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DEVELOPMENT ARTICLE

Improving learning achievements, motivations and problem-solving skills through a peer assessment-based game development approach

Gwo-Jen Hwang · Chun-Ming Hung · Nian-Shing Chen

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Abstract In this study, a peer assessment-based game development approach is proposed for improving students' learning achievements, motivations and problem-solving skills. An experiment has been conducted to evaluate the effectiveness of the proposed approach in a science course at an elementary school. A total of 167 sixth graders participated in the experiment, 82 of whom were assigned to the experimental group and learned with the peer assessment-based game development approach, while 85 students were in the control group and learned with the conventional game development approach. From the empirical results, it was found that the proposed approach could effectively promote students' learning achievement, learning motivation, problem-solving skills, as well as their perceptions of the use of educational computer games. Moreover, it was found from the open-ended questions that most of the students perceived peer assessment-based game development as an effective learning strategy that helped them improve their deep learning status in terms of "in-depth thinking," "creativity," and "motivation."

Keywords Digital game-based learning · Peer assessment · Learning motivation · Learning achievement · Game development

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Introduction

The advancement and popularity of computer and multimedia technologies offer opportunities for educators to design and conduct more meaningful learning activities in technology-enhanced learning settings. Among various computer-supported learning approaches, digital game-based learning has been recognized as a promising approach for motivating students to learn (Kiili 2007; Prensky 2001). On the other hand, researchers have indicated that merely accessing learning content via playing games might not be sufficient to engage students in higher order thinking, such as analysis, evaluation, organization and creation. Therefore, they have suggested the "learning by doing" approach that engages students in developing educational multimedia software or educational games (Kafai et al. 1997; Prensky 2008; Robertson and Howells 2008). Hong and Liu (2003) pointed out that when participating in multimedia or game development tasks, students need to collect, analyze and organize information based on their interpretation of the learning tasks, experience of handling relevant events, and comprehension of the learning contents. It is expected that such a learning approach can engage them in continuous interactions with the learning tasks, contents and contexts, which has great potential in helping them develop problem-solving skills and construct new knowledge (Triantafyllakos et al. 2011). Several studies have reported the benefits of the game development approach in helping students to effectively think and learn (Li 2010; Kafai 2006). For example, the study of Robertson and Howells (2008) showed that the computer game development approach is able to promote students' motivation for learning and determination to reach a higher achievement standard.

However, researchers have identified the problems and difficulties of applying the game development approach (Fuhrmann et al. 2008; Moreno-Ger et al. 2008). For example, Villalta et al. (2011) regarded game-based design as a complex process in which teaching strategies, teaching methods, and availability should be taken into account. Without proper auxiliary systems, students might simply try to integrate the learning contents and games, rather than engage in in-depth thinking and reflection when designing games (Hwang et al. 2013; Triantafyllakos et al. 2011). Therefore, it is important and necessary to include learning strategies or supports for guiding students to make reflections and in-depth thinking when introducing the game development approach into the learning process.

Among various learning strategies, peer assessment has been recognized as an effective strategy for helping students make reflections and experience in-depth thinking (Bouzidi and Jaillet 2009; Chang et al. 2011; Bulu and Yildirim 2008; Boom et al. 2007). In the past decade, many educators and researchers have applied the peer assessment strategy to various fields with promising results (Tsai and Liang 2009; Wen and Tsai 2008), such as science courses in high schools (Tsivitanidou et al. 2011) and English courses in colleges (Yang and Tsai 2010). Therefore, in this study, a peer assessment-based game development learning approach is proposed. It is expected that the game development strategy can provide useful mechanisms for students to interpret the learning content and help them organize what they have learned from the textbooks and daily life experiences when dealing with relevant problems. In the meantime, it is expected that the peer assessment approach can help them make reflections with in-depth thinking. To evaluate the performance of the proposed learning approach, an experiment has been conducted to investigate the following research questions:

(1) Can the peer assessment-based game development approach improve the students' learning achievement?

(2) Can the peer assessment-based game development approach promote the students' science learning motivation?
(3) Can the peer assessment-based game development approach improve the students' problem-solving skills?
(4) What are the students' perceptions of the peer assessment-based game development approach in terms of ease of use, usefulness, and satisfaction?

