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Influences of an inquiry-based ubiquitous gaming design on students' learning achievements, motivation, behavioral patterns, and tendency towards critical thinking and problem solving

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Abstract

In this paper, an inquiry-based ubiquitous gaming approach was proposed. The objective of the study was to enhance students' performances in in-field learning activities. To show the advantages of the approach, an experiment was carried out to assess the effects of it on students' learning achievement, motivation, critical thinking, and problem solving. Furthermore, the students' behavioral patterns were investigated via content and sequential analysis methods. The experimental outcomes show that the approach promoted students' performances of learning achievement and intrinsic motivation; moreover, the students' perceptions of their problem solving and critical thinking were significantly promoted as well. The learning behavior analysis further show that the designated approach stimulated the participants to actively engage in field observation, comparison, and data searching in the context ware in-field learning activity.

Introduction

Inquiry-based learning (IBL) represents a meaningful learning context in which students can explore the natural world via their own investigation activities (Wang, Duh, Li, Lin, & Tsai, 2014). Gillies and Nichols (2015) illustrated that IBL offers students opportunities to explore phenomena and propose a solution. It not only uses some form of problem or task to stimulate students to learn autonomously but also provides guidance for in-field exploring activities (Lin, Liang, & Tsai, 2012; Oliver, 2008). Several scholars have further addressed the potential of adopting IBL for improving students' conceptual understanding as well as their higher level thinking (Hsu, Lai, & Hsu, 2015; NRC, 1996, 2000). Nevertheless, some difficulties in carrying out IBL activities in a real-world environment have been pointed out, including the fact that it is time consuming to implement an IBL activity, the complex information in the contexts and the students' low engagement level (Lim, 2004; Ucar & Trundle, 2011).

Recently, through the remarkable progress in mobile devices and wireless networks, various attempts have been made in educational settings to promote students' learning effectiveness. Researchers have indicated that mobile technology-enhanced learning not only enables students to learn across time and space, but also affords them opportunities to learn from real-world

Practitioner Notes

What is already known about this topic

- Inquiry-based learning (IBL) can provide participants with opportunities to not only explore possibilities and explain phenomena, but also to elaborate and evaluate their solutions.
- With the advance of mobile and network technologies, it has been proven that the mobile technology-integrated IBL environment has positive impacts on learning effects.
- Successful IBL still depends upon a higher level of participants' motivation, describing that they may fail to engage in inquiry activities without sufficient intrinsic motivation.

What this paper adds

- An inquiry-based ubiquitous gaming approach was developed to conduct a context aware in-field learning activity.
- A ubiquitous gaming system was developed based on the proposed approach.
- In addition to promoting students' learning achievement and intrinsic learning motivation, it was found that the approach promoted the students' tendency of problem solving and critical thinking.
- From the learning behavior analysis, it was found that the approach stimulated the participants to actively engage in field observation, comparison, and data searching in the context ware in-field learning activity.

Implications for practice and/or policy

- The findings of this study suggest that "gamification" could be an effective approach for stimulating students to actively engage in in-field IBL activities.
- Integrating gaming strategies into in-field IBL activities has great potential in improving students' higher order thinking performance, such as critical thinking and problem-solving competences.
- It is worth promoting the inquiry-based ubiquitous gaming approach to other educational domains.

contexts (Chu, Hwang, Tsai, & Tseng, 2010; Peng, Su, Chou, & Tsai, 2009). Several potential advantages of using mobile devices to support learning have been illustrated, such as increasing students' inquiry experience as well as engaging students in applying knowledge to real-world contexts (Ruchter, Klar, & Geiger, 2010; Vogel, Kurti, Milrad, Johansson, & Müller, 2014). Moreover, Hung, Hwang, Lin, Wu, and Su (2013) declared that, with the help of mobile devices with access to computer networks, an IBL activity can effectively improve students' in-field investigation performance. In recent years, some research has taken advantage of the mobile technology-integrated IBL environment for guiding students to learn via interacting with real-world targets (Hung *et al*., 2013; Hwang, Wu, Zhuang, & Huang, 2013), showing that they can obtain instant assistance or feedback when collecting and analyzing data, and when explaining a phenomenon in the real-world environment. Nevertheless, it has been found that the level of students' engagement may influence their inquiry learning effectiveness (Rutten, van der Veen, & van Joolingen, 2015). That is, an effective IBL activity still depends upon a higher level of participants' motivation (Lim, 2004), indicating the significance of motivating factors for an IBL activity. Accordingly, it is important to stimulate students' engagement in an IBL environment.

Digital game-based learning (DGBL) is considered by scholars as a good approach for increasing students' motivation and engagement with specific principles and rules in order to acquire educational goals (Hwang, Chiu, & Chen, 2015; Prensky, 2007). DGBL can provide meaningful learning contexts where students can construct their knowledge and promote learning motivation during the process of dealing with gaming tasks (Dorji, Panjaburee, & Srisawasdi, 2015; Simpson & Elias, 2011). For example, Kim, Park, and Baek (2009) described that digital games could serve as an environment for enhancing students' problem-solving skills.

Consequently, in this study, a context ware ubiquitous gaming approach with the 5E (Engagement, Exploration, Explanation, Elaboration, and Evaluation) IBL model is proposed. Based on the model, an inquiry-based gaming environment is implemented for supporting students in real-world IBL activities. Following that, a quasi-experiment is designed to evaluate the he proposed model by examining the participants' learning achievements, motivation, behavioral patterns, and tendency towards critical thinking and problem solving. There are five research questions in this study, as described below.

1. Can the inquiry-based ubiquitous gaming approach benefit the students in enhancing their learning achievement?
2. Can the inquiry-based ubiquitous gaming approach benefit the students in enhancing their learning motivation?
3. Can the inquiry-based ubiquitous gaming approach enhance the students' tendency of problem solving?
4. Can the inquiry-based ubiquitous gaming approach enhance the students' tendency of critical thinking?
5. What are the differences between the learning patterns of those who participate in the inquiry-based ubiquitous gaming activity and conventional inquiry-based ubiquitous learning activity?

Literature review

Mobile technology-supported inquiry learning

Inquiry has been regarded as a multifaceted activity or ability that concerns a series of student-centered or hands-on actions, such as making observations, planning investigations, proposing answers, or explaining everyday phenomena (NRC, 1996, 2000; van Booven, 2015). IBL refers to a learning environment where students can conduct the investigation activities in the natural world by themselves (Wang *et al.*, 2014). Many previous studies have stated the benefits of IBL activities to improve students' conceptual understanding (Gillies & Nichols, 2015; Wilson, Taylor, Kowalski, & Carlson, 2010), as well as their higher level thinking (Raes, Schellens, de Wever, & Vanderhoven, 2012). For example, Artun and Coştu (2013) adopted an IBL activity about the conceptions of diffusion and osmosis, and found that it promoted the students' new conceptual understanding.

