# *Bio Detective:* Student science learning, immersion experience, and problem-solving patterns

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**Abstract:** Many studies have shown that there is a positive impact of serious educational games (SEGs) on student learning. Because of the game graphics, animations, sounds, and narratives, the learners can immerse in the virtual surroundings. Once they immersed, they might try their best to solve the in-game tasks. Therefore, the purpose of this study was to develop a SEG–*Bio Detective* and to evaluate its impact on student science learning outcomes. Moreover, we further investigated the relationships between students' game immersion experience and their science learning and problem solving. The obtained results showed that student science learning can be significantly improved through *Bio Detective* play, but there were no significant correlations between game immersion and learning outcomes. Comparing the problem-solving patterns and problem-solving abilities between students with high- and low immersion experience, we found that students with high immersion experience had a more complete problem-solving pattern and a better problem-solving performance than students with low game immersion experience.

**Keywords:** serious educational games, problem solving, immersion

## 1. Introduction

With the rapid improvement of technology, video game play has become popular entertainment. Most of today's children have the experience of playing video games. Due to the features of video games, such as excellent interaction and attractive entertainment, which engage players so much, researchers and educators commenced considering the probabilities of using video games in education since 2002 (Griffiths, 2002; Squire, 2008). Up to now, serious educational games (SEGs) have gradually become a term indicating any video games which are used for teaching and learning purposes in k-20 educational settings (Annetta, 2008). Mouaheb, Fahli, Moussetad and Eljamali (2012) suggested that playing SEGs is actually the process of learning and many studies have shown that SEGs did have a positive impact on various aspects of learning, such as learning achievement, cognitive development, learning motivation, and learning interests (Hwang, Yang, and Wang, 2013; Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). SEGs have been regarded as a potential vehicle which can enhances student learning because SEGs not only contain the entertaining features of games, but also combine those game features with learning content, which make learners engage in the game and further learn in the virtual surrounding (Van Eck, 2006; Cheng, Su, Huang, & Chen, 2013).It is generally argued that SEGs can provide learners with a vivid world which bridges virtual reality into reality in where players can experience so-called situated learning.

Brown and Cairns (2004) and Cheng, She, and Annetta (2014) contended that games can provide players with game immersion experience. The animations, sounds, and sophisticated graphics of games offer players an immersive environment in where they might ignore changes and forget everything at their surroundings; moreover, they might feel like they are the leading role of the game, and therefore put their whole concentration, thoughts, and even emotions into the game. While players experiencing game immersion, their intrinsic motivation and intrinsic rewards may increase, which subsequently make them actively play the game again and again. If the experience of immersion happened in the learning situation that allows learners to involve in the surrounding without external interference, then they will be willing to invest time and effort to learn. In terms of SEGs, the learners

will try to learn constantly because of the characteristics of SEGs of appropriately combining game features with learning content. Students will be getting familiar with the embedded concepts because of continuing practices while immersing in the game and better learning outcomes will subsequently reached (Liu, Cheng, & Huang, 2011).

On the other hand, the players have to learn the rules and plan and figure out ways to solve tasks and problems in the virtual environment in order to succeed in the game. Garris, Ahlers, & Driskell (2002) proposed the concept of input-process-outcome game model, claiming that SEGs offer an immersive environment which allows players to experience the game cycle of judgment–behavior–feedback and finally debriefing learning outcomes. The game cycle is actually the mechanism that provides the players with the complete problem-solving pathway. Therefore, it is argued that the problem-solving ability of players can be improved if they enjoy and immerse in the game (The Economist, 2005).

Although theoretical claims have been proposed by many researchers to explain why SEGs can improve student learning, there is still a lack of evidence that empirically investigates the impact of SEGs on student learning outcomes and how game immersion experience influences student learning outcomes and problem-solving patterns. Therefore, this study has a dual purpose. One is to develop an SEG, *Bio Detective*, to improve student science learning, and the other is to figure out the relationships between student science learning, game immersion, and problem solving through SEG playing.

## 2. Materials and methods

### *2.1 Serious educational game design*

#### *2.1.1 Bio Detective*

In this study, the developed SEG, entitled *Bio Detective*, is an adventure/role-playing game. The storyline of *Bio Detective* is that there is a murder happened and the player should play as a detective's assistant in the game. What he/she has to do is to collect clues, to conduct experiments to do blood-type and glucose tests, and to interpret data to find out whom the murderer actually is. Therefore, the scientific concepts embedded include the inheritance of blood-types (the inheritance of multiple alleles), blood-type test (antigen-antibody reaction) and glucose test.

