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The Comparison of Solitary and Collaborative Modes of Game-based Learning on Students' Science Learning and Motivation

Ching-Huei Chen*, Kuan-Chieh Wang and Yu-Hsuan Lin
Department of Industrial Education and Technology, National Changhua University of Education, No. 1, Jin-De Road, Changhua, Taiwan // chhchen@cc.ncue.edu.tw // yorainchu@yahoo.com.tw // yousyuan@yahoo.com.tw
*Corresponding author

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ABSTRACT

In this study, we investigated and compared solitary and collaborative modes of game-based learning in promoting students' science learning and motivation. A total of fifty seventh grade students participated in this study. The results showed that students who played in a solitary or collaborative mode demonstrated improvement in learning outcomes. No significant difference was found between the two modes in terms of learning motivation. However, our qualitative results revealed critical insights into our understanding of the effectiveness of game-based learning. Game-based learning encourages students to explore science concepts explicitly and mindfully; furthermore, learning supplemented with collaborative learning can enrich the learning experience and collective problem solving that brings students to the next level of learning. The findings from this study may provide guidelines for what works in the context of game-based learning.

Keywords

Game-based learning, Science learning, Motivation, Collaboration

Introduction

The Program for International Student Assessment (PISA) reported that students' attitudes toward and literacy levels in science decreased tremendously over recent decades. Science educators and researchers have called attention to the need to promote knowledge of what it means to do science rather than rote memorization to solve science problems. Thus, it is critical for science learning to be a meaningful and engaging experience so that students can easily draw connections between conceptual changes in science learning and theoretical changes in the science community. With advances in modern technology and the need to engage students in knowledge inquiry, educational games as tutor, tool, and tutee have increasingly been used as cognitive tools to support science learning. As a result, the guidelines on the effective use of educational games to promote individual knowledge construction and development of social skills such as communication and collaboration have been suggested by the researchers (e.g., Gee, 2003; Li & Tsai, 2013; Prensky, 2001). However, the desired motivational outcomes and learning gains does not occur naturally while playing games (Gros, 2007; Virvous, Katsionis, & Manos, 2005; Salen, 2007). Given the increasing popularity of using games for instructional purposes, researchers have sought to identify factors within instructional settings that can maximize the effectiveness of this instructional medium (Dickey, 2006; Gedik, Hanci-Karademirci, Kursun, & Cagiltay, 2012; Villalta et al., 2011; Wolfe, 2001). To better understand the instructional settings that can make contribution on the game-based learning, this study aims to investigate the effects of solitary and collaborative modes of game-based learning on students' science learning and motivation. In the next section, we focus on research within the context of game-based learning and computer-supported collaborative learning. Following this, we conduct an evaluation methodology at the level of secondary education. In the final section, we analyze and discuss the obtained assessment results with regard to the posed research questions.

Literature review

Game-based learning (GBL)

The use of computer games has continually increased in educational settings. As advanced technology, games have transformed pedagogical strategies about learning and teaching (van Eck, 2006). Games are considered useful instruments for learning specific strategies and for acquiring knowledge. Games can also be used to learn particular content, and they may leave an impression on the learners (de Freitas, 2006; Rieber & Noah, 2008; Ting, 2010). In recent decades, the integration of games as educational tools has been studied at the primary, secondary, and college levels (e.g., Annetta, Minogue, Holmes, & Cheng, 2009; Gros, 2007; Huizenga et al., 2009; Papastergiou, 2009; Watson, Mong, & Harris, 2011) and has been applied in different disciplines, such as mathematics (Lee & Chen, 2009), biology and genetics (Annetta et al., 2009), history (Watson et al., 2011), and social sciences (Cuenca & Martin, 2010), to effectively achieve various educational goals. More recently, the use of ubiquitous educational games that are wirelessly networked has become an emerging teaching strategy in educational settings. Huizenga and her colleagues (2009) found that students who played mobile games attained higher scores on a knowledge test than those who received a series of regular project-based lessons.