An IBL activity utilizes specified problems or tasks as a stimulus for encouraging students to learn autonomously and provides guidance for an investigating activity and exploring research (Lin *et al.*, 2012; Oliver, 2008), in order to promote their learning effectiveness. Gillies and Nichols (2015) described that IBL provides participants with opportunities to not only explore possibilities and explain phenomena but also to elaborate and evaluate their solutions. Having adequate time to inquire, students can develop critical thinking and reasoning abilities as well as learning science content by means of making observations, manipulating materials and conducting investigations (NRC, 1996, 2000). Furthermore, students can be motivated by question-driven or authentic contexts in an IBL activity so as to promote their learning effectiveness (Hsu *et al.*, 2015).

Authentic learning is a good way to improve IBL effects by providing students with opportunities to observe real phenomena and put concepts into practice (Hwang, Tsai, & Chen, 2012; Oliver, 2008). Some research on situated learning has stated that learning happens from interacting with real situations, and the nature of knowledge is affected by learning activities and social contexts (Brown, Collins, & Duguid, 1988; Huang, Liao, Huang, & Chen, 2014). The process of acquiring knowledge may not take place without the support of real contexts, because environments make the learning meaningful. While participating in an activity or a task in a real environment, individuals can meaningfully connect their existing knowledge with the real-world contexts (Hwang, Yang, Tsai, & Yang, 2009; Tsai, Tsai, & Hwang, 2011). Thus, teachers are encouraged to place students in real environments for experiencing meaningful learning.

Due to the complexity and the richness of real-world environments, authentic inquiry investigations could be difficult for students, implying the necessity of providing learning supports (Ucar & Trundle, 2011; Wang *et al.*, 2014). With the advance of mobile and network technologies, several studies have illustrated the benefits of using mobile technology to support IBL activities (Tsai, Tsai, & Hwang, 2012; Vogel *et al.*, 2014). For example, Hung *et al.* (2013) proposed various mobile technology-based supports in IBL activities for ecology observations, and effectively improved students' field observation performance; Hwang *et al.* (2013) utilized mobile technologies to direct students to explore real learning targets in an inquiry-based mobile learning activity, and also obtained positive results.

Meanwhile, several previous studies declared the significance of motivating factors for inquiry (Edelson, Gordin, & Pea, 1999; Minner, Levy, & Century, 2010), implying that the level of students' engagement involved in an inquiry activity may influence their learning effectiveness (Rutten *et al.*, 2015). Furthermore, Lim (2004) illustrated that successful IBL depends upon a higher level of participants' motivation, indicating that they may fail to engage in inquiry activities without sufficient intrinsic motivation. Thus, this study aims to develop an IBL environment with gaming strategies.

Digital game-based learning

DGBL has been considered as a kind of learning approach which integrates digital games into a learning environment (Prensky, 2007), or refers to a competitive activity with specific principles and rules so as to obtain educational goals (Huang, Huang, & Tschopp, 2010; Hwang *et al.*, 2015). DGBL can provide meaningful learning contexts where students can develop their cognitive knowledge and high-order abilities as well as promote their learning motivation (Dorji *et al.*, 2015; Simpson & Elias, 2011). For example, Kim *et al.* (2009) declared that games can offer a problem-solving environment to develop students' relevant skills. Tsai, Tsai, and Lin (2015) considered gaming as an activity which can trigger students' intrinsic motivation.

Numerous previous studies have illustrated the positive benefits of DGBL regarding promoting students' learning motivation and achievement. For example, Erhel and Jamet (2013) described that a gaming environment can boost students' learning motivation via prompting them to actively process the learning materials; Chen, Liu, and Hwang (2015) share similar findings by integrating a progressive prompt-based approach into a competitive board game. Sánchez and Olivares (2011) implemented a series of mobile gaming learning activities and proved their beneficial effects on the promotion of students' problem-solving skills. Furthermore, Proske, Roscoe, and McNamara (2014) explored the motivational effects of different practice conditions and found that educational games can foster students' engagement.

In view of all that has been mentioned so far, a well-designed DGBL has been regarded as an advantageous learning approach for improving students' learning outcomes and promoting their learning motivation; nevertheless, it still remains a challenging issue to probe the effects of integrating DGBL into a mobile technology-supported IBL environment. Thus, an inquiry-based ubiquitous gaming environment was developed in this study for probing this issue.

Inquiry-based ubiquitous gaming environment

In probe the above-mentioned issue, a learning environment was designed and implemented by integrating the 5E inquiry learning model into gaming scenarios to support context aware ubiquitous learning activities. The system was implemented using Visual Studio C# and Android Studio. Figure 1 depicts the structure of the environment which consists of three mechanisms, that is, the “real-world gaming mechanism,” the “help-seeking and discussion mechanism” and the “cloud technology-based learning portfolio management mechanism.”

The interface of the inquiry-based ubiquitous gaming system was designed by taking the conceptual knowledge of “biology and environmental science” as an illustrative example. It should be noted that the map in the game reflects the physical locations of real-world learning targets (ie, plants to be observed) on an elementary school campus. During the learning activity, a set of gaming tasks is presented to guide students to explore the influence of environmental pollution. As shown in Figure 2, the students can freely choose one of the six game stages and accept the challenge of the task. First, the students require moving to a real-world location related to the game stage shown on the mobile device and scan the corresponding QR code. Afterwards, the story of the game stage and a gaming task are shown to guide the students to complete a series of learning activities via field observation, comparison, clue search, data search and reading supplementary materials. The gaming activities are designed based on the 5E inquiry learning model. This learning model has been used in several previous studies to boost the process of conceptual change and to promote the learning effects (Chen, Wong, & Wang, 2014; Dorji *et al.*, 2015; Karpudewan, Roth, & Abdullah, 2015).

For example, if the stage of the “Hostile Water” is chosen, the learning system displays a compelling storyline: “Water was polluted by eutrophication and creatures cannot easily survive under

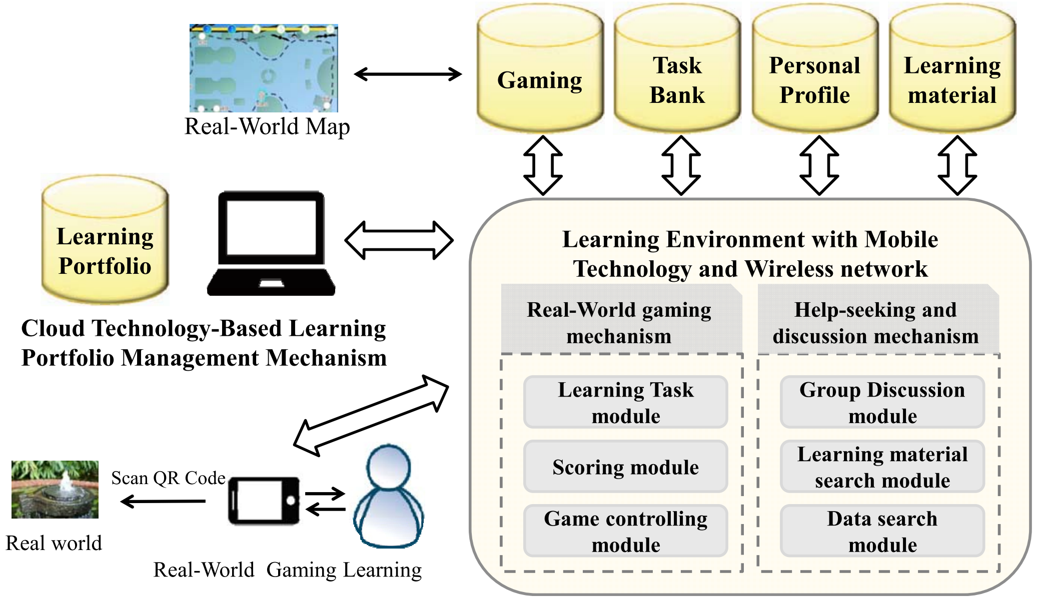

Figure 1: Structure of the inquiry-based ubiquitous gaming environment [Colour figure can be viewed at wileyonlinelibrary.com]

