

A Contextual Online Game based on Inquiry Learning Approach for Improving Students' Learning Performance in a Chemistry Course

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Abstract: Digital game, a technological tool, can be in the form of a scenario or simulation with specific rules and principles for assisting students' construction of knowledge and promoting their motivation. However, how to trigger students for acquiring educational goals in playing game remains to be settled, especially for chemistry course. In this study, a contextual educational digital game based on an inquiry-based learning strategy is developed to improving students' learning performance. An experiment has been conducted on a high school chemistry course to evaluate the effects of the proposed approach on the learning performance of students. The experimental results indicate that the proposed approach effectively enhanced the students' learning performances in terms of their conceptual understanding and learning motivation.

Keywords: Science education, instructional design, learning strategies, active learning

1. Background and Motivation

With the significance of connecting chemical content to real life, researchers are aware of teaching and learning process for chemistry concept in classroom. Chemistry, which is the one of most important discipline, explains daily life phenomena. Its concept related to other concepts in science such as the biology, physics and materials science. The nature of chemistry is abstract content, which need to use imagination for connecting to real life situation. Chemistry requires three different levels of representation, which are macroscopic, submicroscopic, and symbolic level. The topic of adhesive force in chemistry uses three levels of representation for explaining the phenomena. This topic related to understanding the basic phenomena in the science curriculum that student is incomprehensible (Eilam, 2004; Leite et al., 2007). There are many factors related to difficulty in learning chemistry. Sirhan (2007) indicated the main factors of the learning difficulty in chemistry are curriculum content, overload of students' working memory space, motivation, language, and communication. Several researchers revealed that motivation, which is one of physiological processes, influences human behaviors when being doing something (Moos and Marroquin, 2010), especially, learning in an educational environment (Murphy and Alexander, 2000). Moreover, positive attitudes to learning influence motivation to learn led to success in learning (Osborne et al., 2003).

With the rapid growth of technology-enhanced learning approach, teaching and learning by using the digital game-based learning has been recognized as a model that combines computer technology into the instruction, such that the students who learned with the digital game-based learning can gain both enjoyment and knowledge (McNamara et al., 2010). In recent years, researchers have developed the educational digital game-based learning to support learning performance in several areas. For example, Yien et al. (2011) showed that a game-based learning approach could help students to improve their learning achievements in a nutrition course. Yang et al. (2012) proposed a digital game-based learning system for energy education for the children in the

school. Chee and Tan (2012) designed and developed an educational game named Legends of Alkhimia. They found that the developed game effectively fosters learning and supports conceptual understanding of chemistry. Moreover, researchers showed that the digital game-based learning could promote students' learning motivation. For example, Huang (2011) found that the Trade Ruler game could improve students' learning motivation in introduce economic. Papastergiou (2009) found that students who learned with the computer game have more motivational than the non-gaming approach.

Moreover, to trigger trigger students for acquiring educational goals in playing game, the use of inquiry-based learning strategy could encourage students to conceptualize a problem and then conduct experiment to find out possible explanations related to that problem (Olson and Loucks-Horsley, 2000). Hwang, et al. (2015) revealed that a contextual game basing on inquiry-based learning approach to enhance students' learning achievement, learning motivation, satisfaction degree, and flow state on deposits and investments topic in social studies course. Accordingly, the development of digital game with the support of inquiry-based learning activities has become an important and challenging topic, especially in chemistry course. This study extended the digital game developed by Nantakaew and Srisawasdi (2014) for engaging students in meaningful learning activities and examined students' learning performance in terms of conceptual understanding in chemistry course and learning motivation.

2. The development of Contextual Online Game based on Inquiry Learning Approach

In this study, the inquiry-based learning contexts were incorporated into contextual gaming scenarios for promoting students' learning performance in chemistry courses. The main gaming interface enables students to learn in various gaming contexts based on the contextual dramas related to chemistry. There are two games named Pipe-game and Factory-game for encouraging chemistry learning.