Game-based learning (GBL) offers numerous advantages and benefits that can contribute to a variety of learning outcomes (e.g., Dickey, 2007; Gros, 2007; Huizenga, Admiraal, Akkerman, & Dam, 2009). For example, GBL better mimics real-life situations and teaches learners how to directly apply knowledge and how to address real-life problems they may encounter (Chang, Wu, Weng, & Sung, 2012; Lee & Chen, 2009; Mandinach & Corno, 1985; Yang, 2012). GBL is shown to increase students' motivation and promote effective learning (Dickey, 2007; Huang, 2011; Miller, Chang, Wang, Beier, & Klischm, 2011; Tuzun, Yilmaz-Soylu, Karakus, Inal, & Kizilkaya, 2009). However, some scholars perceive GBL as an informal learning activity and worry that the use of this approach will not enable students to achieve expected learning goals (Gee, 2003; Gros, 2007; Virvous, Katsionis, & Manos, 2005). As a result, GBL is a man-machine tool, and importing and using this tool to teach or learn should involve careful evaluation of both the game itself and the learners' perspectives on its usefulness and efficiency (Dickey, 2006; Salen, 2007; Tsai, Yu, & Hsiao, 2012).

Nevertheless, the outcomes of previous studies on the effectiveness of GBL have been mixed (de Freitas, 2006; Tsai et al., 2012). Some researchers have found mixed results (Huang, Johnson, & Han, 2013; Yang, 2012), others have found that games facilitate learning (Miller et al., 2011; Tuzun et al., 2009), and still others have found that games may have a positive effect on learners' motivation (Liao et al., 2011; Virvous et al., 2005). A literature review of systematic reviews and meta-analysis on the cognitive basis of game-based learning, knowledge acquisition through GBL, and effects of GBL on learning motivation concluded that GBL does not affect knowledge analysis but affects the application of knowledge and recommended that more qualitative studies extend our understanding of the nature of engagement and the learner experience in GBL (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). Wouters and his colleagues (2013) conducted a meta-analysis study on the effects of GBL and indicated that games are more effective in learning and motivation when supplemented with other instructional methods such as collaborative learning. This finding echoes a wide variety of GBL studies that recommend that the research community should continue to focus on what works with which instructional or contextual settings and in which context (Dickey, 2006; Gedik, Hanci-Karademirci, Kursun, & Cagiltay, 2012; Ting, 2010; Villalta et al., 2011; Wolfe, 2001).

Collaborative game-based learning (CGBL)

Collaborative learning can generally be defined as an instruction method in which students at various performance levels work together in small groups or pairs toward a learning goal. Compared to individual learning, in which students work individually at their own level and pace toward a learning goal, collaborative learning requires students to verbalize their thoughts, challenge the ideas of others, and collaborate to achieve group solutions to problems (Koschmann, Kelson, Feltovich, & Barrows, 1996). Moreover, students in collaborative learning modes tend to engage in meta-reflection and higher-level cognition (de Freitas & Oliver, 2006; Feltovich, Spiro, Coulson, & Feltovich, 1996; Hummel, Paas, & Koper, 2006). At the same time, collaborative learning can enhance the development of higher cognitive abilities, cultivate the spirit of collaboration, and formulate positive social relationships with others (Sins, van Joolingen, Savelsbergh, & van Hout-Wolters, 2008).

The concept of collaborative learning has been applied in different disciplines such as science (e.g., Chang, Sung, & Lee, 2003; Morris, Hadwin, Gress, Fior, Church, & Winne, 2010; Tao & Gunstone, 1999), social science (e.g., Golanics & Nussbaum, 2008; Heo, Lim, & Kim, 2010; Huang, Wu, & Chen, 2012), medical education (Lu & Lajoie, 2008), and English (Ge, 2011). In science learning, researchers have found that collaborative learning supports learning proficiency in terms of engaging students in the active exploration of core science concepts (Hung, Looi, & Tan, 2005; Jeong & Chi, 2007; Saab, Joolingen, & Hout-Wolters, 2007). Different from traditional collaborative learning, computer-supported collaborative learning environments (CSCL) have been shown to positively influence learning (Tutty & Klein, 2008; van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005). CSCL allows for a deeper elaboration and refinement of individually constructed schemata (Lowych & Poysa, 2001). However, research on collaborative and science learning generally does not involve games that deliberately foster collaboration within the game play (Wouters & van Oostendorp, 2013).

Collaborative game-based learning (CGBL) has been found to provide a platform that allows students to share information in a meaningful way, helps them to overcome their misconceptions about content, and increases reflective thinking and effective problem solving (Foko & Amory, 2008; Mikropolous & Natsis, 2011; Shih, Shih, Shih, Su, & Chuang, 2010). Meluso and her colleagues (2012) experimented with the effects of collaborative versus single game players on fifth grade science content learning and self-efficacy. No significant difference was found in their study regarding whether students learned through gameplay collaboratively or individually. van der Meij and his colleague's (2010) study also found that collaboration did not affect game engagement or individual test scores. Both studies conclude that the benefits of collaborative game-based learning are highly dependent on the specific model and strategies utilized. Adopting games in collaborative learning should consider that their peripherals that could have positive or negative pedagogical practices (Hämäläinen, Oksanen, Häkkinen, 2008). The effects of CGBL on learning are mixed throughout the literature, and the direct effects of collaboration and various collaborative settings remain incompletely understood. More research is warranted to shed light on the effects of collaboration while playing educational games on students' learning outcomes and to delineate the various features of game design and their relationships to collaborative learning, which may influence how students perceive educational games.