Figure 1 is the laboratory scene in the *Bio Detective*. After collecting all the clues, the players are able to enter the lab to conduct experiments. They can drag any equipment they need to the table. If they drag the right equipment to the table, the button "Beginning of the experiment" will show up.


Figure 1. Laboratory Scene.

Figure 2 is the library scene. When the learners encounter problems and they don't know how to solve them, they can go to the library to find information which might be useful in helping them solve the problems.

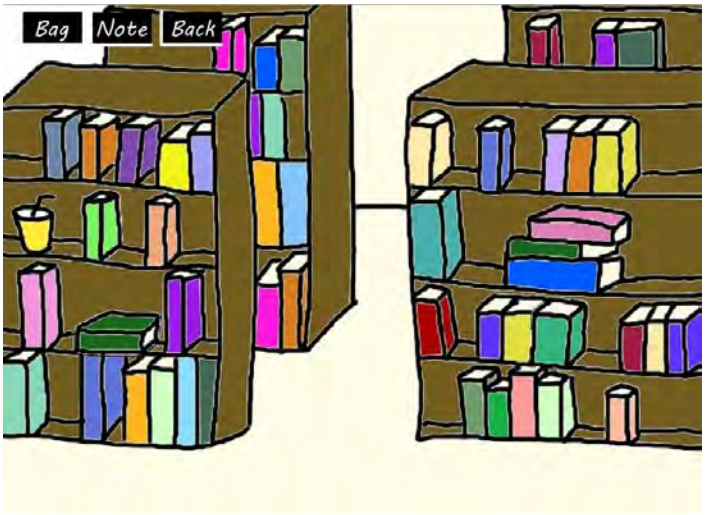


Figure 2. Library Scene.

*Bio Detective* is created in an attempt to provide learners with a virtual environment as well as a vivid context in where they can actively learn the relative biology knowledge which is required for completing the game. It is hoped that students' willingness and interests of learning can be improved because of their immersion in an atmosphere of suspense and excitement.

### *2.1.2 Learning objectives*

According to the scientific concepts and science process skills embedded in the game, several learning objectives were addressed as below:

- Cognitive domain (the learner is able to )
  1. Comprehend principles and procedure of the glucose test
  2. Understand the principles and procedure of the blood-type test
  3. Interpret the experimental results and perceive the meaning
  4. Reinforce the scientific concepts of genes and blood types
- Psychomotor domain
  1. Promoting the learner's ability to conduct the experiment independently
  2. Improving the learner's ability to solve problems
- Affective domain
  1. Fostering the learner's biological literacy
  2. Inspiring the learner's enthusiasm and interest in exploring the field of biology

## *2.2 Participants*

The participants were two classes of seventh grade students. One class consisted of 22 students and the other consisted of 30 students, resulting in a total of 52 students took part in the study.

## *2.3 Instrumentation*

The instrumentation in this study includes the learning achievement assessment, the game immersion questionnaire (GIQ), a semi-structured interview guide and the students' gaming performance.

In order to evaluate students' learning outcomes, the embedded scientific concepts, the inheritance of blood-types and the principles and procedure of blood-type test and glucose test, are included in the learning achievement assessment. The assessment consists of fifteen multiple-choice items and five non-multiple-choice items (two are fill-in-the-blank questions and three are well-structured questions), and its total score is 100. The $KR_{20}$ values of pretest and posttest were 0.75 and 0.78, respectively.

The GIQ was developed by Cheng, She, & Annetta (2014). It consists of 24 items categorized into three dimensions, engagement (9 items), engrossment (7 items) and total immersion (8 items), with

a five-point Likert scale ranging from 1(strongly disagree) to 5(strongly agree). The Cronbach's alpha value of the total questionnaire and three dimensions were 0.94, 0.87, 0.87 and 0.95, respectively.

The semi-structured interview guide is designed to explore the students' problem solving patterns while playing *Bio Detective*. It is divided into three parts. The first part includes questions regarding students' perceptions of the in-game tasks (question 1 to 4). The second part consists of stimulated-recall questions, asking students what were they thinking and doing in the game using the stimulated recall method by viewing the recorded videos of their game play simultaneously (question 5 to 9). The last part is to investigate students' feelings and suggestions regarding *Bio Detective* (question 10 to 13).

Finally, students' gaming performance was recorded in the database, such as the number of times and duration students played the game and whether they have successfully completed the game or not. The gaming performance represents as the efficiency and accuracy of student problem-solving process.

### *2.4 Procedure*

Before playing *Bio Detective*, students received a 45-min lecture about human ABO blood type first. After the lecture, the pre-test of learning achievement assessment was administrated.

