Investigating the Incubation Effect among Students playing Physics Playground

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Abstract: We investigate the Incubation Effect (IE), a phenomenon by which a momentary break facilitates the generation of a solution to a problem, and its relationship with both achievement and affect of middle school students playing Physics Playground. Statistical data reports no significant improvement in the overall performance when breaks are done. Also, the success rate of solving problems after taking a break has no significant difference with the success rate of attempts without breaks. This could be attributed to the fact that the activity done during breaks is very similar to the problem-solving task, but further investigation needs to be done for validation. The results may say IE has not improved the in-game achievement of students, however, majority of IE occurrences resulted to success. This is evidence to support the positive effect of incubation. Also, a significant positive correlation was found between IE incidence and frustration.

Keywords: Incubation Effect, Physics Playground

1. Introduction

When a student, or learner, engages in a problem solving activity, he or she sometimes gets stuck with the problem. A learner who is stuck feels to be out of control, loses focus. “Stuck” often leads to mental fatigue and distress (Burleson & Picard, 2004).

One of the solutions to being stuck is to take a momentary break. Students engage in a different task, after which they return to the original problem, and are suddenly able to find a solution. This short, beneficial break and its positive result is known as the **Incubation Effect** (IE). The phenomenon is divided into three phases (Gilhooly, Georgiou, & Devery, 2013): (a) pre-incubation phase, (b) incubation phase, and (c) post-incubation phase. In the pre-incubation phase, learners start to solve a particular problem. The learner takes a break from the problem-solving task and engages in a different task during the incubation phase. Lastly, the learner goes back to the task and eventually solves the problem during the post-incubation period.

Many studies (Fulgosi & Guilford, 1968; Gilhooly et al., 2013; Penaloza & Calvillo, 2012; Sio & Ormerod, 2009) have claimed that taking a break in the middle of the performance of an engaging task helps results in more effective and creative solutions than continuously working on a problem. Many of these studies recommend engaging in a significantly different activity during the incubation from the task at hand for a better effect. However, another study claims that the task during incubation has no effect (Segal, 2004). Attention withdrawal would be enough to facilitate a shift from a misleading solution to a more useful solution of the problem. It is also suggested that engaging in a task with similar nature would promote priming, where a solution would be unconsciously formed during incubation, and would then eventually emerge during the post-incubation phase (Penney, Godsell, Scott, & Balsom, 2004).

IE’s positive effects are not limited to cognitive outcomes. It is presumed that the underlying processes are emotional in nature (Beeftink, van Eerde, & Rutte, 2008). Those that utilize a flawed strategy often build up negative feelings such as frustration and confusion, and then reach a certain peak that would result in an impasse. Breaks generally minimize the possibility of reaching this impasse.

The presence and effects of IEs and similar phenomena may differ depending on context. For example, studies comparing achievement between private and public schools (Bernardo, Ganotice Jr., & King, 2015; Carbonaro & Covay, 2010; Chua, 2000; Coulson, 2009; Jimenez, Lockheed, & Paqueo, 1991; Jimenez, Paqueo, & de Vera, 1988) showed that students in private schools tend to outperform their public schools counterparts. According to Bernardo et.al (2015), the availability of funding and infrastructure, among others, contribute to this gap. In this study, we consider the possible impact of the school classification on the incidence of IEs.

This study investigates the occurrence of the incubation effect among users who play Physics Playground, a physics-based problem solving game, and its relation to both in-game achievement and observed affective states.

This study asks the following questions:

1. What is the incidence of IEs among users playing Physics Playground?
2. What is the relationship between the incidence of IEs and in-game achievement of the players?
3. What is the relationship between IEs and affect?
4. How does school classification (private or public) affect the incidence of IE?