Literature review

Digital game-based learning

Digital game-based learning has been recognized as a potential approach that provides students with interactive and enjoyable learning opportunities (Prensky 2001). Educators have indicated that, in educational computer games, the teaching content is presented in a vivid and interesting way, and hence attracts students to learn (Dickey 2011b; Garris et al. 2002). Ali (2009) indicated that in an educational computer game learning contents are abstracted and presented graphically, allowing pupils to comprehend the concepts to be learned and the questions to be resolved more easily.

In the past decade, many researchers have further reported the benefits of digital game-based learning with regard to enhancing students' learning motivation (Burguillo 2010; Dickey 2011a; Liu and Chu 2010; Papastergiou 2009) and fostering their independent learning capability (Tuzun et al. 2009; Yien et al. 2011). Several studies have further shown that game-based learning, as a student-centered learning tool, can better attract students than traditional teacher-centered learning can (Schmal et al. 2008). Moreover, properly integrating digital games into instructional design (Ebner and Holzinger 2007) or integrating learning theories, strategies or tools into the development of educational computer games (Kiili 2007; Sung and Hwang 2013) could promote students' learning performance. For example, Hwang et al. (2012a) developed an educational computer game based on students' learning styles and found that the students who learned with the style-fit game gained significantly better learning achievements than those who learned with the non-style-fit game.

On the other hand, educators have pointed out that designing or developing games could further enhance students' information processing ability (Hayes 2008) and cultivate their problem-solving capability (Mayer and Wittrock 2006; Mayer et al. 1986). For example, Robertson and Howells (2008) indicated that engaging children in developing computer applications could promote their higher order thinking performance. Tarkan et al. (2009) also reported that children could acquire permanently beneficial problem-solving skills through the learning process of developing computer applications. Kiili (2007) further indicated that designing or developing digital games might help students cultivate their problem-solving capabilities by situating them in the process of connecting and organizing small pieces of learning contents to a complete and global view (Mayer and Wittrock 2006). Such interpretations of the potential of game development conform to the notion of Mindtools indicated by Jonassen et al. (1998, p. 1) that "technologies should not support learning by attempting to instruct the learners, but rather should be used as knowledge construction tools that students learn with, not from." Jonassen and Carr (2000) further pointed out that using technologies as knowledge construction tools, instead of learning material presentation media, has great potential in assisting students to think and learn in a

constructive way. Therefore, it is worth conducting learning activities with a game development approach to engage them in interpreting, analyzing, synthesizing and organizing their knowledge.

Peer assessment

Topping (1998, p. 250) defined peer assessment as a learning setting in which individuals evaluate or comment on the amount, level, value, quality, or success of the products or learning outcomes of the peers who learned in a similar context; that is, it refers to learners with similar backgrounds evaluating the learning performance of others like an instructor (Falchikov and Goldfinch 2000). In this case, the learning focus of peer assessment would be transferred from teachers to students to enhance their autonomic learning capability (Yang et al. 2006). The objectives of conducting peer assessment activities are to "improve the quality of the learning process, sharpen critical abilities in students, and increase student autonomy" (Topping 1998, p. 253); that is, peers could learn from each other through the interactions. In the meantime, peer assessment could shorten the distance and enhance the trust among peers (Bulu and Yildirim 2008), and further improve their social relationships (Mak and Coniam 2008).

Researchers have further indicated that, when playing the role of a reviewer in peer-assessment activities, students are able to make reflections on the advantages and drawbacks of their learning performance, which enables them to understand themselves better than teachers, do (Chen 2010; Prins et al. 2005; Xiao and Lucking 2008).

On the other hand, feedback provided by peers could also be a good reference for making improvements (Chang and Tseng 2009; Fallows and Chandramohan 2001; Purchase 2000). Several studies have reported that learners could receive a great deal of inspiration from peer assessment results (Chen 2010), which could encourage their learning motivation (Jenkins 2004), enhance their thinking capability (Prins et al. 2005), promote their learning performance (Wang 2004; Xiao and Lucking 2008), and facilitate their self-reflection and communication capabilities (Min 2006). Differing from traditional assessment, peer assessment tends to offer formative qualitative assessment of the work (Liu et al. 2001; Towler and Broadfoot 1992). Consequently, formative qualitative assessment is utilized for peer assessment in this study.

