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Implementation of Game-transformed Inquiry-based Learning to Promote the Understanding of and Motivation to Learn Chemistry

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Abstract

Many studies have used the potential of computer games to promote students' attitudes toward learning and increase their learning performance. A few studies have transformed scientific content into computer games or developed games with scientific content. In this paper, we employed students' common misconceptions of chemistry regarding the properties of liquid to develop a computer game. Daily life situations and everyday phenomena related to the chemical understanding of the properties of liquid were also taken into account. Afterward, we applied a process-oriented, inquiry-based active learning approach to implement the game in a Thai high school chemistry course. We studied the implementation of a game-transformed inquiry-based learning class by comparing it to a conventional inquiry-based learning class. The results of this study include aspects of students' conceptual understanding of chemistry and their motivation to learn chemistry. We found that students in both the game-transformed inquiry-based learning class and conventional inquiry-based learning class had a significantly increased conceptual understanding of chemistry. There was also a significant difference between the gains of both classes between the pre- and post-conceptual understanding scores. Moreover, the post-conceptual understanding scores of students in the two classes were significantly different. These findings support the notion that students can better comprehend chemistry concepts through a computer game, especially when integrated with the process-oriented, inquiry-based learning approach. The findings of this study also highlight the game-transformed inquiry-based learning approach's support of students' motivation to learn chemistry.

Keywords Game-based learning · Digital game · Teaching and learning strategies · Active learning · Inquiry-based learning

Introduction

Due to the significance of connecting the concepts of chemistry to real life, researchers are aware of the teaching and learning processes for chemistry concepts in the classroom. Chemistry, which is one of the important disciplines in science, explains phenomena of daily life. Chemistry is often regarded to be a difficult subject area and is related to other concepts in science, such as biology, physics, and material science. Several studies have revealed that most students often experience a gap between the abstract, difficult chemical concepts that they learn at school and the world they live in (Osborne and Collins 2001; Suits and Srisawasdi 2013). In general, learning at school is limited to the rote-learning mode (Novak 2002). Accordingly, the students are less able to extend their chemistry knowledge beyond the limitations of classroom instruction into their everyday life (Suits and Srisawasdi 2013). There are many factors related to difficulty in learning chemistry. For example, Sirhan (2007) indicated the main factors of this learning difficulty in chemistry are curriculum content, overload of students' working memory space, motivation, language, and communication. Given the abstract nature of chemistry, its content requires using one's imagination to connect concepts to real-life situations. Students must understand the three different levels of chemical representation for explaining chemical phenomena: macroscopic, microscopic, and symbolic representation (Eilam 2004; Leite et al. 2007; Suits and Srisawasdi 2013). Moreover, several researchers have revealed that motivation,

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which is a physiological process, influences human behaviors (Moos and Marroquin 2010), especially in an educational environment (Murphy and Alexander 2000). In other words, motivation is a major factor affecting students' success in learning and achievement, as well as their willingness to learn (Berg 2005), indicating that learning difficulty in chemistry might be reduced by utilizing interesting and motivating material.

In recent years, students have entered the digital age. Students are interested in implementing technology in the classroom (Haussler and Hoffmann 2002; Lamb et al. 2015). Consequently, computer and communication technologies or computer-assisted learning approaches could be involved in the educational system to support students' learning effectiveness (Pedaste and Sarapuu 2006; Li and Lim 2008). These tools and approaches also provide the opportunity for the students to understand both basic and in-depth content. Moreover, such technologies may help them understand complex processes and apply knowledge to their everyday lives. Educational computer games have been recognized as one model that combines computer technology with traditional instruction. Therefore, the students who learn with such games can gain both enjoyment and knowledge (McNamara et al. 2010). For example, Chee and Tan (2012) designed and developed an educational game named Legends of Alkhimia. These authors found that the game they developed effectively fostered students' learning and supported their conceptual understanding of chemistry. Bressler and Bodzin (2016) suggested that educational computer games promoted higher levels of flow experience and scientific practices. Moreover, several scholars have mentioned that computer games can enhance students' learning motivation and degree of satisfaction (Papastergiou 2009; Hwang et al. 2015).

Previous research has designed and developed educational computer games by emphasizing elements of fantasy, enjoyment, challenge, curiosity, reward, and feedback. Several scholars have suggested that appropriate educational computer games provide a balance between academic content and gaming elements (Hwang and Wu 2012). Additionally, an educational computer game should be based on sound pedagogy as well as natural scenarios to deliver learning activities (Dorji et al. 2015). That is, the focus is on transforming scientific content into gaming scenarios and on how the game can be used pedagogically to improve students' learning performance. Therefore, the main purpose of this study was harmonization of an educational computer game and inquiry-based learning pedagogy. In other words, this study applied a process-oriented, inquiry-based active learning approach to a chemistry computer game. Thus, this study empirically compares the conceptual understanding and chemistry motivation resulting from a game-transformed inquiry-based learning approach to that of a conventional inquiry-based learning approach as the usual school setting. This study was guided by the following research questions:

1. Do the students in the game-transformed inquiry-based learning approach, compared to the conventional inquiry-based learning approach, report more conceptual understanding of and motivation to learn chemistry?
2. Are there any differences of students using the game-transformed inquiry-based learning approach and of students using the conventional inquiry-based learning approach regarding gains in conceptual understanding from pre- to post-tests?
3. Are there any differences of students using the game-transformed inquiry-based learning approach and of students using the conventional inquiry-based learning approach regarding increased chemistry motivations from pre- to post-motivation surveys?