Then, students were allowed to spend two sessions (90 min) playing *Bio Detective*. After finishing the play, an identical posttest of learning outcomes with different order of items was distributed to students no matter they succeed or fail the game. Moreover, the post-experience GIQ was also applied to investigate student game immersion after playing *Bio Detective*.

According to the GIQ scores, we selected four students with the lowest GIQ scores as low immersion group and the top four students as the high immersion group to conduct stimulated-recall interviews.

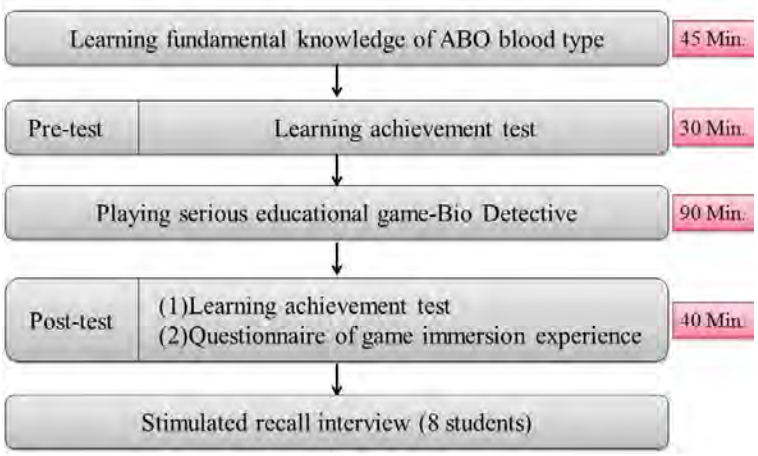


Figure 3. Experiment procedure.

## 3. Result

### *3.1 Knowledge assessment*

Table 1 shows the results of paired-sample t-test. It is demonstrated that there was no significant difference between student performance on pre- and posttest of multiple-choice questions ($t=-0.15$, $p>0.05$), but the performance on the non-multiple-choice test had significantly improved ($t=-4.57$, $p<0.01$). Overall, the students' learning achievement were significantly improved after playing *Bio Detective* ($t=-2.95$, $p<0.01$).

Table 1: Result of the t test showing the per-test and post-test score.

| | Pre-test | | Post-test | | t value (pre-post) |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| Multiple-choice test | 37.92 | 12.95 | 38.08 | 13.54 | -0.15 |
| Non-multiple-choice test | 30.69 | 7.87 | 34.77 | 6.30 | -4.57** |
| Total score | 68.60 | 19.09 | 73.08 | 18.31 | -2.95** |

** $p<0.01$

### *3.2 Impact of immersion on learning achievement*

Table 2 shows the results of Pearson correlations between game immersion experience and students' learning achievement. It is showed that the three scales, engagement, engrossment and total immersion were highly inter-correlated. However, there was no significant correlation between game immersion experience and learning achievement.

Table 2: Result of Pearson's Correlations between Game Immersion Experience and students' learning achievement.

| | Mean | SD | Engagement | Engrossment | Total immersion |
|---|---|---|---|---|---|
| Engagement | 32.06 | 7.36 | | | |
| Engrossment | 20.79 | 7.16 | 0.46** | | |
| Total immersion | 23.25 | 8.78 | 0.56** | 0.71** | |
| Pre-test | 68.60 | 19.09 | 0.23 | 0.00 | -0.15 |
| Post-test | 73.08 | 18.31 | 0.25 | 0.02 | -0.00 |

** $p<0.01$

### *3.3 Impact of immersion on problem solving pathway*

Figure 4 reveals the high immersion group students' problem solving pattern, inferring from the stimulated-recall interview. This shows that the high immersion group students knew what happened in the game. These students show that they had already planned how to find out the murderer before looking for the clues. They also demonstrated the ability to use the resources provided to search for information from the library or discuss with classmates when facing problems in the game. Most of them found the information provided in the library were useful. All of them completed the *Bio Detective* successfully.