Methods

In this study, a quasi-experiment was conducted on the "sustainable home" unit of an elementary school science course. The objective of the course unit was to educate the students about several environmental issues such as pollution, global warming, and resource shortages. Moreover, it is expected that the students would learn to treasure resources and take responsibility for protecting the living environment from pollution. The independent variables were the different modes of learning, while the dependent variables included learning achievement in science, problem-solving skills, science learning motivation, and technology acceptance.

Participants

The subjects included six classes of sixth graders from an elementary school in Taiwan. A total of 167 students participated in the study. The average age of the subjects was 12.

Three classes were assigned to be the experimental group and the other three were the control group. The experimental group, including 82 students, was guided by the peer assessment-based game development, while the control group with 85 students was guided by the game development. All of the students were taught by the same instructor who had taught that natural science course for more than ten years.

Instruments

The test sheets were developed by two experienced teachers. The pre-test aimed to evaluate the students' prior knowledge of learning the course unit "effects of global warming." It consisted of eighteen yes-or-no items, eighteen multiple-choice items and five fill-in-the-blank items, with a total score of 100. The post-test aimed to evaluate the learning achievements of the students in the learning activity. It consisted of thirty yes-or-no items and nineteen multiple-choice items for assessing the students' learning achievement in comprehending environmental pollution problems addressed in the learning content of the selected course unit. The total score of the post-test was 49.

The learning motivation scale, including a total of 34 items, was compiled by Tuan et al. (2005) and is also measured using a five-point Likert scale. The Cronbach's α is 0.93, showing high reliability of the scale.

The problem-solving conception scale, including a total of 30 items, was compiled by Pan (2001) using a five-point Likert rating scheme. The scale has been adopted and validated by several digital game-based learning studies, such as those reported by Hung et al. (2012) and Su and Hsieh (2006). The Cronbach's α value is 0.93, presenting high reliability of the scale.

The technology acceptance questionnaire originates from the questionnaire developed by Hwang et al. (2012b). It consists of 19 items with a seven-point Likert rating scheme, including 6 items for "perceived usefulness," 7 items for "perceived ease of use" and 6 items for "learning satisfaction." The Cronbach's alpha values of the three dimensions are 0.94, 0.94 and 0.93, respectively.

The open-ended questionnaire was conducted by asking the following questions: (1) What are the advantages of the learning approach in comparison with other approaches you have experienced? Why? (2) What are the disadvantages of the learning approach in comparison with other approaches you have experienced? Why? (3) Would you prefer to learn with this approach for other courses in the future? Why or why not? (4) Do you have any suggestions that might improve the learning approach?

The game development tool, Kodu, is free and programmable software developed by Microsoft. The games created by Kodu can be executed on Xbox or personal computers and operated via the Xbox controller, or the computer keyboard and mouse. Students can design their own gaming environment and scenarios, including maps, buildings, roles, dialogues, and missions via a graphical interface.

Experimental procedures

Before the experiment, the two groups of students took a month-long course about the basic knowledge of environmental education, which is a part of the natural science curriculum in elementary schools in Taiwan. Figure 1 shows the procedure of the experiment. In the beginning of the learning activity, the students took the pre-test, and completed the learning motivation and problem-solving conception scales. Following that, both groups of students were arranged to use the same tool to develop games with the same background

story, learning missions and content over a period of 10 weeks, for 50 min per week. In weeks 1–3, an orientation was given to help the students understand the learning content, the criteria of the learning tasks, and the functions of the game development tool. In weeks 4–10, the students were free to design and develop their games with the provided tool on the classroom computers. After the learning activity, the students took the post-test and completed the learning achievement, science learning motivation, and problem-solving conception scales, and the technology acceptance questionnaire.

During the learning activity in weeks 4–10, the students in the experimental group learned with the peer assessment-based game development approach. In each week, they spent 35–40 min developing the game. In the following 10–15 min, they were randomly assigned to review one game developed by their peers based on the assessment guidelines provided by the teacher.

On the other hand, those in the control group learned with the conventional game development approach; that is, the students were asked to complete the same game development task in the ten weeks. They received evaluation results and comments from the teacher in the fifth and the tenth weeks.