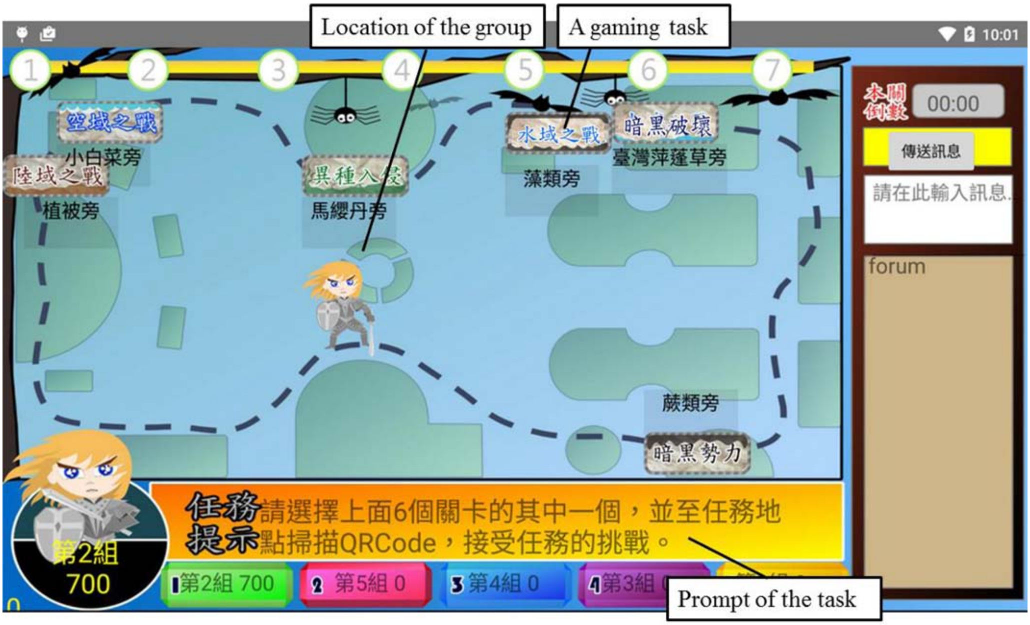

Figure 2: The six game stages [Colour figure can be viewed at wileyonlinelibrary.com]

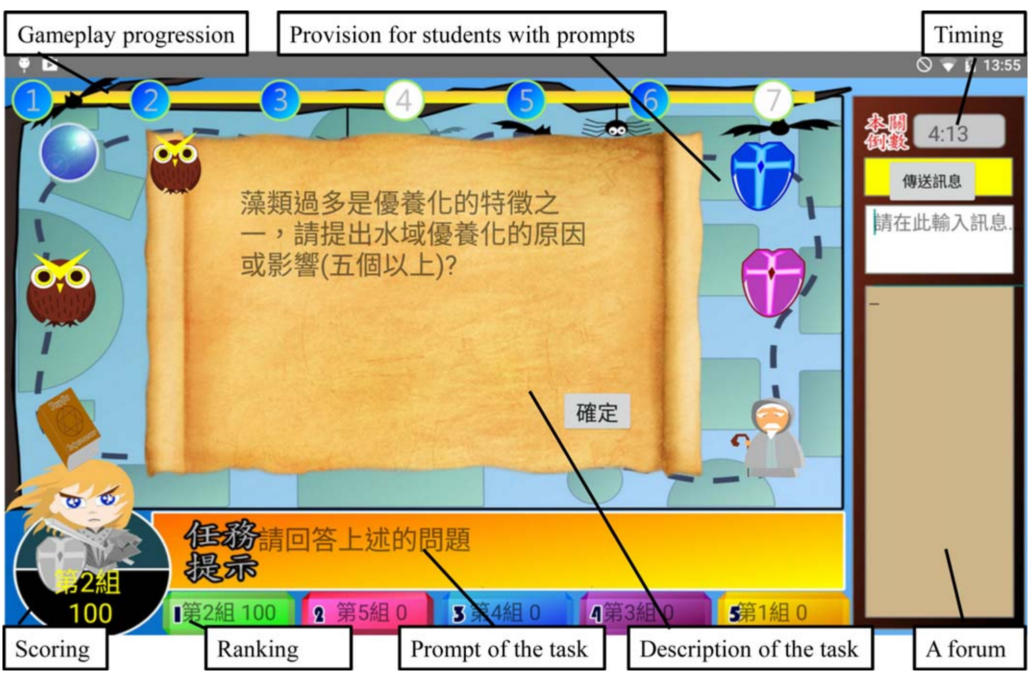

Figure 3: The main context-aware ubiquitous gaming interface [Colour figure can be viewed at wileyonlinelibrary.com]

such adverse circumstances: as a result, territorial waters are in a condition of weak defense." Following this, a gaming task of an open-ended question is shown: "One feature of eutrophication is algal blooms; please explain the cause or effect of eutrophication." The main interface of the ubiquitous learning environment is depicted in Figure 3, including the task descriptions, task

Figure 4: Example of the guidance provided to a student during the gaming process [Colour figure can be viewed at wileyonlinelibrary.com]

prompts, help seeking, gameplay progression, a forum, timing, scoring, and ranking. Such a gaming task corresponds to *Phase 1- Engagement*: a challenge task accesses students' prior knowledge and engages them in the real-world phenomenon via a short activity designed to arouse their curiosity.

In Phase 2 - Exploration: students conduct an investigation activity so as to facilitate their conceptual change via exploring problems and possibilities; afterwards, *in Phase 3 - Explanation*: students give explanations of the phenomenon to illustrate their conceptual understanding and process skills. Thus, during this time, students can take advantage of some assistance in order to complete the task, such as a blue shield, a red shield, a treasury of knowledge, a crystal ball or asking a sage. The blue shield provides assistance for helping them observe the key characteristic of the creature and environment. As shown in Figure 4, when a student touches the blue shield, the learning system shows the information: "Please pay attention to the growth of algae and the color of the water." Once individual students choose the prompt of the red shield, the gaming system tries to guide them to note a comparative creature with opposite characteristics and then make comparisons between the two. Furthermore, a QR code is used to help individual students find the right comparative target.