Literature Review

Chemistry and Its Teaching and Learning Process

Chemistry is a branch of science that explains the composition and properties of matter, the changes of matter and chemical reactions. These chemical phenomena are related to daily life and everyday situations, from the regular to the bizarre. Understanding chemistry is very important, and it is a basis from which to learn other sciences (Noh and Scharmann 1997; Bouwma-Gearhart et al. 2009; Ozmen 2011). Several scholars have argued that chemistry not only explains daily life and visible phenomena but also describes complicated and invisible concepts to delineate the reason for or process behind chemistry-related phenomena. Many students have difficulties learning chemistry and hold several misconceptions about chemistry (Griffiths and Preston 1992; Nakhleh and Samarapungavan 1999; Skamp 1999; Ayyıldız and Tarhan 2013). For example, the properties of liquid are taught at visible and invisible levels and as abstract scientific phenomena at the middle and high school and college levels (Snir et al. 2003; Eilam 2004; Taber and Garcia-Franco 2010; Ozmen 2011). Students may hold misconceptions regarding the air in the bubbles that form during boiling; for example, instead of understanding that liquid particles are divided into their individual atoms during boiling, they may conceptualize that when an amount of a gas turns into a liquid, the gas becomes heavy (Ayyıldız and Tarhan 2013).

Chemistry education researchers have noted that the causes of unscientific conceptions include everyday experience, traditional instructional language, invalid explanations by teachers, the mismatch between the teacher's and students' knowledge of science, and the inconsistency of chemical terms used in textbooks (Bergquist and Heikkinen 1990; Hodge 1993; Schmidt 1999; Schmidt et al. 2003; Demircioglu et al. 2005). Additionally, some researchers have indicated that students' misconceptions are not the sole cause of learning difficulty in chemistry, also noting the importance of pedagogical practices, overload of students' working memory space, lower science motivation, the complexity of language and communication, and the abstract and symbolic nature of concepts in chemistry (Sirhan 2007; Yakmaci-Guzel 2013).

In past decades, researchers and science educators have sought pedagogies, instruments, or innovations to eliminate or reduce students' learning difficulties in chemistry. For examples, Acar and Tarhan (2006) used cooperative learning pedagogy basing on constructivist learning theory to eliminate students' misconceptions, leading to students' improved conceptual understanding regarding the topic of electrochemistry. Several scholars have suggested that integrating technological tools and existing or adapted pedagogies has effects on changing the teaching and learning process in science (Stieff 2011; Srisawasdi 2012). For example, Frailich et al. (2009) used a web-based learning environment with cooperative learning to help students improve their conceptual understanding in chemical bonding. Srisawasdi and Kroothkeaw (2014) used the integration of computer simulation with open-inquiry learning in a dual-situated learning model to promote students' conceptual understanding of light refraction phenomena. As shown by these and other studies, it is very important to support students' learning and reduce their learning difficulties by providing effective learning environments in the chemistry classroom.

Digital Game-based Learning

In past decades, games have provided only entertainment, but recently, educational researchers have attempted to adapt games for learning called educational games or serious games (Sorensen and Meyer 2007; Stone 2009). Games comprising elements of challenge, control, curiosity, and fantasy can motivate students' persistence and enjoyment (Toro-Troconis and Partrigde 2010). Educators have developed games to achieve three goals, including (i) students can learn from playing the game, (ii) the game components can support learning, and (iii) students are motivated to learn by playing the game (McNamara et al. 2010). Game-based learning is a type of constructivist-based active learning. Based on learning research, Watson et al. (2011) suggested that using games in the classroom shifts teaching from a teacher-centered learning environment to a student-centered learning environment.

In recent years, computer games have incorporated dazzling and sophisticated images and sounds alongside textual communication. Players acquire both pleasurable and challenging engagement from playing these games. Educational computer games keep players immersed in digital worlds, so that knowledge, information, and skill development become increasingly accessible outside the confines of formal education (de Castell et al. 2007). Previous research has utilized educational computer games as learning materials. Gaming elements support students in acquiring knowledge in many disciplines, such as mathematics (Lee and Chen 2009), language (Chen et al. 2011), sports education (Mueller et al. 2010), and chemistry education (Kavak 2012; Chee and Tan 2012; Daubenfeld and Zenker 2015).

Previous studies have presented empirical evidence that computer games have a positive effect on student learning achievement and learning attitudes (Giannakos 2013; Pilli and Aksu 2013; Sung and Hwang 2013). Although some chemistry games are available, these games mainly act as an interface for presenting chemistry learning materials or conducting assessments; however, the chemistry content or common chemistry misconceptions are not transformed or used when developing the gaming scenarios. Therefore, it is necessary to develop a game specifically for chemistry learning to address this issue. The use of an educational computer game as a single, isolated, or discrete element might not be suitable to facilitate students' apprehension of the information necessary to attain conceptual understanding of abstract concepts and motivation to learn. Accordingly, proper pedagogy is required to drive the game when the students participate in learning activities (Dorji et al. 2015).

