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A collaborative game-based learning approach to improving students' learning performance in science courses

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A B S T R A C T

In this study, a collaborative game-based learning environment is developed by integrating a grid-based Mindtool to facilitate the students to share and organize what they have learned during the game-playing process. To evaluate the effectiveness of the proposed approach, an experiment has been conducted in an elementary school natural science course to examine the students' performance in terms of their learning attitudes, learning motivation, self-efficacy and learning achievements. From the experimental results, it is found that the Mindtool-integrated collaborative educational game not only benefits the students in promoting their learning attitudes and learning motivation, but also improves their learning achievement and self-efficacy owing to the provision of the knowledge organizing and sharing facility embedded in the collaborative gaming environment.

1. Introduction

In recent years, various issues of educational computer games have been widely discussed owing to the rapid advancement of computer and multimedia technologies (Hwang & Wu, 2012). Researchers have indicated that educational computer games could be an effective way of providing a more interesting learning environment for acquiring knowledge (Cagiltay, 2007; Papastergiou, 2009; Tüzün, Yılmaz-Soylu, Karakus, Inal, & Kızılkaya, 2009). Several studies have reported that educational computer games could enhance students' learning interest and motivation (Burguillo, 2010; Dickey, 2011; Ebner & Holzinger, 2007; Harris & Reid, 2005; Liu & Chu, 2010). Hwang, Sung, Hung, Yang, and Huang (2012) further indicated that well-designed educational computer games might have great potential for improving the learning achievements of students.

Although computer educational games seem to be a promising approach, researchers have pointed out that, without proper design, negative impacts of employing digital game-based learning approaches could occur, such as poor learning outcomes and increasing the players' self-alienating behaviors (Hong, Cheng, Hwang, Lee, & Chang, 2009; Hwang, Sung, Hung, & Huang, 2012; Provenzo, 1992). Kickmeier-Rust and Albert (2010) indicated that one great challenge of developing educational computer games is to provide support and to guide the learners while keeping the balance between learning and gaming, and between challenge and individual learners' abilities. The study of Charsky and Ressler (2011) further confirmed this point via conducting a learning activity using a computer game. Therefore, it is important to provide suitable learning support when employing computer games in education.

Among various computer-supported learning tools, Mindtools have been recognized as being an effective tool for helping students interpret and organize their knowledge (Chu, Hwang, Tsai, & Tseng, 2010; Peng et al., 2009). Jonassen (2000) has indicated that Mindtools are computer applications that engage students in critical thinking about the content they are studying when used for representing knowledge. Hwang, Sung, Hung, Yang, et al. (2012) have further reported that grid-based Mindtools are suitable for helping students organize knowledge for identifying and differentiating a set of learning targets.

In this study, a collaborative educational computer game is developed based on a grid-based Mindtool which aims to guide students to organize knowledge collaboratively for differentiating a set of target plants for the subject unit "Identifying the plants on the school campus"

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of an elementary school natural science course. An experiment has been conducted to evaluate the effectiveness of the proposed approach via investigating the following research questions:

1. Do the students who learn with the Mindtool-assisted collaborative game-based learning approach show better learning achievements than those who learn with a conventional collaborative learning approach and those who learn with an individual Mindtool-assisted game-based learning approach?
2. Do the students who learn with the Mindtool-assisted collaborative game-based learning approach show better learning attitudes toward science than those who learn with a conventional collaborative learning approach and those who learn with an individual Mindtool-assisted game-based learning approach?
3. Do the students who learn with the Mindtool-assisted collaborative game-based learning approach show higher learning motivation than those who learn with a conventional collaborative learning approach and those who learn with an individual Mindtool-assisted game-based learning approach?
4. Do the students who learn with the Mindtool-assisted collaborative game-based learning approach show higher efficacy of group learning than those who learn with a conventional collaborative learning approach and those who learn with an individual Mindtool-assisted game-based learning approach?

