities of history education could be helpful in promoting students' learning motivation and understanding to the learning subject (Shiue, Hsu & Liang, 2016). Cruz、Carvalho& Araújo (2016) developed a mobile game for learning history. They found that students were more aware of the learning goals. In addition, students were more actively searching for extended information, and their comprehension of historical events were also improved.

This study was to propose a novel approach to support learning chemistry history by combining board game with augmented reality technology. While most digital game are for a single player, board game requires multi-players to play face-to-face whether against each other or work together. This kind of collaboration creates opportunities for learners to observe other learners and learn from each other. Nonetheless, board game might not be able to carry rich and dynamic information as the game kits are mostly paper and physical items. Fortunately, augmented reality could be helpful in expanding the boundary by connecting real-world objects with digital artifacts. Moreover, introduction of novel technology might be able to intrigue learners' motivation as well (Steinkuehler, Squire, & Sawyer, 2014). In this study, the research team developed a board game with augmented reality – *AR Chemistry history* to support learning the history of famous chemists and their achievements. The learning subject is part of chemistry history curriculum of senior high schools in Taiwan. In the game, the board game mechanisms were to enable learners to collaboratively learn together and from each other, while augmented reality was used to provide cognitive scaffolds. The game design is to be detailed in the Method section.

Concluding from above, the primary purposes of this study are: Firstly, to evaluate the improvement of students' learning performance with the support of *AR Chemistry history*. Second, to evaluate students' perceptions toward the game - *AR Chemistry history* and their gaming experience. Finally, Gender difference was regarded as an important factor in novel educational applications and males were generally considered as typical players of games (Teo, 2010). Thus, this study is to explore the plausible gender differences in students' perceptions toward the game, gaming experience, and thus their learning performance.

1. Research Methods

1.1. Game design

The game employed in this study was *AR Chemistry history*, an educational game developed by National Taiwan University Mini Educational Game (NTUST-MEG) research group. *AR Chemistry history* was developed using Unity 5.3.4p4. The augment reality module was developed using the Vuforia AR software development kit (SDK). *AR Chemistry history* integrates augmented reality technology with board game. There were five types of cards in the game, namely the chemist card, achievement card, monster card, and bullet card. Each chemist card represented a famous chemist. Achievement cards presented significant findings or breakthroughs in the chemistry history. Each achievement card can be paired with a chemist card. While chemist card and Achievement card were used in pair, monster card and bullet card were used along for battling monster and collecting bullet for battling. The story of game was that alien monsters was invading the Earth and had destroyed civilization and many historical literature. Players were to locate the literature that documented the chemist and their achievements; at the same time, battling with monsters and defeating them to protect the Earth.

The game was consisted of two modules: the first one was the information inquiry module (Figure 1) and the second one was the monster battle module (Figure 2). In the information inquiry module, learners can use the *AR Chemistry history* game app to scan an achievement card or chemist card. The app will show cognitive scaffoldings: e.g., related information as well as external links, such as webpages or videos, while would improve learners' understanding of a specific subject (Figure 1). The second module was to use collected bullets to battle with alien monsters (Figure 2).

Figure 3 showed the game kit of *AR Chemistry history*. At the beginning of the game, each player had to draw three cards from the card deck (black area in figure 3). Two chemist cards were randomly picked and placed in the pairing area (gray area in figure 3). Each group of players have to collect correct cards for pairing collaboratively to win the game together as a collaborative problem solving process. Each round, players can choose to (1). Inquiry the card information; (2). Select an achievement card for pairing; or (3). Attack the monster. At the end of each round, if a player hold less than three cards, the player had to drew cards from the card deck till having three cards in hand. When learners successfully paired a chemist to an achievement, they could collect bullets by drawing a bullet card. As they collected enough bullets, learners could draw a monster card for battling. When learners won the battle, respective scores would be given to the learners. Learners with the highest score was the winner