Purposes of this study

In this study, we developed an educational game that intends to facilitate students' intuitive understanding of science concepts. The purpose of the game was to examine the effects of different instructional settings, namely solitary and collaborative game-based learning, on students' learning outcomes and motivation. This study should shed lights on our knowledge about how different instructional settings interact with game-based learning and provide further information upon the integration of instructional settings to develop an informatics system that supports knowledge construction and motivation. In summary, this study conducts an experiment to answer three research questions: (1) How do students in the individual mode differ from students in the collaborative mode with respect to acquiring knowledge?; (2) How do students in the individual mode differ from students in the collaborative mode with respect to motivation for learning?; and (3) How is the game perceived/experienced by students in both the individual and collaborative modes?.

Method

Participants and design

The participants of this study were fifty seventh grade students from two classes at a local middle school; their average age was 13.41. The participants had not learned the instruction that would be taught in this study. Students participated in the study as a learning activity connected with their regular instruction. Participating students were randomly assigned to experimental groups: the individual group or the collaboration group. For the collaboration condition, students were randomly paired into dyads. Altogether, there were 25 students in the individual group and 25 students in the collaboration group (i.e., 11 pairs and a small group of 3 members). During the study, all students were blind to the experimental design and unaware of the existence of other conditions.

Materials

In this study, we designed and developed a game-based learning environment to promote students' conceptual understanding and motivation in science. Situating learning within the game-based environment can unite two or more unrelated concepts in the minds of learners and can subsequently create a new knowledge schema. This design rationale is not only consistent with constructivist ideas about learning but also helps learners combine new concepts with already understood ideas into a new cognitive structure (Davidson, 1976; Falconer, 2008; Rieber & Noah, 2008). We also strive to design our instructional game that translates what experts know as well as what scientists hold abstractly within their minds into a concrete world that students can physically manipulate (Sun, 2010; Tu et al., 2008; Wolfe, 2001). Lastly, students will form mental models about the instructional game world through inquiry and discovery (Reese, 2003).

The educational goals of our game were (1) to understand the effects of force, (2) to understand the types of force, (3) to describe the force equilibrium condition, and (4) to understand the impact force generated by the object(s). The examples of goals, objects and activities embedded in the game are illustrated in Table 1.

Table 1. Learning goals, objects, and activities used in the game

Learning goals	Objects in the game	Activities in the game
To understand the effects of force	Different sizes of rabbits and carrots	The size of the rabbit will determine the size of the carrot that can be pulled up.
To describe the force equilibrium condition	The growing position of carrots	The carrot can be pulled up successfully when the rabbit's force direction is opposite to the growing position of carrot and its strength is greater than the maximum static friction.

Figure 1. A screenshot of main interface

Figure 2. A screenshot of game levels

Figure 3. A screenshot of Level 2 game environment

Figure 4. A screenshot of instructional manual

As shown in Figure 1, the main interface of the game included: (1) start, (2) manual, (3) ranking, and (4) quit. Our game runs on Android 2.0 and above systems. When the players clicked on Start, they entered the game. The game included three levels (1, 2, and 3), as shown in Figure 2. These levels represented increasing levels of difficulty and contextual feedback for learning. Players in level 1 worked with only one object and moved around the game environment, whereas players in level 2 (as shown in Figure 3) worked with three objects simultaneously. In addition to the increasing number of objects, the minimum score and time for passing each level also became more challenging between levels. For example, to pass level 1, players needed to reach 200 points within 60 seconds, whereas in level 3, players needed to reach 500 points within 60 seconds to pass. The manual was instructional messages that taught students to understand types of force, specifically contact forces and action-at-a-distance forces (as shown in Figure 4).

Instruments

A science learning performance test assessed students' knowledge of force and motion was developed and subsequently evaluated by two science-related course instructors to ensure that the items were adequately and appropriately represented. The items included concept definitions, rules, and application. Three additional open-ended questions were developed to ask students to explain the concepts and give examples. The overall average difficulty level of this test was between .40 and .70, as recommended by Ahmanan and Glock (1981). In addition, this test's discrimination level was less than .40, as also recommended by Ebel and Frisbie (1991).

