The Effects of Integrating Metacognitive Scaffolding in Chemistry Educational Computer Games in High School Students' Learning Outcomes and Game-based Learning

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Abstract: In the last decades, many researchers have discussed the potentials of using computer games in education. The use of educational computer games can provide more active involvement, increase motivation and satisfaction. In particular, science education is generally believed that can benefit from the educational computer games due to the ability of presenting abstract concepts. For learning basic chemistry, learners are required understand chemical reactions which are all abstract concepts to them. As a result, learners often experience difficult learning experience and lack of motivation while learning them. In this study, a chemistry educational computer game designed in our previous research was modified and adopted. The modified version of the game integrated metacognitive scaffolding design which could provide promptly assistance. A total of 171 senior high school students in Taiwan participated in this study. They were randomly assigned to control group (common version of ECG without metacognitive scaffolding design) and experimental group (the ECG with metacognitive scaffolding design). Both groups took pre-test/post-test. Meanwhile, both groups were required to take notes while using the game. The digital game-based learning (DGBL) experience of playing the game was also collected through the questionnaire and semi-structure interview. The results showed that both groups made marked progress by using the game (P<.05). Regarding the real-time hints, it is helpful for the experimental group to answer chemistry conceptual understanding questions (*P*<.05). It showed no difference of using the note-taking function, suggesting that all participants were willing to use the metacognitive scaffolding design in the game. Results also indicate that both groups had game experience. In particular, the experimental group (MS-ECG) expressed that they were not only playing a game but felt that they were learning. In sum, with metacognitive scaffolding design, it is easier for participants to use the educational computer game. Implications for educational practices are also discussed.

Keywords: Chemistry, educational computer games (ECGs), digital game-based learning (DGBL), metacognition, scaffolding, learning outcomes

1. Introduction

Fast development in information technology has radically influenced the ways of teaching and learning (Knezek & Christensen, 2002). It brought out that computer games are no longer considered merely a form of entertainment, but also a form of edutainment. In the last decades, many researchers have widely discussed the potentials of using computer games in education (e.g., Connolly et al., 2012; Gee, 2003, Kebritchi, 2010; Van Eck, 2006). As revealed in previous studies, the use of educational computer games (ECGs) can provide more active involvement, increase motivation and satisfaction (Kebritchi & Hirumi, 2008). Prensky (2001) also proposed the term "digital game-based learning" (DGBL) to describe learning with games which can be combined with curricular goals and content.

Recently, DGBL has been employed in many subjects and more and more ECGs have been implemented in different learning areas (Paraskeva, Mysirlaki, & Papagianni, 2010; Peterson, 2010). For researchers and educators in science education, it is believed that science learners could benefit from learning with ECGs. For science learners, scientific concepts can be relatively more abstract and difficult compared to other learning subjects. Therefore, science learners would sometimes show anxiety and face difficulties. To help them overcome the dilemmas, the use of ECGs to support science learning could be a vital approach. ECGs could be used to present abstract scientific concepts by using digitalized content, and thus could improve learners' motivation and help them learn science better (Shaffer et al., 2004).

In recent years, the adoption of computer games in science learning has received increasing attention from science educators and researchers (Hwang & Wu, 2012). However, in previous research, the educational computer games adopted in science education mainly concerned on interdisciplinary learning (Baytak & Land, 2011), physics or biology learning (Anderson & Barnett, 2011; Sanchez & Olivares, 2011). However, a subject like chemistry, with more abstract concepts than other subjects in science, is short of relevant educational game research. Therefore, this study aims to explore the effects of an ECG for basic chemistry learning, which is designed in our previous research (i.e. Chen & etc., 2012).