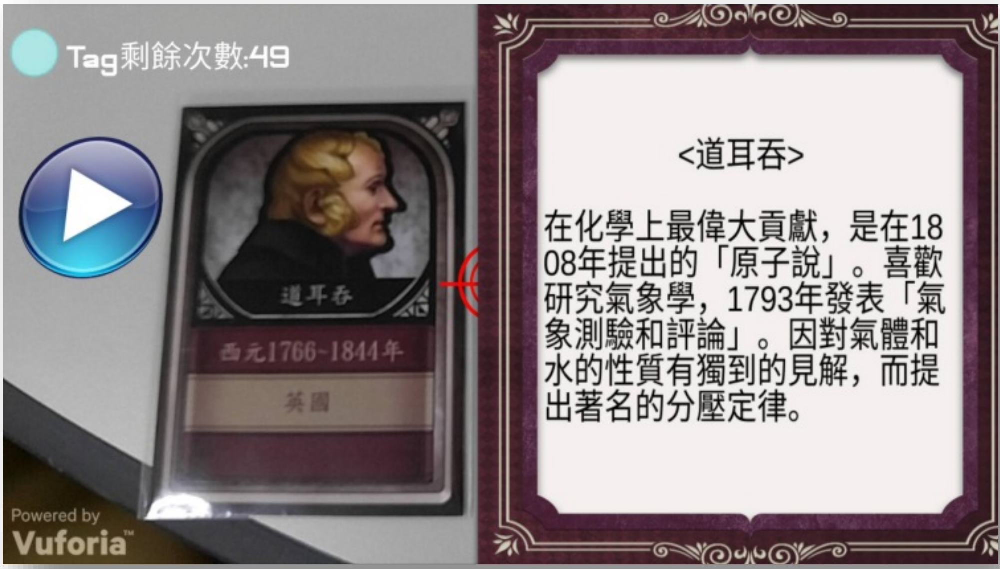

Figure 1. Screen capture of scanning a chemist card, John Dalton in this card.

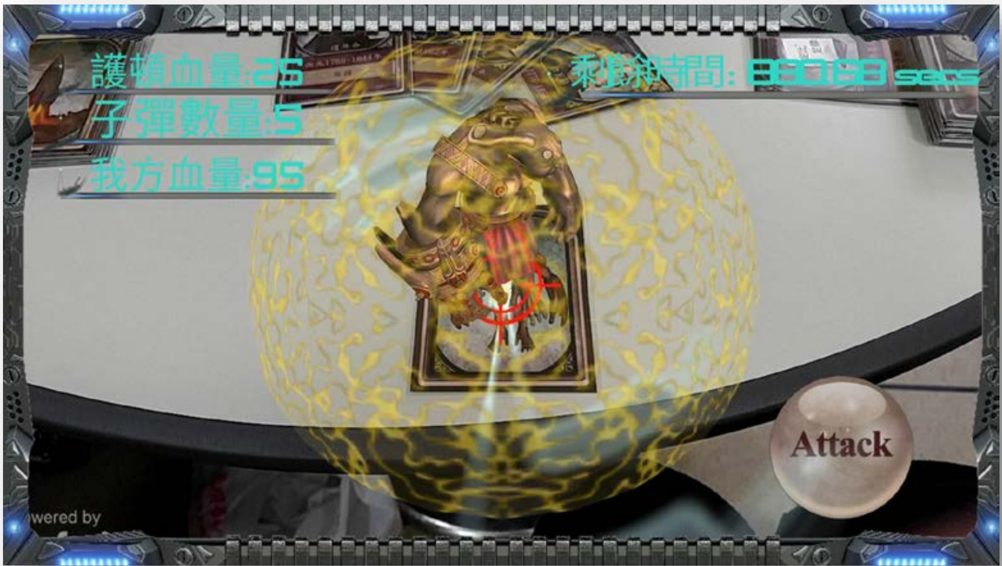

Figure 2. Screen capture of monster battling.

Figure 3. Game kits of *AR chemistry history*

1.2. Participants

The participants of this study were students from a senior high school in northern Taiwan. All students had not yet attended chemistry history course, nor had them played games similar to the one employed in this study. Thirty-five students participated this study, twenty-eight of them were male, seven of them were female. Students were grouped into seven groups, each of five to six members. Students were of age between 15 to 17.

1.3. Measurement

To evaluate *AR Chemistry history*, this study adapted technology acceptance scale (Davis, 1989) and flow scale for game (Kiili, 2006) to measure learners' perceptions toward the game as well as their experience while playing the game.