Peer-assessment approach for game development

In this study, the students were asked to design a game for instructing the knowledge of a sustainable town, that is an ideal and pollution-free town suitable for people to live in. The students needed to utilize their imagination as well as their interpretations of the learning content and objectives. For example, some students designed robots that helped gamers clear out pollutants from their virtual towns. Figure 2 shows a gaming scenario created by a student who presented the notion of a sustainable town by dividing the land into two parts, a non-polluted green island and a polluted island. In addition, there is an "environmental protection" lab that develops intelligent robots to collect information about the polluted area, and provides various types of tools for cleaning up the pollution. Gamers can use the robots to reduce the pollution and gain more credits.

In addition to developing the game, the students in the experimental group were randomly assigned to evaluate the games developed by their peers starting from the fourth

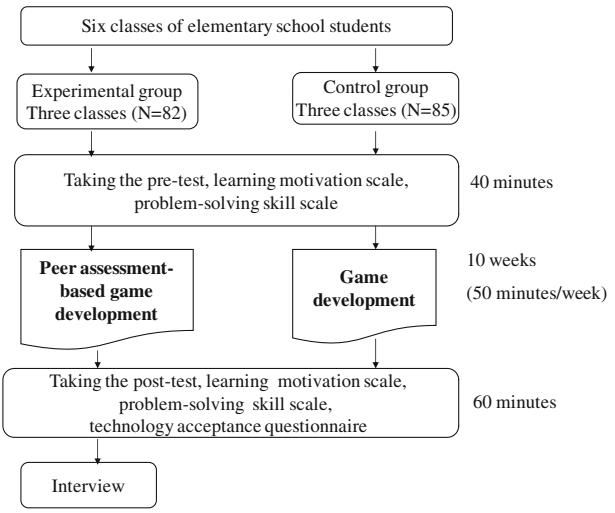

Fig. 1 Schematic diagram of the experimental design

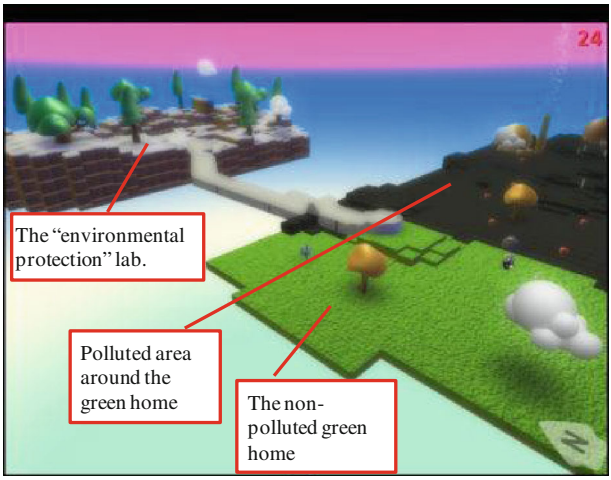

Fig. 2 Example of a "sustainable home" game developed by a student

week, one game per week, based on the assessment dimensions provided by the teacher; that is, each student received an evaluation result from others from the fourth week on. Figure 3 shows the scenarios of a student playing and assessing the sustainable home game developed by a peer. In the top right corner of Fig. 3 is a snapshot of the "environmental protection" lab, where the intelligent robots are produced. In the bottom right corner is a snapshot showing the gamer cleaning the polluted area with a robot.

To help the students provide informative feedback to their peers, assessment guidelines were developed by two teachers who had more than 10 years' experience of teaching the course. Moreover, the guidelines were revised by an experienced e-learning researcher. Table 1 shows the six evaluation criteria and the relevant descriptions for assessing the games developed by peers. As the objective of the peer assessment activity was to engage students in making reflections and sharing ideas instead of scoring the games, a three-point evaluation scheme was used for grading the criteria, where 0, 1 and 2 represent "needs major improvement," 1 "needs minor improvement," and "no further improvement is