In this study, metacognitive scaffolding was designed in the ECG. Metacognition, a psychological term explains the process of learning has been extensively discussed in learning metacognition literally means cognition about cognition, or more informally, thinking about thinking (Metcalfe & Shimamura, 1994). Flavell (1976) defined metacognition as knowledge about cognition and control of cognition. It is a skill to monitor one's own thinking process such as study skills, memory capabilities. In previous studies, metacognition has been proved to become a key factor helping learners to maximize learning (Flavell, 1976; Metcalfe & Shimamura, 1994; Lysaker & etc., 2011). Scaffolding was also adopted for giving learners support during the learning process (Sawyer, 2006). The ECG used in this study was further developed with the metacognitive scaffold design aiming to help learners better acquire the abstract chemistry knowledge and maximize the learning outcomes. In sum, this study explored the effects of the ECG with metacognitive scaffolding design on junior high school students' chemistry conceptual understanding. Also, their DGBL experience was investigated.

1.1 Research questions

In this study, two versions of ECG were designed and used in this study: C-ECG (i.e., common version of ECG without metacognitive scaffold design) and MS-ECG (i.e., the ECG with metacognitive scaffold design). According to the motivation of this study, research questions are listed below.

1. Did the students learn with the MS-ECG significantly outperform those who learned with the C-ECG in their conceptual understanding regarding basic chemical reactions?
2. Did the students in the two groups (i.e., the C-ECG and the MS-ECG groups) perceive significantly different DGBL experience?

3. Methods

2.1 Participants

The participants of this study consisted of 171 junior high school students (80 males and 91 females). These students were randomly divided into two groups, the C-ECG group and the MS-ECG group. The C-ECG group (i.e., the control group in this study) consisted of 84 students while the MS-ECG group (i.e., the experiment group) consisted of 87 students.

2.2 Materials

This study adopted a chemistry educational computer game, "The adventure of Mr. Dalton", designed in our previous study (Chen & etc., 2012). There were two versions in this study. The first version was C-ECG (common ECG) which only covered junior high school basic chemistry reactions including chemical reaction, decomposition reaction, substitution reaction, and double decomposition reaction. Besides the basic chemistry reactions mentioned above, the second version has added the metacognitive scaffolding (MS-ECG). Figure 1 shows the screenshots of the ECG including the main screen, chemical reaction game, decomposition reaction game, and decomposition reaction game. Figure 2 shows the metacognitive scaffolding functions design (real-time hints and note-taking) in the second version of the game.

Figure 1: Screenshots of “The adventure of Mr. Dalton.”

Figure 2: Screenshots of metacognitive scaffolding design (left: real-time hints and right: note-taking)

2.3 Procedure and data collection

Fig 3 shows the procedure and data collection of the study. The participants enrolled in a one day chemistry course which lasted for 8 hours. The learning goal of the course was to learn four chemical reactions. The procedure of the study had pretest, introduction, learning, posttest, and questionnaire and interview sections. In the pretest section, students were given a chemistry achievement test, including multiple choices and corresponding chemistry concepts. In the introduction and learning sections, students were given a 10 minutes lecture for each chemistry reaction. They were randomly assigned to a control group (i.e. with a C-ECG) and an experiment group (i.e. with a MS-ECG). Both groups had to learn the assigned unit for 50 minutes. They all had the access to use the note-taking function in the game. After learning the 4 reactions, students were given a posttest and a DGBL experience questionnaire. A semi-structure interview was also adopted at the end.