Conception of Scientific Inquiry and Its Implementations

Scholars have indicated inquiry-based learning research and found that inquiry strategies and their interplay with relevant prior knowledge can support students in constructing and developing content knowledge and enhancing comprehension of the scientific process and knowledge (Klahr and Dunbar 1988; Schauble 1996; NRC 2000). NRC (2000) suggested that science inquiry should seek to excite students' curiosity, encourage them to investigate questions, and help them conduct a scientific investigation with an understanding of the process of how scientists conduct their work (NRC 2000). Additionally, Bransford et al. (2000) revealed the reasons behind the success of utilizing inquiry-based learning as an instructional method. For example, at least in part, this approach succeeds because it allows students to build scientific understanding and change misconceptions through observations of scientific phenomena. For example, when they discover conflicts between their observations of the scientific phenomena and their understanding, students will modify their scientific understanding by adapting new, plausible explanations, and thereby better comprehend the concepts. Afterward, they are able to transfer this scientific understanding to new contexts. Anderson (2002) asserted that inquiry-based learning facilitates students in transforming information into useful knowledge through their direct experience or observations rather than by memorizing the information. In particular, the students are at the center of learning to investigate the scenarios/problems and find resolutions to the issues. There is a range of inquiry-based learning models composed of different inquiry phases adopted in different studies, such as inquiry-based learning cycles (e.g., 5E learning cycle of engagement, exploration, explanation, elaboration, and evaluation) and inquiry-type laboratories (e.g., guided- and open-inquiry experiments). Buck et al. (2008) indicated the different characteristics of the different levels of the process-oriented, inquiry-based learning approach (confirmation, structured inquiry, guided inquiry, open inquiry, and authentic inquiry). For example, process-oriented, open-inquiry learning has been characterized as an approach in which teachers will provide the problem/question and set up the background and context, while students must determine the procedure/design, perform the experiment based on the specified design, and make the scientific communication and conclusions.

The implementation of inquiry-based learning models in the traditional classroom environment, as well as lecture, chalk, and talk, might not be suitable to facilitate and support students' gathering of the necessary information (Lee and Butler 2003), especially information regarding invisible scientific phenomena, and their ability to conduct meaningful inquiry activities (Lim 2004), especially for science courses. Therefore, with the rapid progress of computer and network technologies, many previous studies have noted the potential benefits of a technology-integrated inquiry-based learning environment. For example, Pyatt and Sims (2012) adopted a computer simulation software to run virtual experiments in science labs. Linn et al. (2014) proposed a computerized automated guidance to encourage students to improve their science learning during an inquiry activity. Moore et al. (2013) utilized interactive online simulations to scaffold and support students' guided inquiry learning through exploration and experiments in a general chemistry class. Srisawasdi and Kroothkeaw (2014) and Srisawasdi and Sormkhatha (2014) implemented simulation-based open inquiry in science classes and found that the learning approach of simulation-based open inquiry effectively promoted better conceptual understanding in science and induced cognitive mechanisms of conceptual change for students. Song and Wen (2018) reported that a seamless inquiry-based learning environment supported by bring-your-own-device applications helped students improve their science knowledge.

Researchers have indicated that utilizing technology as a cognitive support during inquiry-based learning activities not only provides students with opportunities for developing scientific understanding but also motivates them by using visible scientific phenomena (Oliver 2008; Ucar and Trundle 2011). However, there remain many challenges in designing inquiry activities in a complex and ill-structured learning environment (Lim 2004). For example, less fantasy, task challenge, reward, and enjoyment are present in an inquiry-based learning environment for both the traditional and technology-integrated science classrooms. Accordingly, in this study, a game-transformed inquiry-based learning approach is proposed to address these problems.

Current Study

From the literature, it is known that the subject of chemistry is difficult to learn. Computers and communication technologies, especially educational computer games, have been widely used to support students' learning performance. For this study, a computer game regarding the properties of liquid in a chemistry course was developed and aligned to the science learning standards of the Basic Education Core Curriculum of Thailand. The game is a 2D role-playing game and requires less personal computer power and wireless networking communication. Moreover, the game was used as learning material as well as a cognitive tool in the inquiry-based learning pedagogy.

The Computer Game in Chemistry

For this study, a new computer game was designed and developed called *Factory Game*. This game was based on scenarios related to real-life situations and problem situations. These components are challenging and induce students to solve problems within the game. To reduce gameplay difficulty, the game consists of instruction and scaffolding. The scaffolding illustrates not only observable phenomena, which are categorized at the macroscopic level of representation in chemistry, but also unobservable phenomena, such as molecular polarity and molecular stucture, which are classified at the sub-microscopic and symbolic levels of representation. To complete missions in the game, the students have to solve the problem and manage coins and time. In addition, dazzling images and sounds are displayed during gameplay. After playing the game, students are shown feedback information to persuade them to rethink instances in which they failed the mission or to provide information about how to complete the mission.

For this *Factory Game*, there are four gaming stages for the macroscopic-microscopic concepts of the properties of liquid in this chemistry course, in which stages the students learn adhesive force, cohesive force, collision of cohesive particles, and evaporation concepts, respectively, as shown in Fig. 1. For example, to encourage students to achieve meaningful learning of the adhesive and cohesive force concepts, a scenario is presented in the first gaming stage, in which students play the role of a scientist and receive a problematic situation in a factory. The problematic situation in the first gaming stage notifies students that *the water flow through the pipes is slow; if you were a chemist, how would you handle this situation/select the proper pipe to increase the rate of water flow?* Once