2. Literature review

2.1. Educational computer games

Games have been defined by researchers as “an immersive, voluntary and enjoyable activity in which a challenging goal is pursued according to agreed-upon rules” (Kinzie & Joseph, 2008). Prensky (2001) pointed out that combining games with educational objectives could not only trigger students’ learning motivation, but also provide them with interactive learning opportunities. Kickmeier-Rust and Albert (2010) further indicated that the nature of utilizing educational computer games is that playing games is one of the most natural forms of learning. Children learn to talk by playing with sounds, and they learn collaboration and strategic thinking when playing games. In the past decade, many studies concerning educational computer games have been conducted. For example, Burguillo (2010) presented a framework for implementing competition-based learning to motivate students and increase their learning performance. In the meantime, Watson, Mong, and Harris (2010) presented the in-class use of an educational game-based learning in a high school history class and found that the use of the game-based learning approach resulted in a shift from a traditional teacher-centered learning environment to a student-centered environment in which the students were much more active and engaged.

In addition, several studies have shown that educational computer games can also enhance the learning motivation and learning performance of students (Ebner & Holzinger, 2007; Harris & Reid, 2005; Papastergiou, 2009; Wang & Chen, 2010). For example, Huang, Huang, and Tschopp (2010) surveyed 264 undergraduate students after playing an online game, and found a potential relationship between intrinsic motives and extrinsic rewards. Inal and Cagiltay (2007) further investigated the flow experiences of children in an interactive social game environment, and found that the challenge and complexity elements of the games had a greater effect on the children’s flow experiences than did clear feedback. Dickey’s study (2011) investigated the impact of narrative design in a game-based learning environment and found that intrinsic motivation, curiosity and plausibility all benefited from the game-like environment. In the meantime, the study of Brom, Preuss, and Klement (2011) showed that the game-playing approach had a significantly better effect on students’ knowledge retention and perceived educational value than the traditional instruction. Recently, Chang, Wu, Weng, and Sung (2012) found that students revealed more flow experience and better problem-solving performance with a game-based learning approach in comparison with the traditional instruction.

Bourgonjon, Valcke, Soetaert, De Wever, and Schellens (2011) further developed and validated a path model to explain and predict parental acceptance of video games in the classroom. It was found that 59% of the variance in parents’ preference for video games could be explained by the model comprising hypotheses about learning opportunities, subjective norms, perceived negative effects of gaming, experience with video games, personal innovativeness, and gender. It can be seen that educational computer games are considered as a potential way of learning, and the relevant issues have attracted much attention from researchers.

2.2. Collaborative learning

Learning collaboratively not only enables students to learn the spirit of respecting others, but also facilitates their learning performance (Kuo, Hwang, & Lee, 2012; Schellens & Valcke, 2005). Through the process of collaboration and brainstorming in a collaborative learning group, students are able to efficiently receive a large amount of information, which is helpful to them in generating new ideas for completing learning tasks (Lipponen, 2002). Consequently, researchers have indicated that attention should be paid not only to the use of new technological solutions, but also to collaborative learning methods in order to develop students’ skills for their future careers (Hamalainen, 2008).

In the past decade, many studies concerning collaborative educational computer games have been conducted. For example, Delucia, Francese, Passero, and Tortora (2009) conducted an experiment involving university students aimed at evaluating Second Life synchronous distance lectures in the proposed learning environment. The results revealed that the virtual environment successfully supported synchronous communication and social interactions, while the tutors and the teacher noted that the students were really motivated. Huang, Liu and Wu (2011) found that the learning achievements supported by cooperative and collaborative online game-type computer assisted learning systems were significantly better than those of conventional approaches. Hummel et al. (2011) examined how learning outcomes from playing educational computer games could be enhanced by including scripted collaboration. The experimental result showed that the collaborative learning approach significantly enhanced the quality of the learning outcomes. Meanwhile, Sánchez and Olivares (2011) presented the results of conducting a series of learning activities with the mobile game-based learning approach for fostering the problem-solving and collaborative skills of students. The experimental results showed that the approach significantly contributed to the learning improvements of the students.

Furthermore, researchers have also attempted to propose guidelines or frameworks for designing collaborative games. For example, Villalta et al. (2011) proposed guidelines for developing Classroom Multiplayer Presential Games (CMPG), which are conducted on a screen projected at the front of the classroom through which the students interact with the virtual world and among themselves in the shared space. In a CMPG activity, individual players have their own input devices for controlling the representative characters within the game. In the meantime, Triantafyllakos, Palaigeorgiou, and Tsoukalas (2011) presented a framework for conducting game design activities that engage students in designing educational computer games collaboratively. They expected that the proposed framework could simplify the development and employment of effective and efficient collaborative game design sessions in educational settings. Hwang, Wu, and Chen (2012) further reported that promoting interactions among students during the gaming process is helpful to students in improving their learning performance. From these studies, it can be concluded that collaborative learning has been recognized by researchers as one of the potential approaches for developing educational computer games.