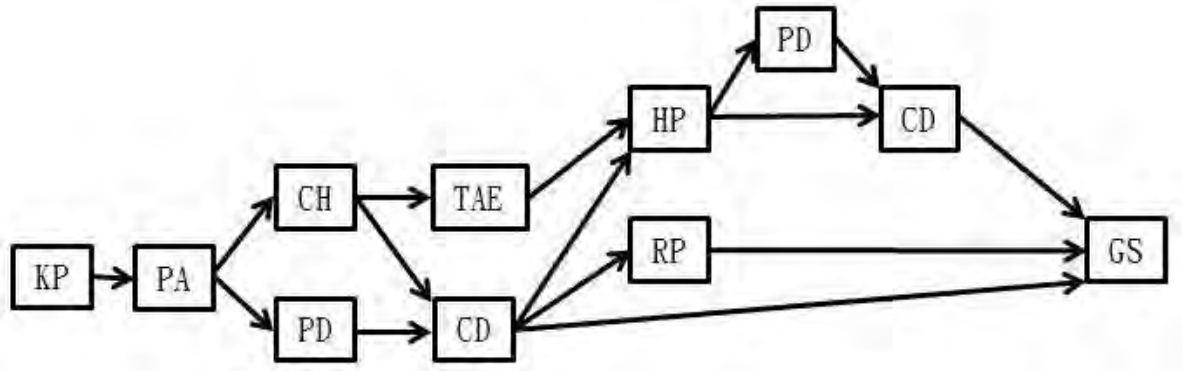


Figure 4. High immersion group students' problem solving pattern.
Note. KP= knowing the problem; PA=Plan in advance; CH=Collect hints; PD=Peer discussion; TAE=Trial and error; CD=Collect data; HP=Have problem; RP=Re-plan; GS=Games success.

Table 3 shows the results of the high immersion group students' accuracy and efficiency of problem-solving ability. Student H1, H3, H4 completed the game in 40 to 45 min. Student H2 spend much more time than others. But his learning progress was better than any others in the high immersion group (pre-test score=46; post-test score=80).

Table 3: High immersion group students' accuracy and efficiency of problem-solving ability.

| Student | Game times | Playtime | Accuracy |
|---|---|---|---|
| H1 | 2 | 41 Min. | success |
| H2 | 4 | 55 Min. | success |
| H3 | 2 | 45 Min. | success |
| H4 | 2 | 42 Min. | success |

Figure 5 depicts the low immersion group students' problem-solving pattern. It shows that the low immersion students might not know what happened in the SEG. These students required teacher's guidance in order to understand the directions of the game. In the low immersion group, not all the students had a plan to find out the murderer. They tend to use trial-and-error strategy to solve problems. Some of them might ask teachers or peers for help when they cannot find the answer.

There was one student who couldn't solve the problem, so she didn't complete the game. While another student used guessing method to identify the suspects.

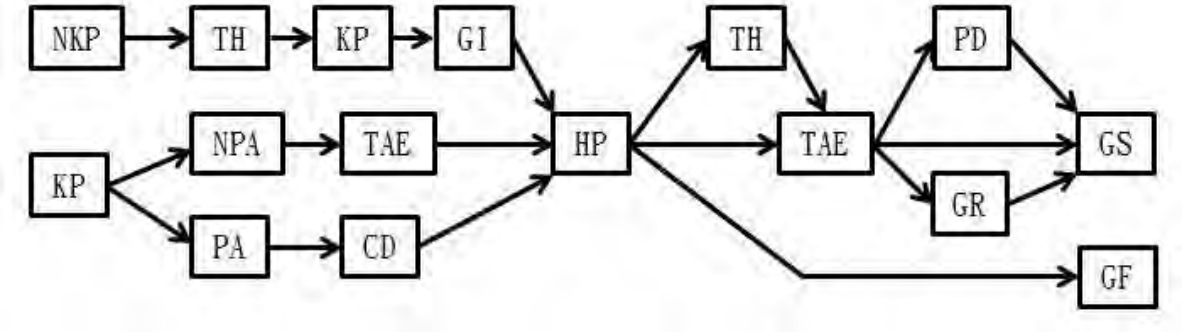


Figure 5. Low immersion group students' problem solving pattern.

Note. KP=Knowing the problem; NKP=Not knowing the problem; TH=Teacher hint; PA=Plan in advance; NPA=Not knowing the problem; GI=Games instructions; PD=Peer discussion; TAE=Trial and error; CD=Collect data; HP=Have problem; GR=Guess result; GS=Games success; GF=Games failed.

Table 4 shows the results of the students' accuracy and efficiency of problem-solving ability low immersion group. Student L3 cost less time than any other. However, she used trial and error method to complete the game. Like other students in the low immersion group, she also didn't have any plan before looking for clues, instead, she find those clues one by one.

Student L1, L3, L4 spends 55 to 65 min to finish the SEG. There was one student who failed to complete the game.