A treasury of knowledge is illustrated and provides information about the relationship between the creature and environment (see Figure 5): For instance, the learning system illustrates the relationship between Algal Blooms and Eutrophication. A crystal ball in this drama has magic powers and is omniscient. Once the crystal ball is touched, the learning system will start a web search engine and individual students can look for the solutions to the problem on the Internet. If individual students make contact with the sage, they can obtain some key clues. The learning system displays the information: "Please observe the circumstance of the territorial waters, including surface waters and deep waters." Students are guided to observe the relationship between the creatures and the environment in the real world. Moreover, each student can review the task by getting in touch with an owl whenever necessary.

Figure 5: The prompt of supplementary materials [Colour figure can be viewed at wileyonlinelibrary.com]

Subsequently, *in Phase 4 - Elaboration*: students extend their conceptual understanding and process skills to conduct additional activities via new experiences. Thus, they need to find a solution to the environmental changes based on what they explored and explained in the learning portfolio.

In Phase 5 - Evaluation: this phase evaluates the students' progress towards achieving the educational objectives. Accordingly, students have to complete two tests in order to complete this stage. One is about the characteristics of the creature or environment, and the other is related to the comparison between two creatures or environments. For example, the learning system displays the tests: "What is the color of the water with eutrophication?" and "Which kind of water has higher water quality and is more valuable?" If students fail to submit the right answer, they can propose another one. At this time, they can utilize any assistance stated above. In the scoring system, the earlier students submit the right answer, the more points they will accumulate. After they successfully accomplish the task, the learning system will display a compelling storyline about winning this stage battle. When all the gaming tasks are accomplished, the game is completed. In order to enhance the entertainment and competition, the top five current scores are shown on the screen to indicate who the top students are during the activity. Furthermore, all contents in the forum are automatically synchronized with the records in the learning portfolio database via cloud and mobile technologies.

Research design

Participants

In this study, a total of 101 sixth graders (11- or 12-year olds) instructed by the same teacher participated in the experiment. All participants (53 males and 48 females) were composed of four classes of students with natural science for four periods per week at an elementary school. Two classes ($n = 50$) were allocated to learn with the inquiry-based ubiquitous game (ie, the experimental group). The other two ($n = 51$) learned with conventional inquiry-based ubiquitous learning (ie, control group).

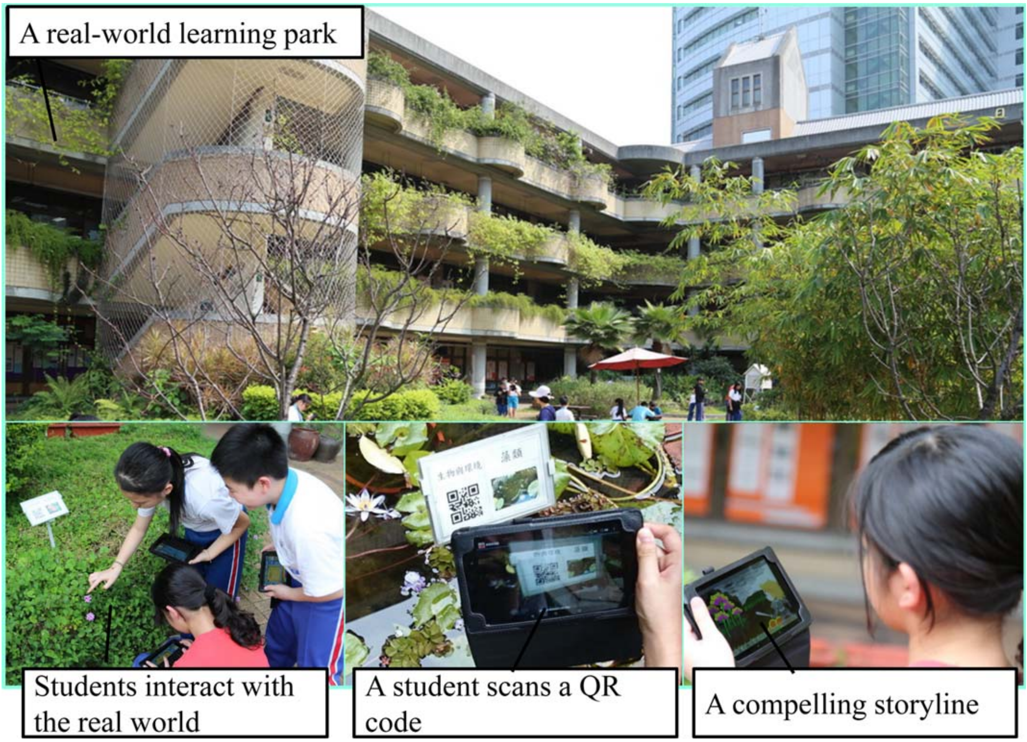

Figure 6: The scenarios of the learning activity [Colour figure can be viewed at wileyonlinelibrary.com]

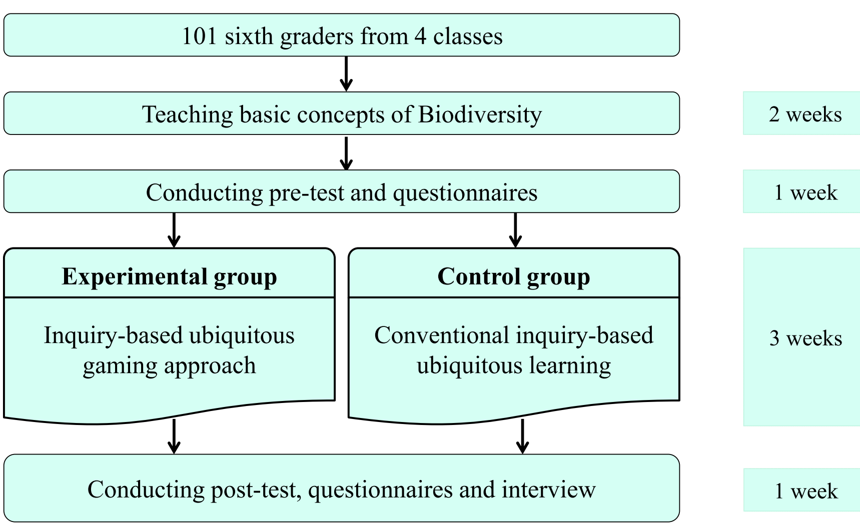

Figure 7: The Experiment Procedure [Colour figure can be viewed at wileyonlinelibrary.com]

Experimental procedure

The scenarios of the learning activity were in a real-world learning park in an elementary school, as shown in Figure 6. A tablet computer provided the necessary guidance, feedback, and compelling story for individual students. Moreover, QR codes were utilized to make sure that the students were situated in the exact contexts.

The experimental procedure is shown in Figure 7. First, a regular eight-period course (2 weeks) on the fundamental knowledge of biodiversity was taught. Afterwards, the participants took the pretest regarding biodiversity conception and the pre-questionnaire about their learning motivation and tendency towards problem solving and critical thinking.