3. Collaborative educational computer game with a grid-based Mindtool

Jonassen (2000) indicated that the process of developing expert systems (i.e., intelligent computer programs that use knowledge from domain experts and inference procedures to simulate the decision-making behaviors of domain experts), results in deep understanding owing to the provision of an intellectual environment that demands the refinement of domain knowledge. Such a knowledge acquisition and organization process has been called knowledge engineering (Chu & Hwang, 2008). That is, involving students in the knowledge engineering process helps them make explicit their own interpretations and reasoning, and further engages them in higher order thinking.

In this study, a well-known knowledge engineering approach, the repertory grid method, is adopted to serve as a collaborative knowledge construction tool of a game-based learning activity. The repertory grid method originated from the Personal Construct Theory proposed by Kelly (1955). This method has been recognized by various studies as being an effective tool for helping domain experts organize the differentiating knowledge for developing expert systems (Edwards, McDonald, & Young, 2009). Recently, it has been adopted by several studies as a learning tool for helping students collect and organize the knowledge related to the learning targets (Chu, Hwang, & Tsai, 2010; Hwang, Chu, Lin, & Tsai, 2011).

A repertory grid can be viewed as a matrix, in which the columns represent elements (i.e., concepts to be learned or learning targets to be identified) and the rows represent the constructs for identifying the elements. A construct consists of a trait and the opposite of that trait. A 5-scale rating mechanism is often employed for representing the relationships between the elements and the constructs, where “1” represents that “the element is highly inclined to the trait,” while “5” represents “highly inclined to the opposite” (Chu et al., 2010). An illustrative example of a repertory grid for identifying a set of learning targets (i.e., the plants on the school campus of an elementary school natural science course) is given in Table 1.

In this study, a Repertory grid-Assisted Collaborative Educational Game (RACEG) is developed, as shown in Fig. 1. It consists of two subsystems, that is, the collaborative educational computer game developed with RPG Maker, a role-playing game-development tool published by Enterbrain Incorporation, and the collaborative knowledge construction system developed with Google Sites, which is a structured collaborative system-development tool offered by Google. The former contains a learning material module and a learning-guiding module. The latter is a web-based collaborative learning environment that assists students in organizing knowledge in the form of a repertory grid based on what they have learned from the game and their discussions with peers.

Fig. 2 shows the collaborative educational computer game-based learning environment of this study. The role-playing game is concerned with a story of an ancient kingdom in which the people are infected by poisoned water in a river. After studying some ancient medical books, the king finds that several plants might be the key to curing his people. Therefore, he decides to look for the plants, which are in fact the plants to be identified and differentiated in the selected subject unit of the elementary school natural science course. Such an approach has been adopted by several studies in developing computer education games for natural science courses (Brom et al., 2011; Hwang, Sung, Hung, & Huang, 2012).

During the learning process, the students play the role of the king to find the target plants. They need to find the detailed information in the game during the game-playing process. In addition, there are several barriers that prevent the students from taking the plants, including a maze, a misty forest, and tests set by fairies to ensure that the king has the knowledge of using the plants to help his people. Once the players collect all of the data about a plant and pass the relevant tests set by the fairies, they are allowed to proceed to the next level of the game. If the students fail to pass the tests, the fairy will give them some hints or illustrative examples. Following the storyline of the game, the students can collect the information needed to develop their repertory grid collaboratively via discussing with their peers, and modify the repertory grid via a shared interface.

4. Experiment design

To evaluate the effectiveness of the innovative approach, an experiment was conducted on an elementary school natural science course to compare the learning achievements and the attitudes of the students who participated in the learning activity with different learning

Table 1
Illustrative example of a repertory grid.