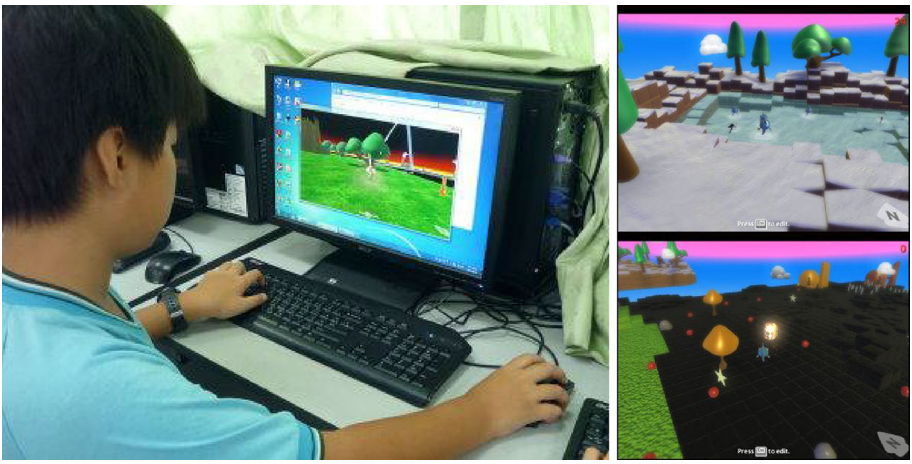

Fig. 3 A student plays and reviews the sustainable home game developed by peers

needed." When students give 0 or 1 for a criterion, they need to provide corresponding comments or suggestions. The instructions of the six criteria are given as follows:

(1) Enjoyment of the game: Is it an interesting game? Do you enjoy playing the game?
(2) Game innovation: Are there new ideas in the game design, such as creative stories, interesting characters, or new gaming rules?
(3) Appearance of the game: How good is the artwork in the game design, including the interface and the characters in the game?
(4) Completeness of the content: Does the game fully include the learning content and the learning tasks?
(5) Accuracy of the content: Are the learning content and the learning tasks of the environmental issues correctly presented in the game?
(6) Relevance to the learning objectives: Are the background story, gaming missions and the gaming scenarios relevant to the learning objectives specified by the teacher?

Data analysis

In the present study, the Statistical Package for Social Science (SPSS 18.0) was used for data analysis, and included computation of *t* test and one-way ANCOVA procedures for analyzing the data collected from the pre-test and post-test scores, and questionnaire ratings of learning motivation, and problem-solving skills. The independent variables were the two levels of learning strategy (peer assessment-based game development and conventional game development). The dependent variables were the learning achievement, learning motivation, and problem-solving skills. The alpha was established a priori at the 0.05 level, as suggested in the literature (Cohen 1988). In addition, the students' feedback to the open-ended questions was coded and analyzed to summarize their opinions and feelings.

Results

Learning achievement

The aim of this study was to examine the effectiveness of the peer assessment-based game development in terms of improving the learning achievement of the students. The mean values and standard deviations of the pre-test scores were 77.53 and 16.39 for the control group, and 73.56 and 22.10 for the experimental group. The *t*-test result shows that there was no significant difference between the two groups with $t = -1.32$ ($p > 0.05$). Consequently, it is evident that the two groups of students had equivalent prior knowledge before the learning activity.

After the learning activity, the analysis of covariance (ANCOVA) was used to test the difference between the two groups by using the pre-test scores as the covariate and the post-test scores as dependent variables. The adjusted mean value and standard error of the post-test scores were 38.03 and 0.55 for the control group, and 40.35 and 0.56 for the experimental group. According to the results ($F = 8.55$, $p < 0.01$), there was a significant difference between the two groups; the students who learned with the peer assessment-based game development showed learning achievements significantly better than those who learned with the game development (Table 2).

Table 1 The six evaluation criteria for assessing games

Dimension	Rating			
	0	1	2	Comments
Enjoyment	The game is boring	There are some interesting features in the game	The game is very interesting	
Innovation	The story and the gaming rules are not new	There are some new ideas in this game	The story and the gaming rules are innovative	
Appearance	The interface and characters in the game are not pleasing to the eye	Parts of the interface or some characters in the game are not pleasing to the eye	The interface and characters in the game look good	
Completeness	Most of the learning materials and the learning tasks are not implemented in the game	Some learning materials or learning tasks are not implemented in the game	All of the learning materials or learning tasks are included in the game	
Accuracy	Most learning materials or learning tasks in the game are incorrect	Some learning materials or learning tasks in the game are incorrect	The learning materials and learning tasks in the game are correct	
Relevance	The story, missions and scenarios of the game are irrelevant to the learning objective. The designer merely put the learning materials anywhere in the game	Parts of the story, missions or scenarios of the game are designed by taking the learning objectives into account	The story, missions or scenarios of the game match the learning objectives well	

Table 2 Descriptive data and ANCOVA of the post-test results

Group	*N*	Mean	S.D.	Adjusted mean	Std. error.	*F*
Experimental group	82	40.00	6.47	40.35	0.56	8.55**
Control group	85	38.36	5.67	38.03	0.55	

** $p < 0.01$

Learning motivation

In terms of the students' science learning motivation, the means and standard deviations of the pre-questionnaire ratings were 3.51 and 0.58 for the experimental group, and 3.61 and 0.50 for the control group. The *t*-test result showed no significant difference between the pre-questionnaire ratings of the two groups ($t = -1.27$, $p > 0.05$), showing that the two groups of students had equivalent learning motivation before participating in the learning activity.