After learning how to operate the learning system, all participants conducted the learning activities with different ubiquitous learning models; that is, the experimental group used the inquiry-based ubiquitous gaming approach and the control group completed used conventional inquiry-based ubiquitous learning. The functions of the two learning systems are the same except for the gaming mechanism. All participants subsequently explored the issue of environmental change and produced reports for three weeks (including the ubiquitous learning activity).

After completing the learning tasks, the students took the posttest and post-questionnaires of learning motivation, and tendency towards problem solving and critical thinking. The experiment procedure ended in a one-on-one interview to collect the opinions of nine students randomly selected from each group.

Measuring instruments

The pretest was designed to assess the students' basic knowledge of biodiversity with 20 multiple-choice items. The posttest was designed for evaluating the students' concepts of "creatures and environment." It comprised 26 multiple-choice items (78%) as well as four short answer questions (22%). The perfect score of both tests was 100. The two experts who developed the pretest and posttest had more than 10 years' experience of teaching the course.

The learning motivation questionnaire originated from the instrument developed by Wang and Chen (2010) based on the items proposed by Pintrich, Smith, Garcia, and McKeachie (1991), as shown in Appendix. It consists of an "Intrinsic Motivation" and an "Extrinsic Motivation" dimension. Each dimension contains three items with a 5-point Likert scale. Its Cronbach's alpha coefficient was 0.79, indicating acceptable reliability for assessing students' learning motivation.

The questionnaire of students' problem solving and critical thinking was designed based on the study reported by Lai and Hwang (2014). Each dimension consists of five items with a 5-point Likert rating scale. The Cronbach's alpha coefficients stated by the original study for the two dimensions were 0.78 and 0.83, implying acceptable and highly acceptable reliability of the students' problem solving and critical thinking questionnaire respectively.

Experimental results

Learning achievement

The one-way ANCOVA was used to compare the two groups' learning achievements by adopting the ubiquitous learning model as an independent variable, while the posttest and pretest scores were respectively the dependent variable and covariate.

After confirming the assumption of homogeneity of regression with $F = 0.82$ ($p > .05$), ANCOVA was performed, as described in Table 1. A significant different was found with $F = 12.17$ ($p < .01$, $\eta^2 = 0.110$), showing that the learning achievements of the two groups were

Table 1: ANCOVA result on students' learning achievement

Group	*N*	*Mean*	*SD*	*Adjusted mean*	*Std. error*	*F*	η^2
Experimental group	50	83.62	10.11	84.78	1.53	12.17**	0.110
Control group	51	78.33	13.83	77.19	1.52		

**$p < .01$.

significantly different because of the different ubiquitous learning models. Thus, the result indicated that the students (adjusted mean = 84.78, Std. error = 1.53) in the inquiry-based ubiquitous gaming group outperformed those in the conventional inquiry-based ubiquitous learning group (adjusted mean = 77.19, Std. error = 1.52). Furthermore, the effect size (η^2) for the ANCOVA results of the ubiquitous learning model indicated a moderate effect size ($\eta^2 > 0.059$) on the basis of the propositions developed by Cohen (1988).

Learning motivation

To analyze the "Intrinsic learning motivation" and "Extrinsic learning motivation" of the two groups, one-way ANCOVA was performed by adopting the pre-questionnaire ratings as the covariate; moreover, the ubiquitous learning model was the independent variable and the post-questionnaire rating was the dependent variable.

After confirming the assumptions of homogeneity of regression for the intrinsic motivation and extrinsic motivation with $F = 0.66$ ($p > .05$) and $F = 0.48$ ($p > .05$), ANCOVAs were conducted to explore the students' learning motivation for the inquiry-based ubiquitous game. As provided in Table 2, the ANCOVA results indicate that a significant dissimilarity was confirmed for the two groups' intrinsic motivation ($F = 10.42$, $p < .01$, $\eta^2 = 0.096$), whereas no significant dissimilarity was found for their extrinsic motivation ($F = 0.17$, $p > .05$, $\eta^2 = 0.002$). Furthermore, the adjusted means of their intrinsic motivation indicates that the inquiry-based ubiquitous gaming approach can enhance students' intrinsic learning motivation, which represents the individual engagement in the task for inherent interest, whereas extrinsic motivation is considered as the accomplishment of the task due to some separable outcome (Keller, 2010; Ryan & Deci, 2000).

Students' problem-solving tendency

After confirming the assumptions of homogeneity of regression with $F = 0.55$ ($p > .05$) for the students' problem solving, the ANCOVA was performed. A significant dissimilarity ($F = 5.55$, $p < .05$, $\eta^2 = 0.054$) was obtained (as shown in Table 3). From the adjusted means, it was ascertained that the inquiry-based gaming approach can facilitate students' perceptions of their

Table 2: The results of the ANCOVA on students' motivation

Variable	*Group*	*N*	*Mean*	*SD*	*Adjusted mean*	*Std. error*	*F*	η^2
Intrinsic motivation	Exp	50	4.29	0.65	4.26	0.08	10.42**	0.096
	Con	51	3.89	0.72	3.91	0.08		
Extrinsic motivation	Exp	50	4.10	0.68	4.10	0.10	2.58	0.026
	Con	51	3.88	0.83	3.88	0.10		

** $p < .01$.
Exp: experimental group; Con: control group.

Table 3: The ANCOVA results for the students' perceptions of their problem solving

Group	*N*	*Mean*	*SD*	*Adjusted mean*	*Std. error*	*F*	η^2
Exp	50	4.06	0.76	4.08	0.10	5.55*	0.054
Con	51	3.79	0.84	3.77	0.10		

* $p < .05$.
Exp: experimental group; Con: control group.

Table 4: ANCOVA results for the students' perceptions of critical thinking

Group	*N*	*Mean*	*SD*	*Adjusted mean*	*Std. error*	*F*	η^2
Exp	50	4.00	0.65	3.98	0.08	4.26*	0.042
Con	51	3.73	0.73	3.75	0.08		

*$p < .05$.
Exp: experimental group; Con: control group.

problem-solving in the ubiquitous learning activity. The effect size (η^2) of the ANCOVA results of the inquiry-based ubiquitous model represented a small effect size ($\eta^2 < 0.059$).

Students' critical thinking tendency
After confirming the assumption of homogeneity of regression ($F = 0.06$, $p > .05$), the ANCOVA was employed and a significant dissimilarity was obtained between the two groups' critical thinking ratings with $F = 4.26$ ($p < .05$, $\eta^2 = 0.042$). From the adjusted means in Table 4, it was ascertained that the inquiry-based ubiquitous game benefited the students more than conventional inquiry-based ubiquitous learning.

Students' learning behavioral patterns
To explore the students' behavioral patterns in the real-world learning activities, all students' learning actions recorded in the learning portfolio were categorized based on the coding scheme in Table 5, which was defined by referring to the learning factors proposed by Zhang, Sung, Hou, and Chang (2014).

The students' portfolios were recorded in the learning system, including all the actions that involved touching the tablet computer screen during the gameplay. A total of 4380 learning actions were recorded in the learning portfolio database. As presented in Table 6, the learning actions of those using the inquiry-based ubiquitous gaming approach are 2384 times (47.68 times per student), while the learning actions of those using the conventional approach are 1996 times (39.14 times per student).