Construct	Trait	Elements			Opposite
		Mexican Petunia	Benjamin fig	Pachira nut	
Leaf edge	Neat	3	1	1	Jagged
Leaf apex	Sharp	1	3	2	Round
Leaf vein Branches	Few	2	2	3	Many
Texture	Coarse	3	1	5	Smooth

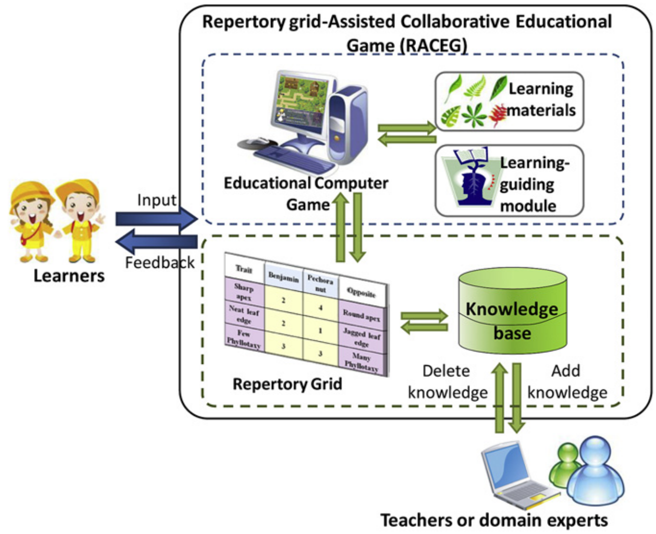

Fig. 1. The structure of the collaborative game system.

strategies. The selected subject unit was "Identifying the plants on the school campus." The aim of the subject unit was to foster students' ability of identifying and differentiating the plants based on their features.

4.1. Participants

The participants of the experiment were three classes of sixth graders of an elementary school in southern Taiwan. A total of ninety-three students participated in this study. One class was assigned to be the experimental group, one class was control group A and the other was control group B. Each of the three groups included thirty-one students. In order to avoid the influence of different instructors on the experimental results, the three classes were taught by the same instructor.

The students in the experimental group learned with the collaborative educational computer game with the repertory grid approach; that is, they played the role-playing game in the mode of three or four students as a team to complete the learning tasks embedded in the story of the game as well as having to complete the repertory grid for organizing the learning content.

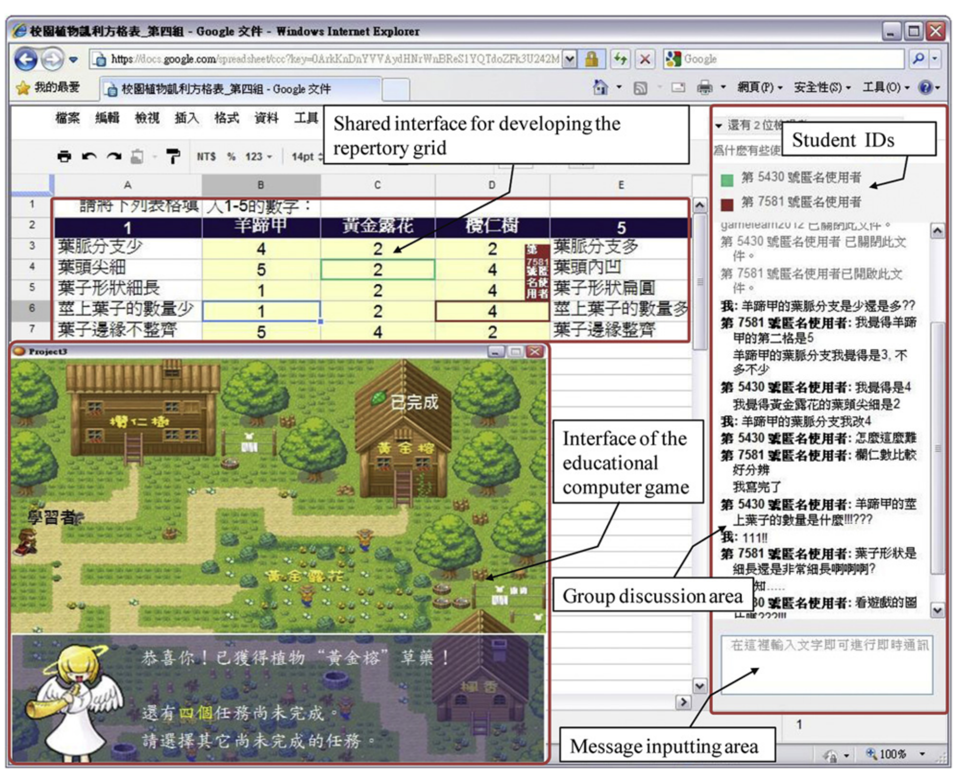

Fig. 2. Collaborative repertory grid-based educational computer game.