Flow scale for game was consisted of two dimensions, namely the flow antecedents and flow experiences, in twenty-three 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. This study adapted technology acceptance scale, which was consisted of two dimensions, namely the perceived ease of use, perceived usefulness. There were 11 items for technology acceptance scale. All items were measured in five-point Likert scale from 1 for strongly disagree to 5 for strongly agree. The higher score of a dimension (sub-dimension) suggested the more positive evaluation or experience. Reliability test suggested high reliability for flow scale (chronbach's α=0.890) and technology acceptance scale (chronbach's α=0.865).

To measure learners' learning performance, a learning assessment for pretest and posttest was employed. The assessment was firstly created by an experienced chemistry teacher in high school. To ensure the expert validity, the assessment was then evaluated and discussed for its relatedness to the game in this study with the authors and other chemistry experts. There are two parts of the learning assessment. The first part was of twenty-five matching questions. Students were asked to match chemists to achievements. Each correct matching was given one point. The second part was of nineteen fill-in questions, Students were asked to fill-in the name of achievements in this part, which involved higher level of memory retrieval. Each correct answer would be given one point.

1.4. Procedure

The learning activity lasted sixty minutes, which are as shown in Table 1. Each group will be given two tablet computers and one set of game kits.

Table 1. Research procedure

Procedure	Session time	Description
Pretest	15 minutes	Students were grouped and asked to complete the pretest.
Game introduction and setup	5 minutes	The researchers helped students to setup the game and introduce the game rules, goals to the students. No learning content was introduced in this session.
Playing game	20 minutes	Each group was allowed for twenty 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 and technology acceptance scale were administered in this session.

2. 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 - *AR Chemistry history* to help students to learn chemistry history.

Table 2. Learning performance of pretest and posttest.

	Posttest (n = 35)		Pretest (n = 35)		
	Mean	S.D.	Mean	S.D.	t-stat.
Posttest - pretest	21.11	6.94	7.66	4.21	12.697^{***}
***: $p < 0.001$					

Regarding the student's perceptions toward and experiences of the game - *AR Chemistry history*, Table 3 summarized the means and s.d. of flow scale for game and technology acceptance scale. As shown in Table 3, students positively evaluated the game - *AR Chemistry history* in general (all exceeds 3.5).

Table 3. Means and standard deviations of flow scale for game and technology acceptance scale.

Dimension	Mean	S.D.
Flow antecedents	3.98	0.52
Challenge	3.76	0.72
Goal	4.41	0.60
Feedback	4.04	0.67
Control	3.97	0.85
Playability	3.73	0.69
Flow experience	4.10	0.56
Concentration	4.14	0.69
Time distortion	4.10	0.84
Autotelic experience	4.33	0.58
Loss of self-consciousness	3.57	0.88
Technology acceptance	4.30	0.54

Perceived usefulness	4.44	0.59
Perceived ease of use	4.11	0.70

To 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 female 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. This finding suggested the game - *AR Chemistry history* had no particular effect on specific gender.

Table 4. Mann-Whitney U test for pretest and posttest scores of male and female.

Dimension	Male (n = 28)		Female (n = 7)			
	Mean	S.D.	Mean	S.D.	U	p
Pretest	7.79	4.24	7.14	4.38	89.00	0.710
Posttest	20.61	6.54	23.14	8.63	81.50	0.495

Table 5 summarized the differences test of flow scale for game and technology acceptance scale. Results suggested there were no significant gender differences among students' perceptions of flow antecedents, usefulness and ease of use of the game - *AR Chemistry history.* In addition, males were usually considered as typical gamer and generally were more into playing games than females. Nonetheless, results of the difference test for flow experience showed there was no gender difference of students' gaming experience. This finding also suggested the game - *AR Chemistry history* could be used to support learning without concern for gender difference.

Table 5. Mann-Whitney U test for flow scale for game and technology acceptance scale.