During the ubiquitous learning activity, all participants could seek diversified prompts whenever they wanted, including field observation, clue search, comparison, data search, and reading supplementary materials. To compare the help-seeking preferences of the two groups over the course of the ubiquitous learning activity, independent *t*-tests were performed on the help-seeking times. As provided in Table 7, a significant dissimilarity was discovered between all the help-seeking events of the two groups with $t = 3.71$ ($p < .001$). From the mean values, it was ascertained that the inquiry-based ubiquitous gaming approach (mean = 11.30, $SD = 6.73$) can stimulate the participants to perform more help-seeking actions than the conventional inquiry-based ubiquitous learning.

Furthermore, significant dissimilarities were confirmed between the two groups' field observation, comparison, and data search behaviors. From the mean values, it was ascertained that the inquiry-based ubiquitous game stimulate the students to have more field observation, comparison and data search behaviors in dealing with real-world tasks than the conversional inquiry-based ubiquitous learning.

A lag sequential analysis on the students' learning behaviors was used to probe the learning behavioral patterns of the experimental group over the inquiry-based ubiquitous gaming activity. Moreover, due to no actions of suspending the learning activity, the E5 code was

Table 5: The coding scheme for students' learning behaviors

Code	Behavior	Description	Example	Record
S1	Selection of a task	Scan a QR-Code and start a new gaming task.	Choose the stage of the "Hostile Water".	Touch a "game stage" button
S2	Field observation	Observe the key characteristic of the creature or environment.	Please pay attention to the growth of algae and the color of the water.	Touch a blue shield
S3	Clue search	Obtain some key clues.	Please observe the circumstance of the territorial waters, including surface waters and deep waters.	Contact a sage
S4	Comparison	Observe acomparative creature or environment with counter characteristic.	Please scan the QR code next to the aquarium in the natural science classroom.	Touch a red shield
S5	Data search	Start a web search engine.	Look for the solutions to the problem on the Internet	Touch a crystal ball
S6	Reading supplementary materials	Provided with the relationship between the creature and environment.	Illustrates the relationship between Algal Blooms and Eutrophication	Read a treasury
S7	Review the task	Review the task of the stage.	Please explain the cause or effect of eutrophication	Contact an owl
S8	Pose a method	Submit an answer.	Reducing phosphates	Press the "submit" button
S9	Correctly recognize a creature/environment	Correctly answer a multiple-choice question of the basic test.	What is the color of the water with eutrophication?	Submit a right answer
S10	Correctly comparing a creature/environment	Correctly answer a multiple-choice question of the comparative test.	Which kind of water has higher water quality and is more valuable?	Submit a right answer
E1	Lack of patience	Skip the learning materials.	Due to impatience, a prompt screen is closed.	Touch the prompt and immediately close the screen(<1s)
E2	Trial and error	Repeat answers without learning.	Repeat the submissions without help-seeking or discussion.	Click the options continuously
E3	Incorrectly identifying a creature/environment	Incorrectly answer a multiple-choice question of the basic test.	What is the color of the waters with eutrophication?	Submit a wrong answer
E4	Incorrectly comparing a creature/environment	Incorrectly answer a multiple-choice question of the comparative test.	Which kind of water has higher water quality and is more valuable?	Submit a wrong answer
E5	Suspend the learning activity	Give up the game or learning activity halfway through.	During an unfinished task, turns off the app.	Turn off the app

neglected in this study. To reach a statistically significant result of the sequence, a *z*-score needs to be higher than 1.96 (Bakeman & Gottman, 1997), and the adjusted residuals table is given in Table 8.

A total of 37 sequences with significant *z*-scores were depicted in the behavior transfer diagrams, as illustrated in Figure 8. Each arrow shows the direction of the learning action transition. S2 had the greatest frequency of significant sequential relationships among the help-seeking mechanism over the inquiry-based ubiquitous gaming activity including directional sequential relationships (ie, S2 → S7, S2 → E3, S1 → S2, S5 → S2) and bi-directional sequential relationships (ie, S2 → S3, S3 → S2, S2 → S8, S8 → S2). It is worth paying attention to the crucial situation of the field observation in the inquiry-based ubiquitous gaming activity. A bi-directional

Table 6: The frequency of students' behaviors in the game process

Code	*Behavior*	*Experimental group (n)*	*Mean*	*Control group (n)*	*Mean*
S1	Selection of a task	350	7.00	357	7.00
S2	Field observation	155	3.10	40	0.78
S3	Clue search	66	1.32	45	0.88
S4	Comparison	95	1.90	30	0.59
S5	Data search	109	2.18	58	1.14
S6	Reading supplementary materials	140	2.80	184	3.61
S7	Review the task	85	1.70	1	0.02
S8	Pose a method	489	9.78	312	6.12
S9	Correctly recognizing a creature/environment	350	7.00	357	7.00
S10	Correctly comparing a creature/environment	350	7.00	357	7.00
E1	Lack of patience	10	0.20	26	0.51
E2	Trial and error	15	0.30	24	0.47
E3	Incorrectly identifying a creature/environment	57	1.14	80	1.57
E4	Incorrectly comparing a creature/environment	113	2.26	125	2.45
E5	Suspending the learning activity	0	0.00	0	0.00
	Total	2384	47.68	1996	39.14

Table 7: The t-test results for students' help-seeking behaviors

Variable	*Group*	*N*	*Mean*	*S.D.*	*t*	*d*
Field observation	Exp	50	3.10	2.88	5.34***	1.069
	Con	51	0.78	1.06		
Clue search	Exp	50	1.32	1.35	1.68	0.334
	Con	51	0.88	1.28		
Comparison	Exp	50	1.90	2.48	3.53**	0.704
	Con	51	0.59	0.88		
Data search	Exp	50	2.18	2.18	2.92**	0.582
	Con	51	1.14	1.28		
Reading supplementary materials	Exp	50	2.80	3.80	−1.17	−0.233
	Con	51	3.61	3.12		
Total	Exp	50	11.30	6.73	3.71***	0.739
	Con	51	7.00	4.74		

**$p < .01$; ***$p < .001$.
Exp. experimental group; Con: control group.

Table 8: Adjusted residuals of the experimental group over the ubiquitous learning