The students in control group A learned with conventional collaborative game-based learning without using repertory grids; that is, they played the game in the mode of three or four students as a team to complete the learning tasks embedded in the story of the game and the learning worksheets. On the other hand, those in control group B learned with the educational computer game individually and developed their own repertory grids.

4.2. Experimental process

Fig. 3 shows the experimental design of this study. The experiment was conducted on the "knowing campus plants" unit of an elementary school natural science course, which aims to teach the students the compositions of the plants (e.g., roots, stems and leaves) and their main functions, and further foster their ability of identifying and differentiating different types of plants in the field based on those characteristics.

Before the experiment, the three groups of students took a two-week course about the basic knowledge of the plants, which is a part of their natural science course. At the beginning of the learning activity, the students completed a pre-questionnaire of learning attitudes, learning motivation and self-efficacy of group learning for science; moreover, a pre-test for evaluating their basic knowledge about the plants was also administered. Following that, the students in the experimental group learned with the collaborative educational computer game with the repertory grid approach; on the other hand, those in control group A learned with conventional collaborative game-based learning; for control group B, the educational computer game with repertory grid approach was used, but the students were required to work individually. The time for the students to complete their learning tasks was one hundred minutes. After the learning activity, the students took the post-test and the post-questionnaire for measuring their learning achievements and any change in their learning attitudes, learning motivation and self-efficacy of group learning. In addition, the students of the three groups filled out the questionnaire of cognitive load for the educational computer game.

4.3. Measuring tools

In this study, the measuring tools were a pre-test, a post-test, the questionnaire for measuring the learning attitudes, motivation and self-efficacy of the group regarding the natural science course, and the questionnaire for surveying the cognitive load of using the collaborative educational computer game and repertory grid system.

Both the pre-test and the post-test were designed by two experienced teachers who had taught the natural science course for a number of years. Such an approach for developing achievement tests has been used by several previous studies (Hwang & Chang, 2011; Wu, Hwang, Su, & Huang, 2012; Yang & Wu, 2011). The pre-test aimed to ensure that the three groups of students had an equivalent basic prior knowledge of the natural science course content. It consisted of forty multiple-choice items with a perfect score of 100 for evaluating the students' prior knowledge of plants. The post-test contained twenty multiple-choice items for assessing the students' knowledge of identifying and differentiating the plants on the school campus, such as "What is the most significant characteristic for differentiating Indian Almond, Orchid Tree and Golden Dewdrop?" The perfect score of the post-test was 100. Its Cronbach's alpha value was 0.65, showing acceptable reliability in internal consistency.