The main objective of the Pipe-game is to improve students' conceptual understanding of adhesive force in chemistry course. The main elements (water and pipe) are executed by the players (students). Thus, the students are encouraged to use knowledge of macroscopic, sub-microscopic and symbolic levels in chemistry to select pipe. The students then get a visual idea of water flow timing when using different material of pipe. Such that the game is not complicated game technology. That is the Pipe-game was simple and based-on the traditional simulation game mechanics like reward, encourage, and rethink. Moreover, the game provides the story and mission to students. That is why the Pipe-game was interested and motivated the students to learn the adhesive force content. In the first stage of our game, the learning objectives are introduced to the students. Before participating in the game, they are asked to investigate their prior knowledge on adhesive force. Moreover, the rules, basic functions, and missions of the game are demonstrated. For example, the students receive the problem situation in the factory. The problem states that the water flow through pipes is slowly; if you were a chemist, how do you handle/select the proper pipe to increase rate of water flow. Once the students understand the situation, the game also provides scaffolding for making decisions. The students can see molecular structure of each pipe. In this part, the students can observe experimental demonstration of the water flow. However, the students need to pay coins for seeing that demonstration. During this stage, the students encounter various challenges that they must overcome in order to progress. In this stage, the students have to buy the various shapes of each pipe for connecting two fixed pipes to each other. The teachers have to encourage them to concern about the coins that they have. Thus, they have to play and win the game in order to save coins for playing in the next stage. The ultimate goal of the students is to fix the water flow through pipes in the factory by saving coins. To achieve the ultimate goal, they have to complete that the four bottles are filled. By completing each bottle, the students can gain the knowledge of adhesive force for different pipes that they select by seeing information of macroscopic, sub-microscopic and symbolic level (See details in Nantakaew and Srisawasdi, 2014).

The main objective of the Factory-game is to improve students' conceptual understanding of properties of liquid topic including the main concepts of cohesive force, evaporation, and boiling in chemistry course. The Factory-game was based-on the mechanics as story and mission, reward,

rethink, and encourage by seeing the visualization of molecule. Thus, the students are encouraged to use prior-knowledge for constructing each main concept knowledge on their own. The main elements (such as chemical boxes, road, and cannons) are executed by the players (students). Such that the game was interested and not complicated game technology for the secondary school students. For example, to gain the knowledge of cohesive force, the students were asked to transfer chemical box through the different surfaces of road as shown in Figure 1. That is, the prior-knowledge about polarity is required. Moreover, the students can use coins to buy visualization to see the molecular structure of the chemicals, which presents in sub-microscopic and symbolic level in chemistry. If the students transfer the chemical box with improper way, the chemical box will be broken and the coins will be decreased. It means that if they can transfer the chemical box with proper way, they can gain more coins to play the next stage for learning the next concepts.

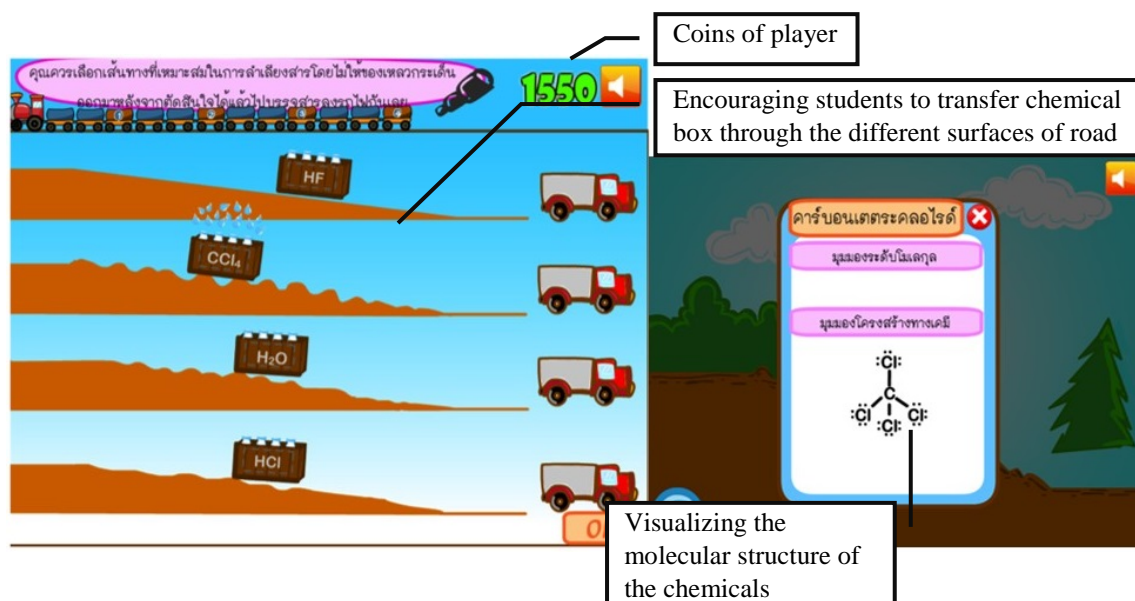


Figure 1. Illustrative examples of gaining the knowledge of cohesive force interface with in the Factory-game