After the learning activity, the two groups of students completed the learning motivation post-questionnaire. Table 3 shows the ANCOVA result of the post-questionnaire ratings of the two groups. The means and standard deviations of the ratings were 3.74 and 0.57 for the experimental group, and 3.55 and 0.64 for the control group. It is found that the post-questionnaire ratings of the two groups were significantly different ($F = 11.75$, $p < 0.01$). As the adjusted mean of the experimental group (3.78) was significantly higher than that of the control group (3.52), it is concluded that the peer assessment-based game development had a significant impact on improving the students' learning motivation in the natural science course.

Problem-solving skills

For the conception of problem-solving, the means and standard deviations of the pre-questionnaire ratings were 3.79 and 0.74 for the experimental group, and 3.73 and 0.64 for the control group. The *t*-test result showed no significant difference between the pre-questionnaire ratings of the two groups ($t = 0.54$, $p > 0.05$), showing that the two groups of students had equivalent problem-solving conceptions before participating in the learning activity.

After the learning activity, both groups of students completed the problem-solving conception post-questionnaire. Table 4 shows the ANCOVA result of the post-questionnaire ratings of the two groups. The means and standard deviations of the ratings were 4.14 and 0.72 for the experimental group, and 3.83 and 0.76 for the control group. It is found that the post-questionnaire ratings of the two groups were significantly different ($F = 7.61$, $p < 0.01$). As the adjusted mean of the experimental group (4.12) was significantly higher than that of the control group (3.85), it is concluded that the peer assessment-based game

Table 3 ANCOVA result of the post-test scores for learning motivation of the two groups

Group	*N*	Mean	S.D.	Adjusted mean	Std. error.	*F*
Experimental group	82	3.74	0.57	3.78	0.05	11.75**
Control group	85	3.55	0.64	3.52	0.05	

** $p < 0.01$

development had a significant impact on improving the students' problem-solving conception in the natural science course.

Learning perceptions

To better understand the students' perceptions of learning with the peer assessment-based game development approach, the students' ratings for the "perceived usefulness," "perceived ease of use" and "learning satisfaction" dimensions were collected and analyzed, as shown in Table 5.

For perceived usefulness, an independent sample t test was performed and the results show significant difference, $t = 3.68$ ($p < 0.001$), between the two groups. The means are 6.09 for the experimental group and 5.43 for the control group, showing that the students highly accepted the peer assessment-based game development as a useful learning strategy.

For perceived ease of use, an independent sample t test was carried out, with the results showing significant difference, $t = 3.01$ ($p < 0.01$), between the two groups. The means are 5.79 and 5.24, showing that the peer assessment-based game development was perceived by the students as an easy-to-follow approach.

For learning satisfaction, an independent sample t test showed significant difference, $t = 4.39$ ($p < 0.01$), between the two groups, with means of 6.08 and 5.29, showing that the peer assessment-based game development approach could better promoting the students' learning satisfaction than the conventional game development approach.

Feedback to open-ended questions

After the learning activity, all of the students in the experimental group were asked to complete an open-ended questionnaire. Although the questions are related to the advantages, disadvantages, future use, and improvement of the learning approach, most students only made comments on the aspects of advantages and future use. From the feedback of the

Table 4 ANCOVA result of the post-test scores for the problem-solving conceptions of the two groups

Group	*N*	Mean	S.D.	Adjusted mean	Std. error.	*F*
Experimental group	82	4.14	0.72	4.12	0.07	7.61**
Control group	85	3.83	0.76	3.85	0.07	

** $p < 0.01$

Table 5 *t* Test result of the technology acceptance questionnaire of the two groups

Variable	Group	*N*	Mean	SD	*t*
Perceived usefulness	Experimental group	82	6.09	0.97	3.68***
	Control group	85	5.43	1.32	
Perceived ease of use	Experimental group	82	5.79	1.12	3.01**
	Control group	85	5.24	1.23	
Learning satisfaction	Experimental group	82	6.08	0.99	4.39***
	Control group	85	5.29	1.30	

** $p < 0.01$, *** $p < 0.001$

students, it was found that they regarded the peer assessment-based game development approach as having the benefits of engaging them in "in-depth thinking" and improving their "creativity" and "learning motivation."