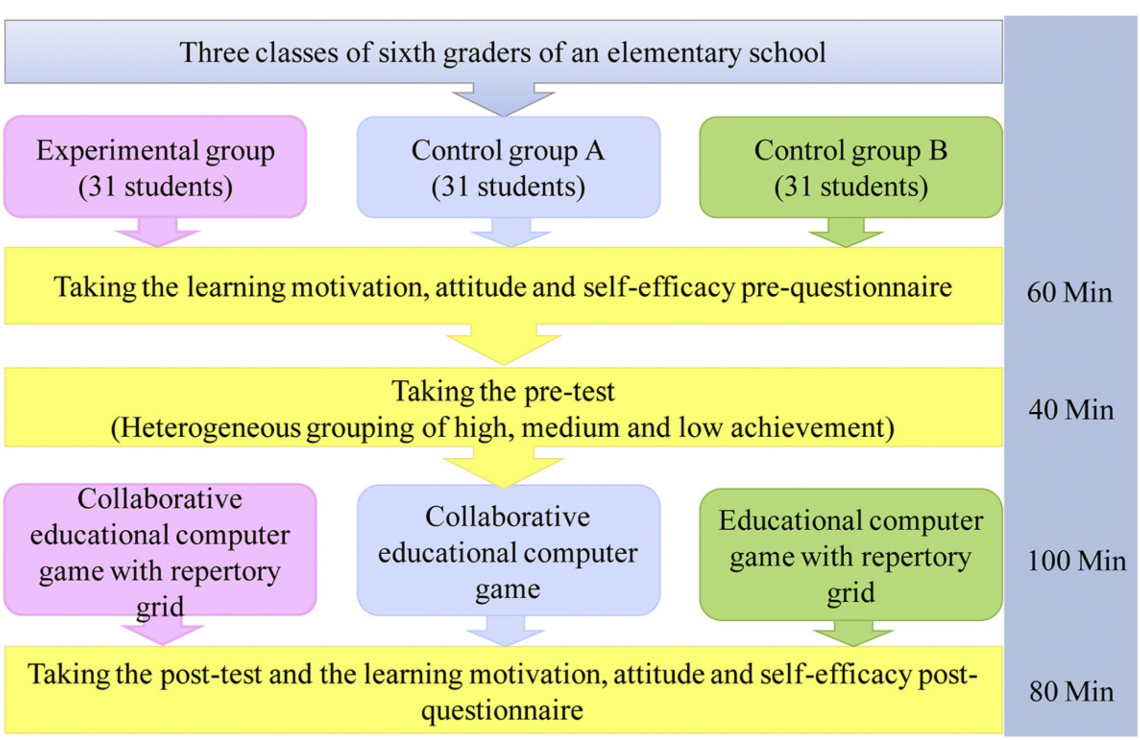

Fig. 3. Experimental design for the learning activities.

The learning attitude questionnaire was modified from that developed by Hwang and Chang (2011). It consisted of 7 items on a five-point Likert scale, where "5" represented "strongly agree" and "1" represented "strongly disagree." The Cronbach's alpha value of the learning attitude questionnaire was 0.85, showing good reliability in internal consistency.

The questionnaire of learning motivation was modified from the measure developed by Pintrich and DeGroot (1990). It consisted of ten items (e.g., "Compared with other students in this class I expect to do well" and "It is important for me to learn what is being taught in this class") with a seven-point rating scheme. The Cronbach's alpha value of the questionnaire was 0.86, showing good reliability in internal consistency.

The self-efficacy questionnaire contains seven items using a five-point Likert scale ranging from 1 to 5. The self-efficacy of group learning examines the eagerness of the students to participate in group learning activities, including raising questions or opinions. It was modified from the measure developed by Hwang, Shi, and Chu (2011). The Cronbach's alpha value of the questionnaire is 0.86.

5. Experimental results

In the present study, the collected data were first examined by descriptive statistics to explore the group means, standard deviations and numbers. Then, one-directional analysis of variance (ANOVA) was performed on the pre-test grades. Analysis of covariance (ANCOVA) was also conducted to examine the effects of using the proposed approach on students' science learning achievements and on their perceptions of the learning activity. In addition, the learning attitudes, learning motivation, self-efficacy of group learning and cognitive load of the students were analyzed.

5.1. Learning achievement

Before participating in the learning activity, the students took a pretest to evaluate their basic knowledge of the science course content. A one-way ANOVA was performed on the pre-test results, which showed non-significant difference of the independent variable and the covariate of the learning achievement test ($F = 1.098$, $p > .05$) among the pretest results of the students in the three groups. Consequently, it is concluded that the three groups had equivalent prior knowledge before the learning activity.

This study conducted an analysis of covariance (ANCOVA) using the students' pre-test scores as the covariate to exclude the impact of the pre-test on their science learning. It was assumed that the regression coefficients between groups were homogeneous (Keppel & Wickens, 2004). After conducting the learning activity, ANCOVA was performed on the post-test results, in which the pretest was the covariant, the post-test results were the dependent variable and the "different game-based learning strategies (three groups)" were the control variable, to examine the relationships among the post-test results of the three groups. As shown in Table 2, the ANCOVA result shows that the variance between the three groups is significant ($F = 11.795$, $p < .001$) after the impact of the pre-test scores on the post-test was excluded. In other words, the post-test scores were significantly different due to the different experimental learning processes. Furthermore, post hoc analysis was performed to examine specific differences in achievement between the experimental groups. An LSD test revealed that the experimental group scores were significantly higher than those of control group A, comparing the adjusted mean of 59.37 for the experimental group with the control group A score of 41.56 ($p < .001$). Additionally, the experimental group scores were also significantly higher than those of control group B which scored 42.5 ($p < .001$).