The motivational survey was primarily adopted from the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich, Smith, Garcia, & McKeachie, 1991). Wu and Cherng (1992) translated and evaluated the MSLQ among secondary students in Taiwan and developed a revised version of the MSLQ that has satisfactory reliability and validity. This study used and modified their MSLQ, which included six constructs: (a) intrinsic motivation, (b) extrinsic motivation, (c) task value, (d) control of learning beliefs, (e) self-efficacy for learning, and (f) expectations of success. The numbers of questions in each construct were four, four, six, eight, five, and three, respectively. The rating was based on a 5-point Likert scale. The reliability for all subscales according to Cronbach's α was 0.86, 0.92, 0.89, 0.84, 0.91, and 0.87 respectively.

The last instrument we collected was the participants' interviews after the completion of the study. A total of seventeen students were selected for the follow-up interviews. The interview questions were semi-structured and questions were (a) "What have you learned from playing this game? Please elaborate or give examples" and (b) "What has benefited your learning experience throughout this study? Please elaborate or give examples". These two semi-structured questions attempted to help the researchers clarify and gain insights from each student. The semi-structured questions were also used to help the researchers clarify quantitative statistical relationships and served to triangulate the numeric findings. The interviews were audiotaped and translated and transcribed into English for analysis. The first author analyzed the interview data following the procedures of initial analysis, the individual coding of interviews, and the indexing and clustering of emerging themes, meta-themes and patterns as suggested by Miles and Huberman (1994). To ensure the validity of our qualitative results, a graduate student who was trained and experienced in qualitative analysis was asked to verify that the results were correctly presented and reported. Any discrepancies in the conclusion were discussed until a high consensus was reached.

Procedure

The experimental procedure of this study is illustrated in Figure 5. All participants first listened to a 10 minutes training session to familiarize themselves with the research study procedure and game environment. A pretest score of the force and motion was collected prior to the start of the intervention. After the pretest, researchers divided students into two conditions (individual and collaboration) and were led to different classroom. The purpose to separate students to different classroom was to avoid students in different condition interfered with each other. The researchers then handed the students a tablet and instructed them to read instruction materials about force and motion before starting the game. If the participants were assigned to collaboration groups, they had to play the game and discuss a worksheet together. The time allocated for playing the game was approximately 20 minutes, followed by a posttest and a motivational survey. The total research time was approximately 120 minutes. After the completion of the study, the selected participants were invited to be interviewed for another 15 to 20 minutes.