Table 4: Low immersion group students' accuracy and efficiency of problem-solving ability.

| Student | Game times | Playtime | Accuracy |
|---|---|---|---|
| L1 | 2 | 59 Min. | success |
| L2 | 4 | 65 Min. | failure |
| L3 | 1 | 28 Min. | success |
| L4 | 3 | 55 Min. | success |

Overall, the high immersion group students demonstrated higher level of problem-solving ability than students in the low immersion group. In the high immersion group, all of them completed the SEG and spend less time compare to the low immersion group.

## 4. Discussion and conclusions

In recent years, many studies have shown that SEGs can provide students with meaningful learning experience, as the design of SEGs attempts to combine learning content with game format which increases the opportunity of motivating and engaging students in the learning activities embedded in the game (Federation of American Scientists, 2006). In other words, proper game design promotes

*immersive* experience of students and increases their willingness to learn the concepts and materials in the game (Cheng, She, & Annetta, 2014). Today, SEGs have been considered one of the potential methods for students to learn and construct knowledge (Pivec, 2007). In this study, a SEGs, *Bio Detective* was developed and its effectiveness was investigated. It is found that the participants did learn the scientific concepts embedded in *Bio Detective* as their performance on the knowledge assessment significantly improved after playing the game. The results are in alignment with previous studies illustrating that learning through playing SEGs can be effective for student biology learning (Cheng, Annetta, Folta, & Holmes, 2011; Cheng, &Annetta, 2012; Cheng, Su, Huang, & Chen, 2013; Cheng, She, &Annetta, 2014).

What is interesting in the study is that, students performed significantly better on non-multiple-choice questions rather than multiple-choice ones. As we might know that multiple-choice questions generally involve tasks related to recognition, and students all have to do is to choose or recognize the knowledge that has been learned. On the contrary, non-multiple-choice questions require students to recall relative information from their memory. Compared to recognition, it is a higher-level information processing because students have to recall specific knowledge and concepts without any clues or hints (Sternberg, 2009). Only when the knowledge has been elaborately processed by students, can they been easily and accurately recalled. As a result, it is more difficult for students to answer non-multiple-choice questions if they are not very familiar with and never elaborately process the concepts. However, our study revealed that the use of *Bio Detective* is much more helpful for students to understand what they have learned and even learned better because of their better performance on the recall tasks.

This study also explored whether the different degree of student game immersion can impact student science learning outcomes through SEG play. The results of Pearson's Correlations indicate that the three dimensions, engagement, engrossment and total immersion were highly inter-correlated. However, there was no significant correlation between game immersion experience and science learning outcomes. The results are pretty much in accordance with the previous study conducted by Cheng, She, & Annetta (2014). Researchers have suggested that cognitive load might be a key that should be considered while learning through SEG play (Cheng et al., 2014; Cheng et al., 2013). What should be taken into account is, in which aspect do the students really invest their mental effort? The game itself such as storylines and narratives or the educational aspect such as the embedded concepts and knowledge required for completing the game? Obviously, more mental efforts students spend in the game, more engaged they are. However, they might ignore the educational materials they should learn in the SEGs because of over immersing in the game.

Furthermore, immersion experience engages and even absorbs learners in a situation. While experiencing game immersion, learners invest much time and efforts in solving the tasks because of the enhancement of their internal motivation. Hence, the ability of problem solving should be considered an important element of learning outcomes of SEG play either. Only assessing the effectiveness of SEGs from the aspect of concept acquisition might underestimate the impact of using SEGs on students' science learning. The obtained results of the study additionally demonstrate that although there were no correlations between game immersion and concept learning, differences in student problem solving patterns did exist between students with high and low game immersion experience. Sternberg (2009) proposed that people who have better problem solving ability will prefer to spend time on planning how to solve the problem. On the contrary, people with poor problem solving ability will cost lots of time to trial and error, without any strategy. According to the playtime, game accuracy and problem solving pattern, we found that students with high immersion performed better than the students with low immersion in the game. The high immersion group would plan how to complete the task before finding the clues and they spent less time completing *Bio Detective* than students in the low immersion group did. Namely, in the high immersion group, students have better problem solving performance. When the students immersed in the SEG, the immersive experience might enhance learning. Students would change their perspective and engage in the game (Dede, 2009) as if they were the real detective. That is why high immersion group had better problem solving performance.

Problem solving is an important aspect of learning. Students learn at school and the teachers provide lots of knowledge for students to learn. It is hoped that students will utilize what they have learned in the classroom to solve daily life problems instead of rote learning. As a pilot study, we found that students with high immersion experience perform better problem-solving strategies in the SEG –

*Bio Detective*. Although SEGs provide learning experience, the problem solving ability which is affected by SEGs need to be further investigated.

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