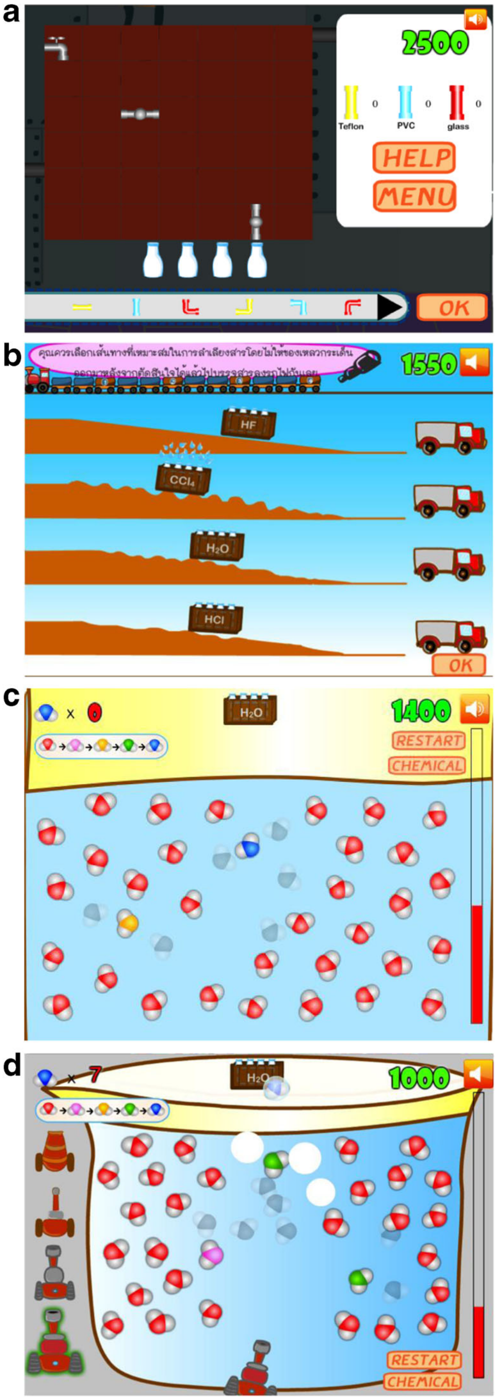


Fig. 1 Examples of screenshots from the *Factory Game* depicting **a** the gaming interface of adhesive force, **b** of cohesive force, **c** collisions of cohesive particles, and **d** evaporation (for more details of the game**:** https://fest.kku.ac.th/game/factory/factory.swf)

the students understand the situation, the game also provides scaffolding for making decisions. The students can see the molecular structure of each pipe, with different types of material (i.e., Teflon, PVC, and glass), as shown in Fig. 1a. In this part of the game, the students can observe experimental demonstrations of the water flow through the pipe by paying with in-game coins. During gameplay, students encounter various challenges that they must overcome to progress. Students must purchase the various shapes of each pipe to connect two fixed pipes to each other. Teachers should encourage them to take note of the number of coins they have. That is, the students have to play and win the game to save coins for playing the next stage. The ultimate goal of the first gaming stage is to fix the water flow through pipes in the factory by saving coins. To achieve the ultimate goal, four bottles must be filled. By completing each bottle, the students can gain knowledge about the adhesive force for the different pipes that they have selected by seeing information on the macroscopic, sub-microscopic, and symbolic levels. In this case, adhesive force, which is another factor affecting flow rate, is the force of attraction between particles of a fluid and particles of another material. For example, glass has a hydrophilic surface; that is, the water's attraction to the glass makes for the slowest water flow rate. Similarly, water flows faster with the PVC and flows fastest with the Teflon. In other words, the students could select the Teflon to increase the rate of water flow.

To gain knowledge about cohesive force in the second gaming stage, the students were assigned to deliver chemical substances by company truck, and they were asked to transport the boxes of chemical substances on different road surfaces. To accomplish this task, prior knowledge about polarity is required. To obtain this knowledge, the students can use coins to buy visualizations to see the molecular structure of the chemicals, which are presented at sub-microscopic and symbolic levels of chemistry representation. If the students transport the chemical boxes improperly, disregarding the influence of cohesive force on the chemical substances, the boxes will break and the number of coins will decrease. However, if students can transport the chemical boxes properly, they will earn more coins to play the next stage and learn the next concepts.

To promote their comprehensive understanding of cohesion, the third gaming stage assigned students to learn about collisions of cohesive particles. In this stage, students received a mission to classify the different types of liquid solution regarding binding or cohesive energy. The students make their own choices to select each chemical solution one time, and then they customize the force of collisions among cohesive particles and observe the molecular phenomena differentiated by solutions.

To illustrate the concept of evaporation at the molecular level in the fourth gaming stage, before students play the game, they receive a mission to collocate suitable chemicals into four thermostat-controlled boxes, each of which has a different interior temperature and level of molecular changes. During gameplay, students learn about evaporation phenomena by shooting molecules with cannons of different power. Each time molecules are shot, students decide different matches between cannons and the chemicals within the different thermostat-controlled boxes; moreover, the simulated vaporization and bubbles are shown. From this information, the students are asked to discuss the concepts of evaporation phenomena. That is, the evaporation phenomenon is a type of vaporization of liquid occurring from the surface of a liquid, and the thermal energy of the selected cannon for a molecule of liquid solution must be sufficient to cause evaporation from the liquid surface. In addition, evaporation happens when atoms or molecules escape from the liquid and turn into a vapor; this phenomenon was also illustrated in the game. When finishing the game, the students who had the most coins were declared the winners.

Setting Learning Activities

Inquiry-based learning is a type of constructivist-oriented science instruction in which students are asked to investigate information and construct knowledge by interacting with learning activities. For this study, open-inquiry instruction was adapted to the setting of a chemistry learning environment called game-transformed inquiry-based learning by using the *Factory Game* as learning material, as shown in Fig. 2. The open-inquiry learning approach was used as the theoretical background for driving the game environment in this study because the teacher must ensure that student will have sufficient information to perform and summarize all information and concepts from playing the game by themselves.