In terms of "in-depth thinking," 33 participants shared the similar point that developing games engaged them in thinking and exploring various possible ways of organizing the learning content. Moreover, the feedback of peers during the game development process further helped them think and learn in depth, especially for those contents that were ignored in the original game design. For example, student S60607 stated that "after reviewing the game developed by others, I found several improvements to be made in my own game. In the meantime, I was able to interpret the learning content from different aspects." S60420 indicated that "playing the games developed by others helped me find out what I had missed and possible ways to improve my work," while S60902 pointed out that "the comments given by others made me pay attention to what needed to be improved and to think about some problems I did not notice before." S60107 stated that "through the game design and peer assessment process, I learned more about how to protect the Earth, which is an issue I did not think about in depth or take seriously before. Now I know it is related to everyone." S60632 further indicated that "this way of learning is not only interesting, but also helpful to me in thinking more about the environmental problems and the possible methods of preventing the problems. Some comments from others are helpful."

In terms of "creativity," 39 participants mentioned that their creativity and confidence could be enhanced in the game development process. Moreover, they could generate more ideas via reviewing the games developed by others and receiving the comments from them. For example, S60907 mentioned that "exchanging games with others allows me to develop my game and learn the knowledge in a more creative way. Some others' ideas are interesting and worth studying." S60401 indicated that "I feel satisfied as a result of generating new ideas and designing details for developing the game." S60411 indicated that "I can find out new points about designing games during the peer-assessment process," while S60117 stated that "I have learned a lot about how to design a game and how to protect the earth. The games developed by others have inspired me." S60121 indicated that "My classmates gave me several good ideas for developing a small island based on the natural science course. After playing their games, I had better ideas about designing the island." S60916 also indicated that "I like this way of learning. I can explore and interpret the learning contents on my own and accomplish some innovative ideas." Both S60620 and S60630 mentioned that "In this learning activity, I can freely design games, which makes me more creative than other activities."

In terms of "learning motivation," 45 participants considered the learning model as attractive and interesting, just like playing games, which enabled them to learn more actively than the traditional instruction. For example, S60403 indicated that "It is more interesting than other learning activities. I can determine every detail of the game by myself. Moreover, it is interesting to play the games developed by others." S60423 stated that "learning by developing games is of course more interesting and attractive. It is exciting to know others will play the game designed by me," while S60624 indicated that "I believe that many students will be more than happy to learn in this way; that is, integrating game development activities into the course." S60932 shared the same point that "Designing games in the course is more interesting and effective. I believe that every student will like to learn in this way." S60611 mentioned that "I enjoy this learning activity. I can intangibly learn about the environmental problems with game-based design, without any pressure, and largely enhance the learning interest in this course." S60102

mentioned that "I paid more attention to the lesson than before. The class became more interesting in this way," S60409 said that "With such an interesting learning approach, I can better concentrate on the course and am full of confidence to complete the learning tasks." S60601 also indicated that "learning by developing and sharing games could induce our curiosity so as to better understand people, affairs, and objects related to nature. I really like to learn in this way."

In addition, several participants referred to the effectiveness of the peer assessment-based game development model and would like to recommend it for use in other courses, including Chinese, Social Studies, Mathematics, Physical Education, Integrative Activities, Science and Technology, and Arts and Humanities. For example, S60407 stated that "The peer assessment-based game development activity helps me concentrate more and achieve better learning results than before." S60419 indicated that "With this learning approach, it becomes easier for me to absorb new knowledge via engaging in the game designing process. I think it is better than the traditional instruction." S60109 hoped to apply it to Social Studies for creating his imaginary world, while S60407 would like to apply it to Mathematics and Chinese by designing two islands where one was the main character's island and the other was a challenging Mathematics island. He believed that such design of games would let students enjoy Mathematics lessons. S60601 hoped to apply the learning approach to Mathematics, which he was not interested in. S60612 hoped to integrate physical games into the design of physical education, while S606201 hoped to apply it to Chinese so that he could play Word Chain with Chinese idioms, and S60625 would like to apply the design and ideas to Arts and Humanities.