	S1	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*E1*	*E2*	*E3*	*E4*
S1	−7.79	3.67*	−2.06	1.39	−0.09	9.28*	−3.02	16.34*	−5.28	−8.52	−0.44	−1.63	−2.83	−4.58
S2	−4.95	−3.44	2.32*	−1.81	−0.49	−2.20	2.38*	12.57*	−0.76	−5.41	0.43	−1.04	2.81*	−2.91
S3	−3.17	2.32*	−1.41	−1.07	−1.23	1.60	−0.94	8.64*	−2.41	−3.11	−0.54	−0.66	−0.49	−1.86
S4	−3.82	−0.13	−1.07	−2.05	−1.21	−1.63	−0.82	11.61*	−0.95	−4.18	−0.65	−0.80	2.50*	−2.24
S5	−4.11	2.66*	−0.05	−0.71	−2.37	1.43	2.11*	2.45*	4.85*	−3.94	−0.70	−0.86	−0.42	−2.41
S6	−4.69	−0.45	0.55	−2.07	6.39*	−2.72	9.26*	0.36	3.42*	−3.91	0.53	−0.98	0.89	−2.35
S7	−3.61	0.60	1.73	−1.38	1.59	4.14*	−1.83	4.94*	−1.47	−3.64	2.77*	−0.76	1.38	−2.12
S8	−9.55	8.07*	6.50*	12.38*	7.51*	1.86	4.40*	−12.8	11.63*	−10.45	2.26*	−2.00	4.96*	−5.37
S9	−7.79	−5.41	−3.11	−4.18	−4.49	−4.15	−3.64	−10.45	−8.52	29.15*	−1.33	−1.63	−2.83	25.4*
S10	48.31*	−4.95	−3.17	−3.82	−4.11	−4.69	−3.61	−9.55	−7.79	−7.79	−1.22	−1.49	−2.94	−4.19
E1	−1.22	−0.85	−0.54	−0.65	−0.70	−0.80	−0.62	−1.63	6.66*	−1.33	−0.21	−0.25	1.55	−0.71
E2	−1.49	−1.04	0.90	−0.80	−0.86	−0.98	−0.76	−2.00	8.53*	−1.63	−0.25	−0.31	−0.61	−0.88
E3	−2.94	−2.04	−0.49	−1.57	−1.06	−1.93	−1.49	−3.94	11.44*	−2.83	−0.50	24.56*	−1.21	−1.72
E4	−4.19	−2.91	−1.28	−2.24	−2.41	−1.94	−2.12	−5.61	−4.04	24.59*	−0.71	−0.88	−1.72	−2.46

*$p < .05$.

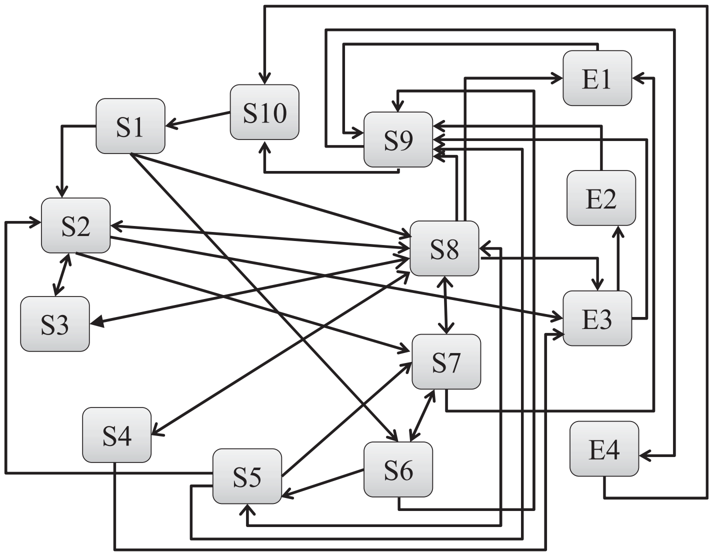

Figure 8: Experimental group' behavior transfer relationships

sequential relationship between S2 and S3 described that the participants conducted the clue search after the field observation, and sequentially carried out the field observation, implying the significance of providing clues to the field observation in the inquiry-based ubiquitous gaming activity. In terms of proposing a solution to the problem, S8 had the bi-directional sequential relationships with S2 (field observation), S3 (clue search), S4 (comparison), and S5 (data search), illustrating that the participants in the inquiry-based ubiquitous game actively searched for more information about the task after submitting a solution.

With regard to the learning behavior pattern of the control group in the conventional IBL activity, a lag sequential analysis was executed to explore the pattern of students' behavioral transitions. The adjusted residuals are provided in Table 9.

As schematized in Figure 9, a total of 39 statistical sequences with significant *z*-scores are depicted in the behavior transfer diagram. In contrast to the help-seeking approaches utilized during the inquiry-based ubiquitous gaming approach, S6 was the highest frequency of significant sequential relationships among the help-seeking mechanism over the conventional inquiry-based ubiquitous learning activity, including S1 → S6, S8 → S6, S6 → S2, S6 → S3, S6 → S5, S6 → S8, S6 → S9 and S6 → E3. Accordingly, the supplementary materials played a crucial role for the conventional inquiry-based ubiquitous learning activity. Moreover, the sequential relationship linking S3 (Clue search) and S2 (field observation) indicated that the participants conducted the clue search before the field observation. In terms of proposing a solution to the problem, S8 had bi-directional sequential relationships with all the actions of the help-seeking approaches.

Some differences were obtained between the learning behaviors of the two groups. The experimental group displayed the significant behavioral sequence linking S1 (selection of a task) to S2 (field observation), indicating that the students using the inquiry-based ubiquitous gaming approach interacted more with the real-world target than those with conventional inquiry-based ubiquitous learning after receiving a task; moreover, after posing a problem-solving method for the task, the participants kept on observing the target based on the evidence of the behavioral continuity of "S8 to S2." Meanwhile, the control group showed the significant behavioral

Table 9: Adjusted residuals of the control group over the ubiquitous learning

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	E1	E2	E3	E4
S1	−9.04	−0.97	0.68	3.56*	4.25*	13.65*	−0.47	14.16*	−3.11	−9.91	0.63	−2.34	−2.27	−5.48
S2	−2.76	−0.93	−0.98	3.09*	0.76	1.76	−0.14	8.53*	−2.2	−3.03	−0.74	−0.71	−1.32	−1.67
S3	−2.93	4.33*	−1.04	−0.85	−0.30	0.9	−0.15	7.72*	−1.66	−3.22	3.15*	−0.76	−1.41	−1.78
S4	−2.39	−0.80	1.60	−0.69	−0.97	−1.16	−0.13	10.12*	−2.14	−2.62	0.96	−0.62	−1.14	−1.45
S5	−3.34	−0.18	2.36*	−0.97	−1.36	−0.68	−0.18	4.25*	4.94*	−3.67	−0.9	−0.86	−0.26	−1.48
S6	−6.16	2.30*	3.48*	−1.16	3.42*	−4.61	−0.32	8.12*	5.05*	−6.56	1.71	−1.59	4.07*	−3.74
S7	−0.43	−0.14	−0.15	−0.13	5.71*	−0.32	−0.02	−0.44	−0.47	−0.47	−0.12	−0.11	−0.21	−0.26
S8	−8.33	5.48*	4.43*	3.60*	2.07*	6.01*	2.29*	−8.43	11.77*	−8.82	3.67*	−2.15	10.01*	−5.05
S9	−9.04	−2.62	−3.22	−2.62	−3.67	−6.76	−0.47	−9.14	−9.91	24.89*	−2.43	−2.34	−3.74	24.14*
S10	44.1*	−2.76	−2.93	−2.39	−3.34	−6.16	−0.43	−8.33	−9.04	−9.04	−2.22	−2.13	−3.95	−4.99
E1	−2.22	0.65	−0.79	0.96	1.42	0.36	−0.12	−2.24	4.2*	−2.43	−0.6	−0.57	4.9*	−1.35
E2	−2.13	−0.71	−0.76	−0.62	−0.86	−0.89	−0.11	−2.15	7.74*	−2.34	−0.57	6.89*	−1.02	−1.29
E3	−3.95	−1.32	−1.41	−1.14	−1.60	−2.56	−0.21	−3.99	12.78*	−4.04	−1.06	19.66*	−1.89	−2.39
E4	−4.99	−1.67	−1.78	−1.45	−1.48	−3.42	−0.26	−5.05	−5.48	23.9*	−1.35	−1.29	−2.39	−3.03

*$p < .05$.