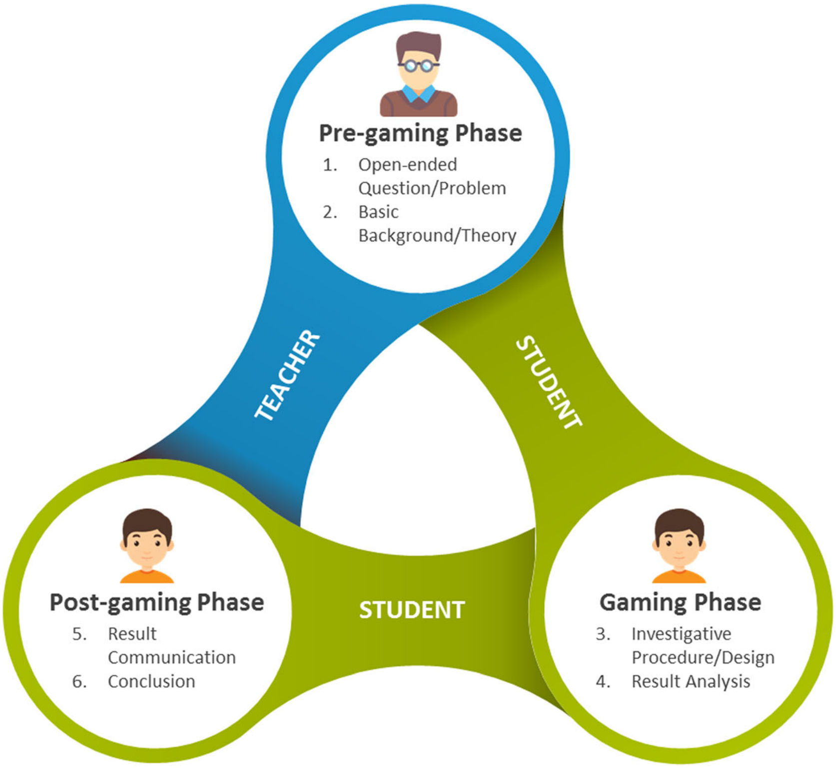
There are two main characteristics of game-transformed inquiry-based learning. Firstly, in the pre-gaming phase, the teacher provides an open-ended question or problem and basic background related to a desired concept before students play the game. Secondly, in the gaming phase, students learn the concept by interacting with cognitive tools or activities to investigate data and formulating and correcting scientific explanations during gameplay. In the post-gaming phase, the students are asked to communicate and defend scientific arguments with peer-to-peer and peer-to-teacher interactions after finishing the game (NRC 2000; Hofstein et al. 2005; Srisawasdi 2015). The *Factory Game* is a cognitive tool that can not only assist students in learning the scientific concepts of the properties of liquid but also can help them pay more attention to learning chemistry-driven phenomena.

Methods

Context and Sample Descriptions

A public secondary education school in the northeastern region of Thailand was used in this study for to study students' learning about the topic of liquid properties in a chemistry course based on the Basic Education Core Curriculum of Thailand. The school implements a technology infrastructure that includes the internet, wireless communication, and

Fig. 2 A conceptual model of game-transformed inquiry learning approach



personal computers with the support of the Office of the Basic Education Commission of Thailand. A total of 62 11th-grade science students from two classes participated in this study. One class (31 students) was assigned to receive learning with the game-transformed inquiry-based learning approach, and another (31 students) participated in the conventional inquiry-based learning approach without the computer game. The same teacher taught the students in the two classes to ensure that the same content was delivered and did not impact the students' outcomes.

Before the class began, the students took a conceptual pre-test to evaluate their prior knowledge of the properties of liquid, followed by the pre-learning chemistry motivation questionnaire, which lasted for 60 min. Afterward, over a period of 3 days (a total of 250 min), the students learned about the properties of liquid (i.e., adhesive force, cohesive force, and evaporation and boiling) in three lessons. Learning activities with a game-transformed inquiry-based learning approach were conducted in the computer lab in the school, while learning activities with the conventional inquiry-based learning approach without the computer game were conducted in a chalk and talk class. After the class ended, the students took a conceptual post-test to evaluate their conceptual understanding of the properties of liquid, followed by filling out the post-learning chemistry motivation questionnaire, which lasted 60 min.

Data Sources

To answer the research questions of this study, pre- and post-conceptual understanding tests and pre- and post-chemistry motivation surveys were implemented as the data sources.

Conceptual Understanding Tests

Both the pre- and the post-tests were adapted from Leite et al. (2007) and Bridle and Yezierski (2012) and were translated into the Thai language by the researchers. The pre- and post-tests were verified by three experienced teachers. Each test contained seven multiple-choice items (one score for each correct answer) and three open-ended questions (two scores for each correct answer); therefore, the total score of the tests was 13. The pre-test aimed to evaluate the students' prior knowledge of the properties of liquid. On the other hand, the post-test aimed to evaluate the students' conceptual understanding after participating in the learning activities.