Therefore, the learning achievements of the experimental group students were significantly better than those of the students in control groups A and B, whereas non-significant difference was revealed between the students in the two control groups. Accordingly, it was found that the collaborative educational computer game with the repertory grid approach was helpful to the students in improving their learning achievements in comparison with the conventional collaborative game-based learning without using repertory grids and the individual game-based learning approach with repertory grids.

5.2. Learning attitudes toward science

This study performed ANCOVA using the learning attitude scale of the students toward science as the covariate to exclude the impact of the learning attitude pre-questionnaire scores. According to the non-significant interaction of the independent variable and the covariate of the learning attitude scale ($F = 2.40$, $p > .05$), the use of ANCOVA is appropriate.

As shown in Table 3, the ANCOVA result shows that the learning attitudes of the three groups were significantly different ($F = 3.90$, $p < .05$) after the impact of the learning attitude pre-questionnaire scores was excluded. Furthermore, post hoc analysis was performed to examine specific differences in achievement between the experimental groups. An LSD test revealed that the experimental group scores were significantly higher than those of control group A, comparing the adjusted mean of 4.54 for the experimental group with the control group A score of 4.32 ($p < .01$). Additionally, the experimental group scores were also significantly higher than those of control group B which scored 4.38 ($p < .05$). In other words, the post-questionnaire scores were significantly different due to the different learning approaches. The significantly better score of the experimental group than that of control groups A and B suggests that the collaborative educational computer game with repertory grid approach has improved the learning attitudes of students toward science.

Table 2
Descriptive data and the ANCOVA result of the learning achievement post-test for the three groups.

Variable	Group	*N*	Mean	S.D.	Adjusted mean	*F* (2,89)	Post hoc
Post-test	(1) Experimental group	31	57.26	16.87	59.37	11.795[a]	(1) > (2)
	(2) Control group A	31	43.07	14.24	41.56		(1) > (3)
	(3) Control group B	31	43.07	14.47	42.50		

[a] $p < .001$.

Table 3
The ANCOVA result of the learning attitudes post-questionnaire for the three groups.

Variable	Group	*N*	Mean	S.D	Adjusted mean	*F* (2,89)	Post hoc
Attitudes toward science learning	(1) Experimental group	31	4.62	0.38	4.54	3.90[a]	(1) > (2)
	(2) Control group A	31	4.24	0.62	4.32		(1) > (3)
	(3) Control group B	31	4.40	0.59	4.38		

[a] $p < .05$.

5.3. Learning motivation in science courses

After the learning activity, the three groups of students took the learning motivation post-questionnaire. Table 4 shows the ANCOVA result of the post-questionnaire ratings of the experimental group, and control groups A and B. It is found that the post-questionnaire ratings of the three groups were significantly different ($F = 4.84$, $p < .05$). Furthermore, post hoc analysis was performed to examine specific differences in achievement between the experimental groups. An LSD test revealed that the experimental group scores were significantly higher than those of control group A, comparing the adjusted mean of 6.13 for the experimental group with the control group A score of only 5.61 ($p < .001$). Additionally, the experimental group scores were also significantly higher than those of control group B which scored 5.81 ($p < .05$). It is therefore concluded that the collaborative game-based learning with repertory grid approach had a significant impact on improving the students' learning motivation in the natural science course.

5.4. Analysis of self-efficacy of group learning

The self-efficacy of group learning questionnaire is presented with a five-point Likert scale where "5" represents strong agreement or positive feedback and "1" represents high disagreement or negative feedback. Table 5 shows the paired-samples *t*-test of the questionnaire results before and after learning for the experimental group, and control groups A and B. For the students in the experimental group, the self-efficacy of group learning attained significant improvements. That is, the collaborative educational computer game with the repertory grid enhanced the students' self-efficacy of using computers to learn, and their confidence in and expectations of learning collaboratively with their peers. On the other hand, for the students in control groups A and B, there was non-significant improvement after the learning activity.

It should be noted that although the students in control group A played the educational computer game collaboratively, their collaboration mainly focused on how to complete the game missions instead of organizing the knowledge obtained from the game. This could be the reason why their self-efficacy of group learning did not significantly improve after the learning activity. On the other hand, the students in control group B played the game and developed the repertory grids individually; that is, they did not engage in any collaboration activity during the learning process, which could be the reason why their self-efficacy in expectations of using technology to learn and of cooperating with their peers was not improved.