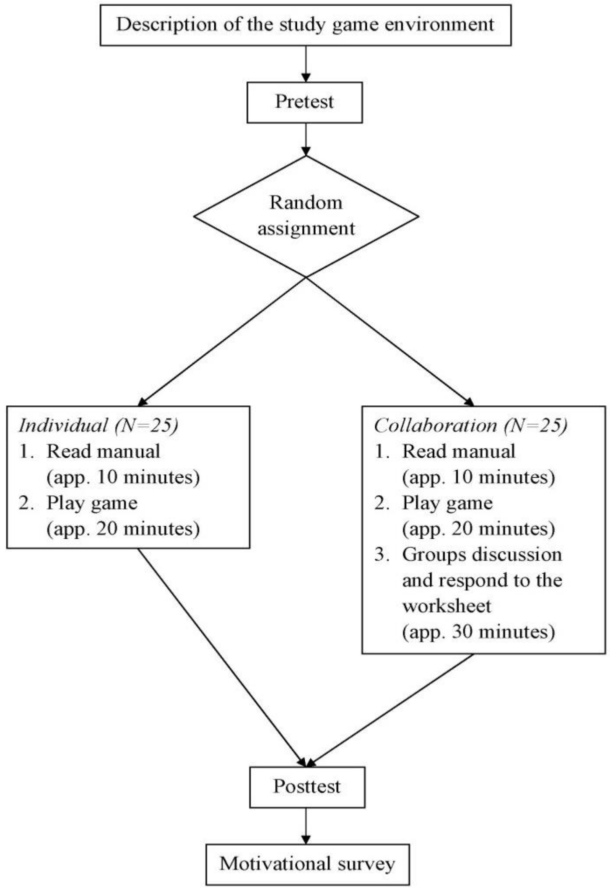

Figure 5. The experimental procedure of this study

Results

Learning performance

To measure the differences in each student's learning performance in different group conditions, a one-way repeated measure analysis was performed. The data analysis for student science learning performance was carried out as a repeated measures analysis with two groups (individual and collaboration) as the between-factor and time of measurements (pretest and posttest) as a within-factor. Dependent variables were scores of the science learning performance. Assumptions for the statistical measures were checked using Levene's test for equality of variances among the groups. A repeated measures ANOVA with a Greenhouse-Geisser correction determined that science learning performance differed significantly between time points, $F(2, 48) = 5.61$, $p = .032$. It indicated a significant difference in science learning performance change over time in the two groups. Individual ($M = 43.80$, $SD = 11.20$) and collaboration ($M = 45.40$, $SD = 14.54$) groups had similar scores on the pretest at the beginning of the instruction. The individual group ($M = 60.01$, $SD = 14.21$) scored higher than the collaboration group ($M = 56.40$, $SD = 19.86$) on the posttest. The individual students increased 16% from the pretest to the posttest. In the collaboration group, students' scores increased 11% on the tests. The effect size of the gain difference between the two groups was .91.

Motivation

Another dependent variable for student motivation was measured in terms of intrinsic motivation, extrinsic motivation, task value, control of learning beliefs, self-efficacy, and expectations of success. We performed the

Bonferroni-adjusted one-way multivariate analyses of variance to analyze if any differences existed between the two groups in learning motivation. The results showed no difference between the groups for all motivation subscales. The means and standard deviations of these measures for the two groups are presented in Table 2.

Table 2. Descriptive statistics for the individual and collaboration groups

	Individual (N = 25)		Collaboration (N = 25)	
	M	*SD*	*M*	*SD*
Intrinsic motivation	3.10	0.98	3.42	1.10
Extrinsic motivation	3.23	0.63	3.25	1.00
Task value	3.10	0.84	3.43	1.12
Control of learning beliefs	3.32	0.54	3.52	0.64
Self-efficacy*	3.12	0.84	3.62	0.99
Expectancy for success*	3.12	0.79	3.93	0.84

*$p < .05$.

Qualitative results

Our qualitative data mainly involved interview data to answer the research question three: "How is the game perceived/experienced by students in both individual and collaborative modes?". Data analysis revealed six themes which collapsed into two major themes: GBL encouraging exploration of implicit science knowledge, and CGBL enriches learning experience and collective problem solving. Pseudonyms were used to protect the identities of the participants, and the experiment condition is indicated in parentheses. The examples from the qualitative data we collected exemplified instances that were influenced and facilitated by playing the game. The major findings of the interviews are summarized below.

GBL encourages exploration of implicit science knowledge

The interview data showed that the game had a positive effect on helping students make connections between awareness of what was known and unknown. Carey (collaboration) and Henry (collaboration) said, "This game embedded scientific knowledge that is easy to remember" and "This game allowed me to brainstorm and utilized learned knowledge into practice." In the traditional classroom, students are usually taught from teachers or textbooks. They seldom ask to explore science concepts on their own. Sofia (individual group) expressed, "I like this game because it had interesting content to learn and play. I think I would like to know more about some of the concepts covered inside." By playing the game, the students had to explore their knowledge background and think about how the game related to the science content. For example, Winnie (collaboration group) said, "I figured out what contact force is from playing this game, and I also learned friction and gravity by pulling radishes in the game."

CGBL enriches learning experience and collective problem solving

Collaboration is critical in genuine educational experiences. The findings of interview data showed that collaborative game-based learning can increase social interaction and promote reconstruction or co-construction of knowledge schema. For instance, Cindy (collaboration group) and Fong (collaboration group) said, "When I did not understand the problems encountered in the game, my partner would give opinions" and "When we failed to pass the level, we would discuss the reasons and come up with other strategies." Additionally, we found that collaborative game-based learning can support authentic activities and encourage deeper discussion through collective problem solving and the discussion of rich descriptions of science concepts. Winnie (collaboration group), Henry (collaboration group), and John (collaboration group) expressed how they benefited from their peers: "I enjoyed collaborative learning because you can discuss and interact with others"; "Collaborative learning allows us to help each other and discuss difficulties when encountering problems"; and "I like collaborative learning. For example, my partner had thought about the force direction, which I did not." These students built relationships with others as they struggled, handled failure, and eventually worked to master the problem presented. Throughout this process, students were not only critically thinking about their strategies but also developing their cognitive abilities. As students tried out various strategies and assessed the outcomes, they learned to manage problems and understood the importance of working together.