2. Physics Playground (PP)

Physics Playground (PP), formerly Newton's Playground, is a two-dimensional computer game that is designed for high school students to better understand qualitative physics. These are concepts of how the physical world operates in relation to Newton's laws of motion: balance, mass, conservation and transfer of momentum, gravity, and potential and kinetic energy (Shute & Ventura, 2013). Players are presented with a series of challenges in which players draw using the mouse, and their drawings become part of the physics environment. The core mechanic of the game is to guide a green ball to a red balloon by drawing physical objects and simple mechanical devices (i.e., ramp, lever, pendulum, springboard) on the screen that come to life once drawn. The example level of PP shown in Figure 1, for example, requires a pendulum as its solution. Everything obeys the basic rules of physics relating to gravity and Newton's three laws of motion (Shute & Ventura, 2013).

Figure 1. Example level of Physics Playground.

The 74 levels in PP encourage the player to solve levels in different and creative ways that adhere to the laws of physics via drawing different simple machines, representing agents of force and motion: inclined plane/ramps, levers, pendulums, and springboards. A ramp is any line drawn that helps to guide a ball in motion. A ramp is useful when a ball must travel over a hole. A lever rotates around a fixed point, usually called a fulcrum or pivot point. Levers are useful when a player wants to move the ball vertically. A swinging pendulum directs an impulse tangent to its direction of motion. The pendulum is useful when the player wants to exert a horizontal force. A springboard (or diving board) stores elastic potential energy provided by a falling weight. Springboards are useful when the player wants to move the ball vertically. In addition, players can create their own levels and watch replays of how they completed a level (Andres & Rodrigo, 2014).

When a player solves a level, he or she receives a gold or silver badge. A gold badge is awarded when the player solves the problem at or below a par value of agents previously determined by the game designers. If a player solves the level with more objects than the ideal solution, a silver badge is awarded. Figures 2a and b illustrate the icons for gold and silver badges.

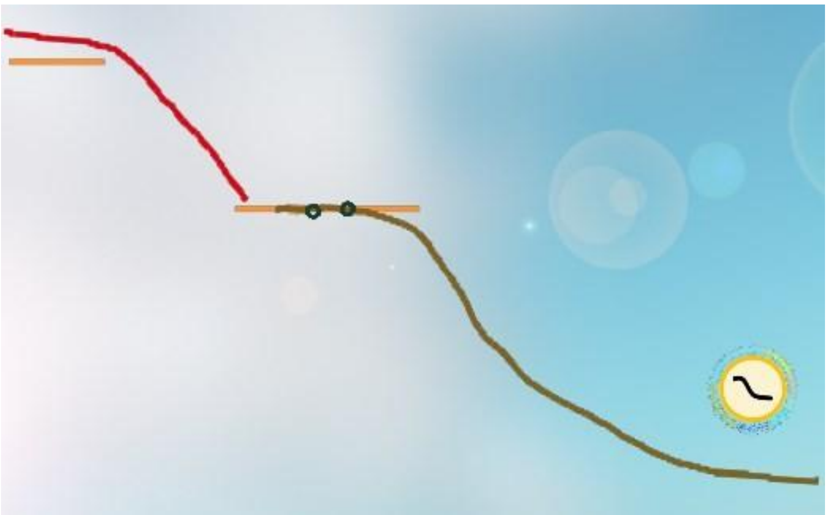

Figure 2a. A gold badge is awarded after solving a level in PP

Figure 2b. A silver badge is awarded after solving a level in PP

3. Methodology

3.1 Data Set

The participants were 60 eighth grader or 2nd year high school students from Baguio City, Philippines. Twenty-Nine students were from Bakakeng National High School (BNHS), a public junior high school; and 31 from the University of the Cordilleras (UC), a private university. Age ranges from 13 to 18 years old (M=15.7). Of the 60 participants, 31 are male and 29 are female. All students were asked to play Physics Playground for 90 minutes.

Two types of data were collected and used in this study: *interaction logs* and *human observations*. Interactions logs are generated automatically in PP during gameplay. For each level played, the players' interaction events were tracked and logged into a file. Relevant events examined in this study were:

- *Level Start*. Player starts a level attempt;
- *Level Restart*. Player resets the level to start another attempt;
- *Level End*. Player completes a level and PP gives out a badge for the specific agent used.
  - *Badge*. A visual representation (i.e. gold or silver) awarded due to a player for completing an event.
  - *Agent*. One of the four identified simple machines.
- *Menu Focus*. Player returns to the main menu.