Chemistry Motivation Survey

Pre- and post-chemistry motivation surveys were used to measure students' motivation to learn chemistry before and after participating in the learning activities, respectively. The Science Motivation Questionnaire II (Glynn et al. 2011) based on social cognitive theory was revised by Srisawasdi (2015) for use as a discipline-specific version of the motivation questionnaire and was used in this study to explore students' motivation to learn chemistry. This questionnaire consists of 25 Thai language items scored on a five-point Likert scale, in which "5" represents "always," "4" represents "usually," "3" represents "sometimes," "2" represents "rarely," and "1" represents "never." There are five dimensions of the questions: intrinsic motivation, career motivation, self-determination, self-efficacy, and grade motivation. Intrinsic motivation relies asks about interesting, curious, relevant, meaningful, and enjoyable learning activity. Career motivation refers to how to get a good job, career promotion, career advantage, use scientific knowledge in one's career, and related career topics. Self-determination asks how hard it is to learn science, to prepare well, to expend enough effort, to spend time learning, and to use strategies. Self-efficacy refers to earning good scores, feeling confident on tests, gaining knowledge, understanding, and feeling confident to perform scientific tasks. Grade motivation focuses on scoring, high grades, grade concern, grades' importance, and gaining better grades in chemistry learning. The questionnaire's internal consistencies of the subscales by Cronbach's alphas are 0.79, 0.81, 0.81, 0.89, and 0.85, respectively. The Cronbach's alpha value for the Thai version of the motivation questionnaire is 0.92 (Srisawasdi 2015), implying good reliability for the survey.

Results

Students' Conceptual Understanding in Chemistry

To compare conceptual understanding in chemistry between the game-transformed inquiry-based learning class and the conventional inquiry-based learning class, since our questions proved reliable, the conceptual pre- and post-test scores were analyzed with independent sample *t* tests and two-way repeated measures ANOVA. All assumptions were checked, and all analyses were performed in SPSS 22 (IBM, Inc.).

The *t* test revealed that there was no significance difference between the conceptual pre-test scores for game-transformed inquiry-based learning students ($M = 2.71$, SD = 1.553) and for conventional inquiry-based learning students ($M = 2.82$, SD = 1.268), $t(60) = 0.313$, $p < 0.05$, as shown in Table 1. This result indicates that the students were not significantly different in their understanding of the properties of liquid prior to participating in the learning activities. The classes were then compared using a two-way repeated measures ANOVA to see if the classes significantly increased their scores on the test from pre to post, as shown in Fig. 3. Students' scores were significantly higher on the conceptual post-test (game-transformed inquiry-based learning: $M = 5.47$, SD = 2.439, conventional inquiry-based learning: $M = 3.85$, SD = 1.916) than

Table 1 *t* test results of the two classes

Measures	Game-transformed inquiry learning class			Conventional inquiry-based learning class			*t* test	
	n	*M*	SD	*n*	*M*	SD	*T*-score	*p* value
Pre-test	31	2.71	1.553	31	2.82	1.268	0.313	0.755
Post-test	31	5.47	2.439	31	3.85	1.916	2.896	.005*
Post-Pre	31	2.76	2.759	31	1.03	2.109	2.767	.008*

$^*p < 0.05$

on the conceptual pre-test ($F_{(1,\ 60)} = 35.976$, $p < 0.05$), as shown in Table 2. This significant difference indicates that the students in both classes increased their conceptual understanding of the properties of liquid.

Notice, however, that while the students still scored approximately 50% on average, they only scored 3–6 out of 13, which is not the improvement one might hope for in their conceptual understanding of the properties of liquid. However, students in the classes were significantly different on their conceptual post-test scores ($t(60) = 2.896$, $p < 0.05$) when compared, as shown in Table 1. This result was also confirmed by the two-way repeated measures ANOVA results, which revealed that the classes were also significantly different from one another when averaging the test scores for the conceptual post-test ($F_{(1,60)} = 9.690, p < 0.05$), as shown in Table 2. This result indicates that the students who followed the game-transformed inquiry-based learning approach ($M =$ 5.47, SD = 2.439) gained a higher understanding of the properties of liquid than those who followed the conventional inquiry-based learning approach ($M = 3.85$, SD = 1.916) after participating in the learning activities. Each class significantly and similarly increased their scores between the conceptual pre- and post-test, as indicated by the graph in Fig. 3. The two-way repeated measured ANOVA also showed that there was a significant difference between the gains of both classes between the conceptual pre- and post-tests ($F_{(1,60)} = 7.860$, $p < 0.05$), as shown in Table 2. This result was also confirmed by the *t* test results of the conceptual post-test scores minus the conceptual pre-test scores for each class ($t(60) = 2.767$, $p < 0.05$), as shown in Table 1.

Students' Chemistry Motivation

To compare motivation in learning chemistry between the game-transformed inquiry-based learning class and the conventional inquiry-based learning class, since our questions proved reliable, the pre- and post-motivation ratings were analyzed with non-parametric hypothesis tests. All assumptions were checked and all analyses were performed in SPSS 22 (IBM, Inc.).

A Mann-Whitney *U* test was conducted to analyze the students' pre-chemistry motivation before starting the two classes.