However, some students in the collaborative game-based learning group had serious reservations about collaboration when playing the game with others. Ken (collaboration group) expressed, "I dislike collaboration in the game playing because my partner was too assertive and slow." Sometimes students just do not get along because their personalities clash. This seems to be even apparent in game-based learning because games are highly interactive, more fun and thrilling, and addictive; thus, certain personality traits will be more adversely affected by playing (Anderson, 2004; Gentile, Lynch, Linder, & Walsh, 2004; Markey & Markey, 2010). Shane (collaboration group) also said, "We made a rule, each one of us, to take turns playing the game. We did not discuss at all." We often see that the disadvantages of collaborative learning are that some members of the group do not work well together, do not like to work with others, and argue with others. It should be noted that that certain personality traits may lead to an unproductive group. In addition, students' cultural characteristics may affect their collaborative learning. A past study found that Asian students tend to work cooperatively rather than collaboratively (Zhang, Peng, Hung, 2009). As a result, collaborative game-based learning may present serious challenges for students in this highly competitive culture.

Discussion and implications

The findings of this study indicated that both individual and collaboration groups did not perform differently in the posttest. Aligned with Meluso et al. (2012) and van der Meij et al. (2010)'s findings, this study found the students who played collaboratively did not differ from those who played individually in terms of learning outcomes. Nevertheless, both groups made significant improvement from the pretest to the posttest, which indicates that gaming experience enhanced their overall learning. Our qualitative data offers detailed information on the effects of game-based learning on students' learning. The results revealed that the game can encourage exploration of implicit science knowledge. While much of human conceptualization involves implicit metaphorical projection from one domain of understanding to another, a game-based learning environment that includes a list of possible sources for science learning can possibly promote conceptual understanding.

In regard to students' affective perspectives toward learning through playing the game, the results showed that students who played in solitary or collaborative modes had no differences in learning motivation. While no differences were found between the individual and collaboration groups on the learning performance or motivation measures, our qualitative data uncovered veil of collaborative game-based learning that further extends our instructional practices with educational games. In the light of this study, collaborative game-based learning allows students to re-construct or co-construct knowledge schema and encourages collective problem solving and discussion of rich descriptions of science concepts. While collaboration activity in game-based learning can help students solve problems together with diverse perspectives, a positive group dynamic for collaborative learning is necessary to function at its highest efficiency. Conflict between individuals can diminish or stall a group's ability to work together, which raises a significant problem when personality traits or cultural backgrounds are too diverse to allow for fully formed conflict resolution skills. Mismatched personalities can cause unsatisfactory collaborative learning.

Game-based learning in educational settings has become a common practice. Many of our students are digital natives who already use or play games on their own to understand their world and to learn, often in nontraditional ways, outside of formal education structures. When games are properly used and deployed, we can improve learning, and we can scale up this improvement. This study adds to the existing literature that suggests that games can serve as transformative technological powers for learning and confirms previous studies that found that game-based learning can facilitate learning, particularly conceptual understanding and building (Miller et al., 2011; Tuzun et al., 2009). To extend the current research on game-based learning, we collected qualitative data to extend our understanding of the nature of engagement and learner experience in GBL. It is suggested that the game-based learning approach encourages students to explore science concepts explicitly and mindfully. Although in this study we found that individual and collaboration modes are both beneficial to science learning, our study revealed that game-based learning supplemented with collaborative learning can enrich the learning experience and collective problem solving that brings students to the next level of learning.

Limitations and future research

Modified replication of this study is necessary with the use of alternative designs such as cohort studies or control-group designs so that possible effects of game-based learning can be ensured. Although our game was designed to promote conceptual understanding in the science domain, it is hoped that such instructional approach can transfer learning and support cognitive development in other content domains. In the solitary mode of game-based learning, future study should provide adequately evidence on the interrelationships between motivation, attitude to learning, and learning outcomes. While the recent research has achieved great strides in integrating models of adaptive learning with technology, game environments adapting to individual needs and abilities are still in its infancy. For collaborative game-based learning, future study should investigate individual accountability in addition to group goals in the collaboration process. Moreover, the dialogues of the collaborative pairs could be recorded to provide a more comprehensive understanding of the effective elements of collaborative game-based learning settings. Research investigating game didactics or group assignments is also valuable to advance our knowledge about collaborative game-based learning. The future study should also consider to use larger sample sizes to detect possible effects of various forms of game-based learning.

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