6. Discussion and conclusions

In this study, a collaborative game-based learning environment was developed by integrating a grid-based Mindtool originating from a knowledge engineering method, which is quite different from most studies, such as those reported by Cagiltay (2007), Papastergiou (2009) or Tüzün et al. (2009) that aimed to provide more interesting learning environments for students to acquire knowledge, or those that mainly employ digital games as an approach for promoting students' learning motivation (Burguillo, 2010; Dickey, 2011; Ebner & Holzinger, 2007; Harris & Reid, 2005; Liu & Chu, 2010). Instead, this study aims to improve the learning performances of students from both the aspects of cognition (e.g., learning achievement) and affection (e.g., learning motivation and attitudes) by gaining benefits from both the Mindtool and the digital game.

Charsky and Ressler (2011) and Hwang, Sung, Hung, Yang, et al. (2012) have further pointed out the problems encountered as well as the potential benefits of integrating Mindtools with digital games. Although Mindtools could help students organize knowledge and engage them in higher order thinking, some students might have difficulty learning with Mindtools on their own; moreover, without proper integration, the use of Mindtools might become an interference rather than a learning support in the game-based learning process (Charsky & Ressler, 2011). To cope with this problem, this study integrated the knowledge construction process using the grid-based Mindtool into the game missions in a collaborative gaming environment.

From the discourses of the students during the collaborative learning process, it is found that the students in the experimental group tended to pay more attention to the development of the repertory grid, while those in Control Group A spent more time discussing how to complete the tasks in the game. For example, one of the experimental group students asked, "In comparison with Mexican Petunia, is the leaf edge of Pachira nut more neat or jagged?" On the other hand, one of the control group students asked, "I think the number of leaf vein branches of Benjamin fig is large, so why did the fairy not let me pass?" Consequently, it is concluded that the more time the students spent

Table 4
Descriptive data and the ANCOVA result of the learning motivation post-questionnaire for the three groups.

Variable	Group	*N*	Mean	S.D.	Adjusted mean	*F* (2,89)	Post hoc
Attitudes toward science learning	(1) Experimental group	31	6.13	0.69	6.13	4.84[a]	(1) > (2)
	(2) Control group A	31	5.53	1.14	5.61		(1) > (3)
	(3) Control group B	31	5.89	1.10	5.81		

[a] $p < .05$.

Table 5
Paired-samples *t*-test result of the self-efficacy of group learning for the three groups.

	N	M (SD) (before learning)	M (SD) (after learning)	*t*
Experimental Group	31	3.64 (0.58)	3.97 (0.50)	−4.08[a]
Control Group A	31	3.91 (0.47)	4.00 (0.51)	−1.04
Control Group B	31	4.03 (0.72)	4.10 (0.79)	−1.25

[a] $p < .001$.

on discussing and organizing the knowledge they acquired, the better learning performance they revealed. Such a finding also conforms to what has been reported by some previous studies, namely that computerized Mindtools are able to help learners organize what they have learned and hence can assist them in improving their learning performance (Chu et al., 2010; Jonassen, Peck, & Wilson, 1999).

In addition, several experimental group students shared the same feeling that the shared repertory grid provided them with a clear objective to discuss, which made them feel more challenged and interested in playing the game. This might explain why the students in the experimental group revealed significantly better learning attitudes toward science and higher learning motivation in the science course than those in the two control groups. Most of them also indicated that the use of the shared repertory grid was helpful to them in exchanging information in an efficient way. This further explained why their self-efficacy of group learning was significantly improved.

Although the proposed game-based learning approach has shown significant effectiveness in improving the students' learning performance, some limitations of using this approach need to be noted. First, researchers have indicated that the grid-based method is more suitable for organizing the knowledge for differentiating a set of learning targets that share some common features; that is, to deal with the learning content related to ill-structured knowledge, graphical Mindtools such as concept maps might be a better choice. Second, it is time consuming to develop such collaborative educational computer games for other applications. To cope with these problems, we are trying to develop other Mindtool-integrated computer educational games. Moreover, we plan to develop a template for this type of collaborative educational computer game so that teachers can use it to develop new games for other applications in the future. In the meantime, we also plan to apply the proposed approach to the learning activities of other science and social science courses to investigate more research issues, such as the effect of students' learning styles and achievement levels on their performance.

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