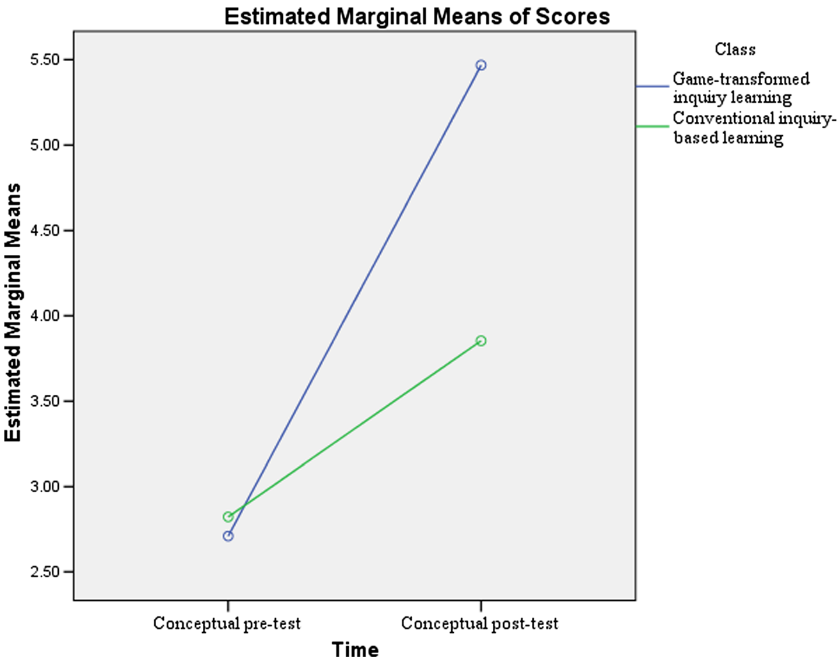


Fig. 3 Two-way repeated measures ANOVA plots of the two times and the two classes

Table 2 Two-way repeated measures ANOVA results of the two classes

		Repeated measures ANOVA	
		F	*p* value
Class	Game-transformed inquiry learning vs. conventional inquiry-based learning	9.690	0.004*
Time	Post vs. pre	35.976	0.000*
Time × class	All four groups	7.860	0.009*

$^*p < 0.05$

There was no significant difference between the pre-chemistry motivation ratings for game-transformed inquiry-based learning students and for conventional inquiry-based learning students, as shown in Table 3. This result indicates that the students were not significantly different in their motivation to learn chemistry prior to participating in the learning activities.

To explore the effectiveness of each class, another analysis was conducted to compare the chemistry motivation improvement of the students in the two classes. A Wilcoxon signed-rank test was performed to analyze the pre- and post-chemistry motivation for each dimension: intrinsic motivation, career motivation, self-determination, self-efficacy, and grade motivation. Ratings of self-determination and self-efficacy dimensions of students were significantly higher on the post-motivations than on the pre-motivations, as shown in Table 4. This significant difference indicates that the students improved in their self-determination and self-efficacy after the learning properties of liquid in either the game-transformed inquiry-based learning class or the conventional inquiry-based learning class. As shown in Table 4, the chemistry motivation improvement of career motivation (post- vs. pre-motivation) was significantly different only in the game-transformed inquiry-based learning class ($Z(60) = 2.117$, $p < 0.05$). Obviously, after learning the properties of liquid with the game-transformed inquiry-based learning approach, the students improved their career motivation.

Furthermore, to evaluate how chemistry motivation was affected by the implementation of the two classes, the post-chemistry motivation ratings were analyzed with a Mann-Whitney *U* test, as shown in Table 5.

Table 5 shows that there were significant differences in the post-chemistry motivations in terms of intrinsic motivation ($Z(60) = 2.299$, $p < 0.05$), self-determination ($Z(60) = 2.530$, $p < 0.05$), and self-efficacy ($Z(60) = 2.153$, $p < 0.05$) between the two classes. This result indicates that the mean ratings of intrinsic motivation, self-determination, and self-efficacy of the students who participated in the game-transformed inquiry-based learning approach were significantly higher than those who learned with the inquiry-based learning

Discussions and Conclusions

This study evaluated the performance of a game-transformed inquiry-based learning approach regarding the ability of eleventh-grade students at a secondary school to learn chemistry, specifically, on the topic of the properties of liquid. The main objective of this study is to compare the conceptual understanding and chemistry motivation on the topic of the properties of liquid between students who learned with a game-transformed inquiry-based learning approach and those who learned with a conventional inquiry-based learning approach in their usual school setting without an educational computer game. In other words, the study helps in understanding whether the *Factory Game*, through open-inquiry learning, contributed to conceptual understanding and chemistry motivations. It was found that the students in both approaches (i.e., game-transformed inquiry-based learning approach and conventional inquiry-based learning approach) significantly improved their conceptual

Table 3 Mann-Whitney *U* results of the pre-chemistry motivation ratings of the classes

Chemistry motivation	Conventional inquiry-based learning class ($n = 31$)		Game-transformed inquiry learning class ($n = 31$)		*Z*	*p* value
	M	SD	*M*	SD		
Intrinsic motivation	16.72	2.132	16.83	2.221	0.264	0.346
Career motivation	16.97	3.987	15.87	3.394	0.898	0.184
Self-determination	16.30	2.016	15.58	1.586	1.627	0.052
Self-efficacy	13.50	1.978	13.43	2.441	0.718	0.236
Grade motivation	18.04	2.126	17.14	2.587	1.421	0.077

Table 4 Wilcoxon signed-rank test results of the pre-chemistry motivation vs. the post-chemistry motivation of the two classes