These 4 events were used to identify the player's in-game behavior, which was later used to deduce the player's in-game performance (Shute & Ventura, 2013).

Prior works have been done on this data set. One determined the occurrence of wheel-spinning, a phenomenon where players try to solve a problem over and over again but to no avail of progress, among players (Palaoag, Rodrigo, & Andres, 2015). Certain classifiers were set to determine the occurrence of this phenomenon. The study found out that wheel spinning is present, and that it is a non-random occurrence. The other one is on the persistence of players (Palaoag et al., 2015). Markers on persistence as prescribed by Shute et al. (2013) were indicative not only of persistence, but that of wheel-spinning as well, as described by the previous study.

3.2 Identifying IE Occurrences

To identify the incidences of IE, the logs were pre-processed. Unnecessary columns were removed and remaining data were sorted by players, level, and time. Thereafter, the 3 IE phases were operationalized in the context of PP as follows:

Pre-Incubation Phase. The player attempts a level, X, for the first time, fails, and decide to leave the level.

Incubation Phase. After quitting level X, the player returns to the main menu and attempts other game levels.

Post-Incubation Phase. The player returns to the original level X and succeeds, earning either a gold or silver badge.

When a player returns to level X after the incubation phase, all attempts are labeled ***Potential IEs***. But once a player completes phase 3 with a gold or silver badge, the attempt is considered **IE-True**. An attempt is considered **IE-False**, on the other hand, when a player fails to solve the problem in the final phase despite the momentary pause exhibited.

3.3 Identifying Affect

The Baker-Rodrigo-Ocumpaugh Monitoring Protocol (BROMP) is a protocol for quantitative field observations of student affect and engagement-related behavior, described in detail in (Ocumpaugh, Baker, & Rodrigo, 2012). The affective states observed within Physics Playground in this study were engaged concentration, confusion, frustration, boredom, happiness, and delight. The affective categories were drawn from (Ocumpaugh et al., 2012).

Participants were divided equally between two BROMP-certified observers present per session. Students from School A were observed in groups of 10, giving each BROMP coder 5 students to observe per session. Students from School B were observed in groups of 15, giving one coder 7 students, and the other coder, 8 students to observe per session.

Students were observed in 5 to 8-second intervals throughout the 90-minute observation period, resulting in at least two observations per student per minute. If the student exhibited two or more distinct states during his or her respective observation period, the observers only coded the first state.

The observers recorded their observations using the Human Affect Recording Tool, or HART. HART is an Android application developed specifically to guide researchers in conducting quantitative field observations according to BROMP, and facilitate synchronization of BROMP data with educational software log data.

We synchronized the affective states with the PP interaction logs using a small utility program we wrote in Java. The result of the program were used to identify the affective states in the time frame of the 3 IE phases.

4. Results

4.1 Incidence of IE in PP

A total of 106 (5%) incidences of potential IEs were observed in the PP logs. Sixty-nine (65%) of these resulted to either a silver or gold badge and were considered as IE-true. The remaining 35% were classified as IE-false for not successfully solving the problem during the post-incubation phase. All other attempts without a break were considered as Non-IE.

Out of the 60 players, 37 (62%) exhibited potential IEs with an average of 3 potential IEs per player. These identified players took a momentary break, came back to the level, and tried again. Of the 37, there were 34 (92%) who had at least one incidence of IE-true.

4.2 IE and Player In-game Achievement

The IE success rate per student was calculated as the count the student's IE-true occurrences divided by that student's total potential IE occurrences. The average of all the students' IE success rates was 75% (SD=34%). The Non-IE success rate per student was calculated as the count of the student's badges earned without taking a break divided by that student's non-IE attempts. The average of all the students' Non-IE success rate was 66% (SD=18%). A paired two-sample for means t-test was conducted to compare the IE success rate and Non-IE success rate of the 37 students who exhibited IE. There was no significant difference in the IE success rate (M=75%, SD=34%) and Non-IE success rate (M=66%, SD=18%), $t(36)=1.44$, $p=0.16$. The result suggests that there is no statistical difference on the likelihood of solving a problem whether the learner took a break or not. At first glance, this may imply that taking a break does not make a difference. However, recall that the students who took the break and then returned to the problem were stuck on the problem during the prior attempt. The IE success rate implies that leaving the problem and then coming back to it gives the student a good chance of getting unstuck. One factor that might have affected the IE success rate is the incubation duration. However, when correlated, the result was not significant, $r(37)=-0.24$, $p=0.15$.