Discussion and conclusions

In this paper, a peer assessment-based game development approach was proposed. From the experimental results, it was found that the proposed approach improved the students' learning achievements, motivations and problem-solving skills in comparison with the conventional game development approach. Moreover, most of the students highly recognized that the peer assessment-based game development was helpful to them in terms of improving their "in-depth thinking," "creativity" and "learning motivation."

Regarding learning achievements, several previous studies that conducted peer assessment activities in in-class learning (Tsivitanidou et al. 2011) or web-based learning, (Yang and Tsai 2010) have reported the potential of peer assessment in helping students make reflections, which could further help them find out their learning problems and the possible ways of dealing with the problems (Merrill and Gibert 2008). The students' feedback to the open-ended questions also shows that the proposed approach has encouraged the students to think deeply about the game development task and the learning content from different aspects when reviewing peers' work. Furthermore, it can be seen that the total time that the teacher spent on providing feedback to the control group students was longer than the time for students to provide peer feedback in the experimental group. Moreover, when the teacher was providing feedback to one student in the control group, all other students received the feedback, too. From this aspect, the students in the control groups received more feedback than those in the experimental group. In addition, it should be noted that the peers' feedback is not always "good" or "correct" since they are just learners of the course content. On the other hand, the teacher can provide higher quality feedback. That is, the better learning performance of the experimental group was not due to the provision of more feedback or better feedback from peers; rather, the good

performance could be due to the self-reflections made by the students when reviewing peers' work. Several studies have revealed that serving as a reviewer or tutor not only fosters students in making reflections, but also engages them in higher order thinking (Prins et al. 2005; Xiao and Lucking 2008). Many researchers have further indicated that making reflections can benefit students in terms of improving their learning performance (Chen et al. 2009; Hsieh et al. 2011). Therefore, serving as a reviewer in the peer-assessment activity of this study could be the reason why the students' problem-solving skills and learning achievements were significantly improved.

It is also interesting to find that, although both groups of students were asked to develop games, their learning motivations were quite different after the learning activity. From the experimental results and the students' feedback to the open-ended questions, it is apparent that the students were happy to have their games played and reviewed by their peers. On the other hand, they also liked to play and review the games developed by others. That is, peer assessment is a promising strategy for engaging students in enjoyable and effective game development tasks. These experiences can serve as a valuable reference for researchers who are interested in utilizing the peer assessment strategy in game-based learning activities or investigating the effects of game development-based learning activities.

Although the present study showed some promising results of the peer assessment-based game development approach, it has some limitations. First, the interactive behaviors among the students were not recorded and analyzed, meaning that some interesting interactive and learning patterns could have been ignored. Second, the students' innovation and creative performance, which is an important competence emphasized by educators, was not taken into account in this study. Third, personal factors, which might be relevant to individuals' knowledge levels, learning habits, or cognitive process, were not measured and analyzed in this study. Accordingly, several relevant research topics, which are worth further investigation in the future, are suggested as follows:

(1) Analyze peer assessment behaviors: It would be interesting to analyze and categorize students' peer-assessment behaviors and investigate the relationships between different types of behaviors and the learning performance of the students.
(2) Evaluate the students' innovation and creative performance: In peer assessment-based game development activities, students play the roles of reviewers and game designers. It would be interesting to investigate whether the roles they play and the work they are engaged can improve their innovation and creative skills.
(3) Investigate effects of personal factors on students' learning performance in peer assessment-based game development activities: Students with different personal factors, such as learning styles, cognitive styles and knowledge levels, might have different learning performances; therefore, it is worth investigating the effects of these factors on students' learning performance in peer assessment-based game development activities.
(4) Conduct collaborative game development activities: In addition to peer assessment, collaboration between peers is an alternative way of promoting peer interactions and knowledge sharing. It would therefore be interesting to investigate the effects of the collaborative game development approach on students' learning performance.

In addition to investigating those research issues, we are planning to employ the proposed approach in other courses, such as social science, mathematics and language learning. Moreover, several human factors, such as knowledge levels, learning styles and

personal preferences, will be taken into account when analyzing the learning performance and perceptions of the students.

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