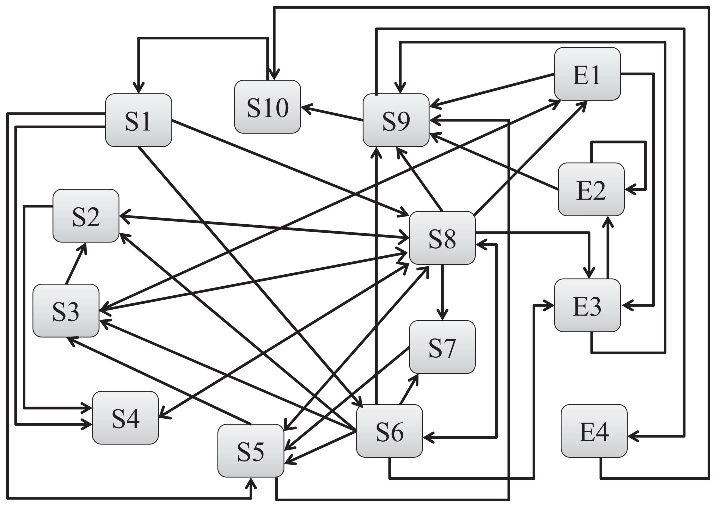

Figure 9: Control group' behavior transfer relationships

sequence linking S8 (pose a method) to S6 (reading supplementary materials), implying that students using conventional inquiry-based ubiquitous learning significantly adopted the action of "reading supplementary materials" after posing a solution to the problem. Furthermore, the E2 → E2 sequence described that the action of "trial and error" may continuously repeat in the conventional inquiry-based ubiquitous learning activity.

Discussion and conclusions

An inquiry-based ubiquitous gaming approach was developed for incorporating the inquiry-based gaming scenarios into real-world learning contexts and an experiment was designed to evaluate it. According to the analysis on the experimental data, it was evident that the inquiry-based ubiquitous gaming approach not only improved the students' learning achievement and intrinsic motivation, but also promoted their perceptions of problem-solving and critical thinking.

The experimental result of students' learning motivation corresponds to the view stated by Hoffman and Nadelson (2010) and Tsai *et al.* (2015), who considered gaming as an activity which can trigger students' intrinsic motivation. With the promotion of intrinsic learning motivation, participants are likely to fully engage in the learning activities (Huang *et al.*, 2010; Malone, 1981). Moreover, by way of illustration, Lim (2004) claimed that successful IBL depends upon a higher level of participants' motivation, indicating that they may engage in inquiry activities with sufficient intrinsic motivation. Thus, it is infer that the inquiry-based ubiquitous gaming approach benefited the participants in terms of learning achievement because of this. Such a result is accordant with those asserted by several scholars who indicated that a gratifying experience can motivate individuals to pursue an activity (Csikszentmihalyi, 1991; Killi, 2006).

According to the number of times utilizing the help-seeking approaches, it was also evident that the inquiry-based ubiquitous gaming approach can facilitate participants' engagement in the ubiquitous learning activity. Having enough opportunities to inquire, students can develop high-order skills as well as learning science content via observations, manipulations, and investigations (NRC, 1996, 2000). This could explain why the inquiry-based ubiquitous gaming approach showed a significantly positive impact on the students' perceptions of critical thinking and problem solving.

From the discrepancy of the adoption of the help-seeking approaches and learning behaviors in the two groups, it was proved that the experimental group with the inquiry-based ubiquitous gaming approach preferred active exploration, including field observation, comparison, and data search. This is also accordant with those presorted by several scholars, describing that games can facilitate students' engagement in an active means of learning (Simpson & Elias, 2011). In the meantime, Chen *et al.* (2014) asserted that the 5E inquiry learning model can stimulate learners to actively utilize acquired knowledge or skills to a real-world scenario; Karpudewan *et al.* (2015) illustrated that an active inquiry approach can improve students' abilities to develop new knowledge. Thus, it is reasonable to infer that a well-designed game promotes the influence of IBL on students' active learning.

To sum up, the inquiry-based ubiquitous gaming approach is beneficial to students in several learning dimensions. Such an approach can be implemented with the ubiquitous learning activities in other courses (eg, social science, mathematics, or language courses) as well as for other in-field learning activities (ie, museums, zoos, or natural parks) by replacing the story and the learning contents. Moreover, to benefit more students, it is crucial to explore the influence of the approach on the learning effectiveness of students with distinguishing characteristics, such as cognitive styles.

On the other hand, there was a limitation on the present study. In measuring students' tendency of critical thinking and problem solving, which refer to the students' awareness or concepts of the two dimensions, self-reported surveys were employed; that is, in this study, only the "awareness or concepts" instead of the "ability" of critical thinking and problem solving were measured. To investigate students' critical thinking and problem-solving performances or abilities in the future, long-term experiments with relevant tests are required.

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Statements on open data, ethics, and conflict of interest

The data can be obtained by sending request e-mails to the corresponding author.

The participants were protected by hiding their personal information during the research process. They knew that the participation was voluntary and they could retreat at any time.

There is no potential conflict of interest in this study.

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Appendix : Questionnaires

Learning motivation

Intrinsic motivation
1. In a class like this, I prefer course material that really challenges me so I can learn new things.
2. In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.
3. When I have the opportunity, I choose course assignments that I can learn from even if they do not guarantee a good grade.

Extrinsic motivation
1. Getting a good grade in this class is the most satisfying thing to me.
2. If I can, I want to get better grades in this class than most of the other students.
3. I want to do well in this class because it is important to show my ability to my family, friends, employer, or others.

Problem-solving tendency

1. When solving a problem, I try to identify the problem type first.
2. Before solving a problem, I think I need to understand the cause of the problem.
3. Except the problem itself, the cause related to the problem should also be clarified.
4. When solving a problem, I would think about the strategy and the process for solving the problem.
5. When solving a problem, I would compare each possible consequence caused by different solutions.

Critical thinking tendency

1. I ask myself periodically if I am meeting my goals.
2. I periodically review to help me understand important relationships.
3. I find myself pausing regularly to check my comprehension.
4. I ask myself how well I accomplish my goals once I am finished.
5. When I finish a task, I ask myself whether what I learned from the task was sufficient.