Figure 2 shows how to gain the concept of boiling with in the Factory-game. Before playing game, the students received the mission for collocating suitable chemicals into four thermostat boxes in which each box has the different temperature inside and the levels of molecular changes. During playing game by shooting molecule with the different power of cannons, the boiling phenomena will be shown. For each molecule-shooting, it is consumed different times of deciding matching among chemicals with the different thermostat boxes. Moreover, the simulated vaporization and bubble are shown. From this information, the students were asked to discuss the concepts of evaporation and boiling phenomena. That is, the evaporation phenomena is a type of vaporization of liquid occurs from the surface of liquid, while boiling phenomena occurs when liquid is heated and then bubble is shown. When finishing the Factory-game by gaining the concept of boiling, the students who had the maximum coins are said winner.

3. Research Design

To evaluate the effectiveness of the proposed approach in this study, a quasi-experiment with non-equivalent groups was employed. The aim of the experiment was to compare the conceptual understanding and learning motivation of the students who learned with the contextual online game based on inquiry learning approach and those who learned with the lecture-based inquiry learning approach.

3.1. Participants

An experiment was conducted on a high school in chemistry course. The participants of this experiment were eleventh graders secondary school in Northeast of Thailand. A total of 63 students participated in this study. 32 students were assigned to be the experimental group, and 31 ones were assigned to be the control group. The students in control group learned with the lecture-based inquiry learning approach, while those in the experimental group learned with the same lesson by the contextual online game based on inquiry learning approach.

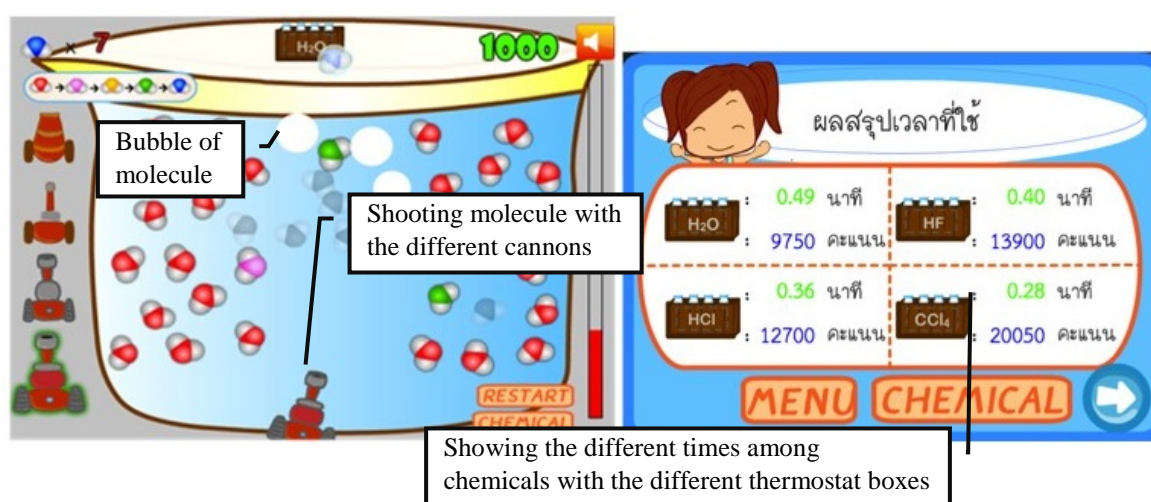


Figure 2. Illustrative examples of gaining the knowledge of boiling interface with in the Factory-game

3.2. Measuring Tools

In this study, a pre- and a post-conceptual understanding tests were implemented as the measuring tools. Both the pre- and the post-test were accommodated from Leite, Mendoza and Borsese (2007), Bridle and Yeziarski (2012) and were translated into Thai language by researchers. These 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 thirteen. The pre-test aimed to evaluate the students' prior knowledge of the adhesive force and properties of liquid content. On the other hand, the post-test aimed to evaluate the conceptual understanding of the students after participating in the learning activities.