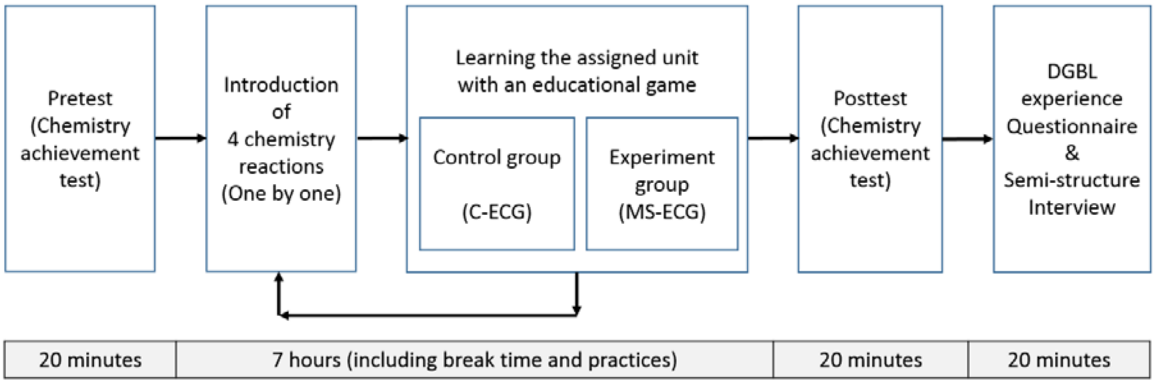

Figure 3. Procedure and data collection

3. Major findings and Conclusions

3.1 Major findings

3.1.1 The effects of using ECG with metacognitive scaffolding function in chemistry conceptual learning

The results showed that both experimental and control groups made marked progress by using the ECG (Table 1) (P<.05). Regarding the metacognitive scaffolding, it is helpful for the experimental group (with real-time hints) to answer chemistry conceptual understanding questions (Table 2) (*P*<.05).

Table 1 Students' learning outcomes of their conceptual understanding regarding basic chemical reactions (n=171)

		Pretest		Posttest	
		Mean	S.D.	Mean	S.D.
Participants	Experimental Group (MS-ECG) (n=87)	19.46	3.84	24.01	3.06
	Control Group (C-ECG) (n=84)	17.81	4.86	22.50	3.63

Table 2 The ANCOVA adjusted means and standard error of variables of students' learning outcomes and the results of ANCOVA (n=171)

		Mean (adjusted)	Standard error	*F*-value
Participants	Experimental Group (MS-ECG) (n=87)	23.79	0.34	4.64*
	Control Group (C-ECG) (n=84)	22.73	0.35	

*p<.05, **p<.01

3.1.2 The effects of using ECG with metacognitive scaffolding in students' perceived DGBL experience

Results also indicate that both groups had game experience. In particular, the experimental group expressed that they were not only playing a game but felt that they were learning (P<.05) (Table 3). In brief, the metacognition scaffolding design, it is easier for participants to use the chemistry educational computer game. From the results of semi-interview, the participants expressed that the metacognitive scaffolding design (real-time hints and note-taking) in the game can facilitate their learning. They liked the game design and especially the note-taking function which helped them to notice their learning process. In addition, the two groups showed no difference of using the note-taking function, suggesting that all participants were willing to use the metacognitive scaffolding design in the game.

Table 3 Metacognitive scaffolding design and DGBL experience *t*-test summary

		mean	S.D.	*t*
Playing games	Experimental Group (MS-ECG)	7.48	1.98	0.99
	Control Group (C-ECG)	7.45	2.05	
Learning Chemistry	Experimental Group (MS-ECG)	7.69	1.77	2.07*
	Control Group (C-ECG)	7.08	2.05	
Note-taking	Experimental Group (MS-ECG)	72.89	0.54	9.75**
	Control Group (C-ECG)	39.17	31.70	
Prompting (seconds)	Experimental Group (MS-ECG)	502.67	478.13	1.86
	Control Group (C-ECG)	380.13	379.41	

*p<.05, **p<.01

3.2 Conclusions

In conclusion, the chemistry educational computer game did help learners acquire the abstract concepts of four basic chemical reactions. With the real-time hints function, learners learned better, suggesting that the metacognitive scaffolding is crucial in the digital game-based learning design. In other words, learners need scaffolding that can provide instant assistance while using ECGs. Regarding the note-taking function, learners had the chance to monitor their own thinking process. This design may help learners to maximize their learning outcomes. From the investigation of DGBL experience, we found out that an educational game with metacognitive scaffolding design also could increase the learning experience in a game. The participants also provided some valuable suggestions for future game design. Based on the findings in this study, the "The adventure of Mr. Dalton" may be improved and applied to the teaching practices.

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