Class	Chemistry motivation	Pre-chemistry motivation		Post-chemistry motivation		*Z*	*p* value
		M	SD	*M*	SD		
Conventional Inquiry-based learning ($n = 31$)	Intrinsic motivation	16.72	2.132	16.54	1.351	0.229	0.409
	Career motivation	16.97	3.987	17.10	3.259	1.930	0.423
	Self-determination	16.30	2.016	15.19	2.079	3.951	0.000*
	Self-efficacy	13.50	1.978	13.43	1.869	3.125	0.001*
	Grade motivation	18.04	2.126	18.62	2.908	0.459	0.323
Game-transformed inquiry learning game ($n = 31$)	Intrinsic motivation	16.83	2.221	17.54	1.351	0.663	0.253
	Career motivation	15.87	3.394	17.45	3.434	2.117	0.017*
	Self-determination	15.58	1.586	17.09	2.308	2.236	0.012*
	Self-efficacy	13.43	2.441	15.64	2.405	2.401	0.008*
	Grade motivation	17.14	2.587	17.86	2.875	0.687	0.246

$^*p < 0.05$

post-test scores from conceptual pre-test scores. That is, the characteristics of the inquiry-based learning approach, such as posing questions, problems or scenarios, rather than simply presenting established facts; encouraging investigative procedures and practices regarding the posed questions, problems or scenarios; and fostering investigative reflection and conclusions in students helped them to construct their own conceptual understanding and improve their learning. Interestingly, this study indicates that the students who received the developed chemistry computer game called the *Factory Game* through open-inquiry learning pedagogy significantly outperformed students who received the conventional inquiry-based learning without the educational computer game in conceptual understanding and motivation to learn chemistry, in terms of intrinsic motivation, self-determination, and self-efficacy in chemistry learning. As such, the results of this study verify that chemistry computer games could serve as important cognitive tools in enhancing students' conceptual understanding in chemistry courses. In the meantime, the results revealed that students who learned with the game-transformed inquiry-based learning activities showed higher chemistry motivation in terms of intrinsic motivation, self-determination, and self-efficacy than those who learned with the conventional inquiry-based learning activities.

In the *Factory Game* activities, the students were asked to act, react, apply knowledge, view experiment demonstrations, and observe molecular changes in phenomena through their involvement in gamified activities. The students explored adhesive force in pipes and the rate of water flow by visualizing the macroscopic, sub-microscopic and symbolic levels in different materials of pipes, and simulating water flow through each pipe encouraged them to acquire knowledge of adhesive force. Students' explorations involved rewards, encouragement, and time to rethink errors to save as many coins as possible, since feedback was provided after finishing each stage of the game. The students could connect liquid splashing when moving across the different road surfaces with the cohesive force of liquid content. Moreover, when shooting molecules using cannons with different power levels, students were presented with what happens to molecules when evaporation and boiling occur, which are non-observable in everyday life. Students also faced challenges from limited time, coins, and feedback

Table 5 Mann-Whitney *U* test results of the post-chemistry motivation ratings of the two classes

Chemistry motivation	Conventional inquiry-based learning class ($n = 31$)		Game-transformed inquiry learning class ($n = 31$)		*Z*	*p* value
	M	SD	*M*	SD		
Intrinsic motivation	16.54	1.351	17.54	1.351	2.299	0.010*
Career motivation	17.10	3.259	17.45	3.434	0.524	0.300
Self-determination	15.19	2.079	17.09	2.308	2.530	0.005*
Self-efficacy	13.43	1.869	15.64	2.405	2.153	0.017*
Grade motivation	18.62	2.908	17.86	2.875	1.260	0.104

$^*p < 0.05$

data. These characteristics interested and motivated the students to learn the content regarding the properties of liquid. In other words, during gameplay, students found that learning about the properties of liquid was interesting and relevant to their life, which promoted their intrinsic motivation. Students expended sufficient effort and spent a large amount of time learning about adhesive force by rethinking their errors and receiving hints from teachers to save coins, which promoted their self-determination. Moreover, they were confident in understanding content and in labs thanks to visualizing the macroscopic, sub-microscopic, and symbolic levels of different pipes, which promoted their self-efficacy. Additionally, with the process of open-inquiry strategies, they could share and communicate the results and scientific phenomena provided by the game with their peers and teachers. Afterward, students could modify their understanding while developing their own knowledge about the properties of liquid. Meanwhile, students in the conventional inquiry-based learning activities mainly focused on concepts related to content with text-based layout, practice, and drills that required less conceptual construction and learning motivation. This difference could be the reason why the game-transformed inquiry-based learning approach significantly improved the students' conceptual understanding and promoted their chemistry motivation (i.e., intrinsic motivation, self-determination, and self-efficacy). The results comply with the view expressed by Huang (2011), Erhel and Jamet (2013), and Daubenfeld and Zenker (2015) that the game could promote students' learning motivation and engage them in learning with enjoyment. Furthermore, Antunes et al. (2012) and Dorji et al. (2015) also indicated that simulating real-life situations in games could support students' conceptual construction in an exploratory manner.

Although the experimental results show that the game-transformed inquiry-based learning approach was helpful to the students in terms of improving their conceptual understanding and promoting chemistry motivation (i.e., intrinsic motivation, self-determination, and self-efficacy), the results are based on the data collected from a single school; therefore, more experiments on chemistry courses need to be conducted in further study to ensure the same results. In addition, there are several concerns to be addressed within further study. First, it would be challenging to categorize students' learning styles when formatting game interfaces. Moreover, it takes time for teachers to prepare hints/feedback for the macroscopic, sub-microscopic, and symbolic levels of the different materials without assistance; therefore, it is important to develop supporting tools for teachers. In addition, to make this approach worth further study, it is necessary to improve the game by addressing the conceptual difficulty level for students in each gaming stage.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Mahidol University Central Institutional Review Board, Thailand with the COA No. MU-CIRB 2018/091.0105 declaration and its later amendments or comparable ethical standards.

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