Moreover, a pre- and a post-chemistry learning motivation questionnaires were used to evaluate their chemistry learning motivation before and after participating in the learning activities, respectively. According to Glynn et al. (2011), the Science Motivation Questionnaire II (Glynn et al., 2011) based on social cognitive theory was revised by authors for using as a discipline-specific version of the motivation questionnaire, and was used in this study to explore students' motivation to learn chemistry. It consisted 25 Thai language items on 5-point Likert scale in which "5" represents "always", "4" represents "usually", "3" represents "sometimes", "2" represents "rarely", and "1" represents "never". There were five dimensions of the questionnaire: intrinsic motivation (IM), career motivation (CM), self-determination (SDT), self-efficacy (SEC), and grade motivation (GM), and its internal consistencies of the subscales by Cronbach's alphas were 0.79, 0.81, 0.81, 0.89, and 0.85, respectively. The Cronbach's alpha value for the motivation questionnaire in Thai version was 0.92 implying good reliable.

3.3. Experimental Process

The experiment was conducted on the topic of the adhesive force and properties of liquid of eleventh grade students in chemistry course. Before the experiment, the students took the pre-test for evaluating their prior knowledge of the adhesive force and properties of liquid followed by the pre-

learning motivation questionnaire. The learning activities lasted 50 minutes in each class. The learning content for both the experimental and control group was the same. The students in experimental group learned with the proposed game, whereas those in the control group were taught with traditional teaching method. After learning activities, a post-test was conducted; moreover, the students were asked to response the post-learning motivation questionnaire.

4. Experimental Results

4.1. Students' Conceptual Understanding

Before conducting the inferential statistic tests, we found that pre-test scores from the control group were normally distributed by Shapiro-Wilk test ($p = 0.071$), while those from the experimental group were not normally distributed as indicated by Shapiro-Wilk test ($p = 0.001$). Therefore, we deal with non-parametric hypothesis test, Mann-Whitney U test is used to analyze pre-test scores from both the control group and the experimental group. It was found that the mean \pm standard deviation of pre-test of the experimental group was 2.71 ± 1.553 , and of control group was 2.82 ± 1.268 . There was no significant difference between the mean score of pre-test of the control and the experimental groups ($z = 0.468, p = 0.320$), indicating that the students in both the groups had similar prior knowledge regarding the topic of the adhesive force and properties of liquid content. Furthermore, to examine how the conceptual understanding was affected by the teaching and learning method after the implementation of the proposed game, the post-test scores of both control and experimental groups were analyzed with non-parametric hypothesis test, Mann-Whitney U test, as shown in Table 1.

Table 1. Mann-Whitney U result of the post-test

Groups	N	Mean \pm SD	Z	p-value
Control Group	31	3.85 \pm 1.916	2.664	0.004*
Experimental Group	32	5.48 \pm 2.401		

* $p < 0.05$

The results in Table 1 shows the mean score of post-test for the experimental group were significantly higher than that for the control group, implying that the proposed game could enhance better promoting conceptual understanding in the adhesive force and properties of liquid content in chemistry course.

4.2. Students' Learning Motivation

Non-parametric hypothesis test, Mann-Whitney U test, was employed to analyze the students' pre-learning motivation by adopting teaching and learning methods (i.e., the proposed game and traditional teaching). Six students and five students in control and experimental group non-responded to the questionnaire, respectively. As shown in Table 2, the Mann-Whitney U result shows that the students in both the groups had similar learning motivation before participating in learning activity.

Table 2. Mann-Whitney U result of the pre-learning motivation questionnaire

Learning motivation	Control Group (N=25) Mean \pm SD	Experimental Group (N=27) Mean \pm SD	Z	p-value
Intrinsic motivation	16.72 \pm 2.132	16.83 \pm 2.221	0.264	0.346
Career motivation	16.97 \pm 3.987	15.87 \pm 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

Furthermore, to evaluate how the learning motivation was affected by the teaching and learning methods after the implementation of the proposed-game learning method, the post-learning motivation of both control and experimental groups were analyzed with non-parametric hypothesis test, Mann-Whitney U test, as shown in Table 3.