Dimension	Male (n = 28)		Female (n = 7)			
	Mean	S.D.	Mean	S.D.	U	p
Flow antecedents	4.03	0.46	3.79	0.74	70.00	0.247
Challenge	3.80	0.67	3.57	0.93	81.00	0.470
Goal	4.46	0.49	4.21	0.95	89.00	0.694
Feedback	4.11	0.60	3.79	0.91	70.00	0.235
Control	4.00	0.84	3.86	0.94	86.00	0.613
Playability	3.79	0.64	3.50	0.87	72.00	0.267
Flow experience	4.13	0.51	3.98	0.74	85.50	0.605
Concentration	4.21	0.65	3.86	0.84	73.50	0.308
Time distortion	4.09	0.87	4.14	0.75	97.50	0.983
Autotelic experience	4.33	0.56	4.32	0.73	98.00	1.000
Loss of self-consciousness	3.63	0.79	3.36	1.21	76.00	0.352
Technology acceptance	4.34	0.56	4.16	0.46	74.50	0.330
Perceived usefulness	4.50	0.55	4.21	0.71	76.00	0.343
Perceived ease of use	4.12	0.75	4.10	0.50	93.00	0.833

3. Discussion and conclusion

3.1. Discussions

This study developed an educational board game with augmented reality – *AR Chemistry history*. The game was to help learners to learn chemistry history. In specific, to know famous chemists with their respective achievements. To evaluate the game, this study adapted the flow scale for game (Kiili, 2006) and technology acceptance scale (Davis, 1989). Meanwhile, an assessment for measure students' learning performance was developed by 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 – *AR Chemistry history* as challenging, provided clear goals and feedback, having a sense of control and playable. With these positive perceptions of flow antecedents, students generally reported positive gaming experience. One thing to note is that playability was relatively lower among all flow antecedents. This finding might be attributed to the nature of educational game. Once students were aware of the learning subject, they might perceive educational game as less enjoyable, or less playable. On the other hand, loss of self-consciousness was relatively lower than other sub-dimensions of flow experience. This finding might also be attributed to the learning nature of educational game. Students might experience time distortion, fully concentration, or autotelic experience. Nonetheless, they were still in the classroom with a learning activity. Subsequent research could design an experiment to determine how the context might affect students' evaluations of an educational game. Lastly, students generally evaluated the game as easy to play (ease of use) and useful to support their learning (usefulness).

As for effectiveness of the game - *AR Chemistry history*, results showed there was a significant difference between pretest and posttest. In specific, after playing the game, students generally have higher score than they did before playing the game. This finding suggested the effectiveness of the game – *AR Chemistry history* in supporting students' to learn chemistry history.

Lastly, gender difference was regarded as an important factor in technology acceptance (Teo, 2010). Therefore, this study conducted difference test in students' learning performance, perceptions toward the game as well as their gaming experience. Results pointed out that there were no significant differences in learning performance as well as sub-dimensions of flow antecedents and flow experience. As males were generally regarded as typical gamers, our finding suggested that *AR Chemistry history* didn't lay stress on particular gender.

In conclusion, *AR Chemistry history* is a hybrid educational game that combines real-world board game and digital technology – augmented reality. This hybrid game design could take the benefit of the collaborative nature of board game. At the same time, with the support of novel technology, the boundary of physical world could be expanded and students could access rich and dynamic information while playing the game. In this preliminary study, we showed the effectiveness and students' positive evaluation and gaming experience. Nonetheless, there would be research limitations, which also shed light on the ways for future research.

3.2. Research limitation and future research

The primary research limitation is the small sample size as the preliminary stage of this studs is in. Thus, interpretation of the results of this study should be with cautious. Future research is encouraged to conduct a larger scale research and collect more evaluations from the learners or domain experts. These kinds of feedback could improve our understanding of how to integrate board game with novel information technologies, such as augmented reality in this study. Secondly, this study didn't analyze the behavioral patterns of students' interaction as analyzing the interaction of board game can be difficult and labor-intensive. Future research can use videotaping along with observers to log students' interaction when playing the game. The collected log can be subsequently used for interaction analysis to depict a clearer picture of how gaming might help students learn better (Bakeman & Gottman, 1997; Hou, 2015). Lastly, future research is also encouraged to adapt the game mechanism in this study to a new learning subject, such as introducing other historical or cultural assets. By expanding the learning subject using board game with novel information technology, we would thus able to develop a more comprehensive understanding of how gaming might contribute to better learning outcomes.

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