Table 3. Mann-Whitney U result of the post-learning motivation questionnaire

Learning motivation	Control Group (N=25) Mean ± SD	Experimental Group (N=27) Mean ± SD	Z	p-value
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

* $p < 0.05$

The results in Table 3 shown that there are significant differences of the post-learning motivation: intrinsic motivation, self-determination, and self-efficacy scores between the experimental group and the control group. In the other words, the mean scores of post-learning motivations on intrinsic motivation, self-determination, and self-efficacy for the experimental group were significantly higher than those for the control group, suggesting that the proposed game learning method could improve intrinsic motivation, self-determination, and self-efficacy in topic of properties of liquid more than the traditional teaching and learning method.

5. Discussions and Conclusions

The main objective of this study is to compare the conceptual understanding and learning motivation on the topic of the adhesive force and properties of liquid content between students who learn with the contextual online game based on inquiry learning approach and those who learned with the lecture-based inquiry learning approach. The experimental results were presented, which help in understanding whether the contextual online game based on inquiry learning approach contribute to conceptual understanding and learning motivation. It was found that the game significantly improved the students' conceptual understanding. As such, our study results verify that the game could play an important tool in enhancing the conceptual understanding for students in the adhesive force and properties of liquid content. In the meantime, the results revealed that students who learned with the game showed higher learning motivations: intrinsic motivation, self-determination, and self-efficacy than those who learned with the conventional teaching approach.

From the developed games, it was found that students were asked to action, reaction, apply knowledge, see experiment demonstration, and see molecular changes in phenomena by being involved in contextual scenarios. For the first game, the students were asked to explore adhesive force in pipes and the rate of water flow from visualizing the macroscopic, sub-microscopic and symbolic level in different material of pipes and simulating water flow through each pipe encouraged them to

acquire adhesive force knowledge. Students' explorations involved reward, encourage, and rethink from errors for saving coins as much as they can. For the second game, there are feedback after finishing each stage. Students could connect liquid splashing when moving through the different surfaces of road with the cohesive force of liquid content. Moreover, when shooting molecule using the different power of cannons, the students were asked to show their understanding about evaporation and boiling phenomena. These are non-observable in everyday life. They also faced challenge with limited time, coins, and feedback data. These were interested and motivated the students to learn the properties of liquid content. In other words, during playing game, learning properties of liquid was interesting and relevant to their life led to promote students' intrinsic motivation. They could put enough effort and spent a lot of time learning adhesive force by rethinking from errors and receiving teachers' hints for saving coins led to promote their self-determination. Moreover, they were confident in understanding content and on labs from visualizing macroscopic, sub-microscopic and symbolic level of different pipes led to promote their self-efficacy. Meanwhile, the students in the conventional teaching approach mainly focused on concepts related to content with text-based layout, practice, and drill that required less conceptual constructing and learning motivation. This could be the reason why the developed digital educational chemistry games significantly improved the students' conceptual understanding and promoted their learning motivations (i.e., intrinsic motivation, self-determination, and self-efficacy). The results comply with the view expressed by Erhel and Jamet (2013), Huang, Hung and Tschopp (2010), Daubenfeld and Zenker (2015) that the game could promote students' learning motivation and engage them in learning with enjoyment; furthermore, on Dorji, Panjaburee, and Srisawasdi (2015) and Antunes et al. (2012) indicated that simulating game could support students' conceptual construction in an exploration manner. Moreover, these experimental results are in line with previous studies, which stated that the game with authentic scenarios could improve learning achievement and learning motivation (Chee and Tan, 2012; Hwang et al., 2015; Sung et al., 2017).

Although, the experimental results show that the game effectively enhanced the students in terms of conceptual understanding and leaning motivations (i.e., intrinsic motivation, self-determination, and self-efficacy). In particular, students' conceptual understanding mean score is less than a half of total score, implying that the mean score is quite low. This suggests the need to provide additional supports to students with particular method in the future. For example, teachers can take role to provide hints/feedback for macroscopic, sub-microscopic and symbolic level for assisting students during exploring in the gaming contexts. In addition, to make worth further study, it is to improve the game by concerning conceptual difficulty level of students in the gaming context manner.

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