We also analyzed the relationship of IE incidence per student and the overall in-game success rate per student. The student's IE incidence was the student's number of Potential IE over all of the student's attempts during game play. Overall in-game success rate per student was the number of badges the student earned over all of the student's attempts. The result showed a strong negative correlation between the two factors, $r(60)=-0.62$, $p<0.01$. With this, one might say that higher IE incidence led to a lower overall in-game success rate. But it was observed that students with high incidence of IE had low non-IE success rate. It should be noted that non-IEs compose 95% of all attempts. This very high incidence of non-IEs has dominated the learner's overall success rate. Thus, even if the learner had a high incidence of IE, it is possible that the learner's overall success rate turned out low because of the low non-IE success rate. This aspect makes the negative correlation non-conclusive.

4.3 Affective States surrounding Potential IE and IE-True in PP

The incidence of the affective states surrounding all potential IEs were computed as the total count of observation per affective state over the total number of observations during the 3 phases of all potential IE incidences per student. The average of the computed percentages is presented in Table 1. From the results, engaged concentration was the most commonly observed cognitive-affective state, followed by frustration and confusion. Students also exhibited occasional boredom and happiness. On the other hand, surprise, excitement, delight, and pride were rarely observed.

Table 1: Cognitive-affective states of students over all potential IE incidences

Affective State	**Percentage**
Engaged Concentration	76.22
Frustration	8.47
Confusion	5.87
Give Boredom	4.34
Happiness	3.50
Others (Surprise, Excitement, Delight, Pride)	1.61

We then attempted to determine the relationship between potential IEs with the 5 most common cognitive-affective states observed: engaged concentration, frustration, confusion, boredom, and happiness.

First, we determined the correlation between the cognitive-affective states and the incidence rate of potential IEs per player. With a confidence level of 95% and using the False Discovery Rate (FDR) correction for multiple comparisons, only the positive correlation between IE incidence and frustration ($r(37)=0.42$, $p=0.01$, $\alpha=0.01$) was found significant.

Second, we looked at the relationship of the cognitive-affective states with the players' IE success rate but no significant result was found.

4.4 Relationship of School Classification with the Incidence of IE

To determine the relationship of the school classification in relation to IE, the Chi-Square test of independence was used. There is no significant dependency, $c^2(1,N=37)=1.62$, $p=0.20$, between the number of students who exhibited potential-IE and the school classification, whether private or public. In terms of success rate, the number of IE-true over the number of potential-IE from each school showed no dependency on the school classification $c^2(1,N=37)=0.04$, $p=0.84$. Even in the performance of the students, there is no significant dependency between the number of students who exhibited IE-true over the number of students with potential-IE, $c^2(1,N=37)= 0.06$, $p=0.80$, and the school where they are from.

5. Discussion, Conclusion, and Contributions

Prior work hypothesizes that taking a short break from a problem-solving activity, most especially when stuck, can help students arrive at solutions. In this study, we investigated this phenomenon, the incubation effect, within the context of Physics Playground. We also examined its relationship with in-game achievement and user affect.

Based on results, the higher their IE incidence, the lower their overall in-game success rate is. But due to the very low incidence of IE (5%) from all attempts made, the success rate of IE is very much under-represented in the overall success rate. And with the high incidence of Non-IEs (95%), it's success rate had a high representation in the overall in-game achievement result. The students during the experiment were not told to have an actual break. This scenario might explain the low incidence of IE.

Moreover, it was observed among the 37 players that attempts with break in between have an average success rate of 75% while those attempts that have no incubation have an average success rate of 66%. This difference, though not statistically significant gives evidence that the break enabled students to solve the problem. Thus, it may be inferred that taking a break can help learners to get unstuck from a problem they were previously stuck with. This validates some earlier studies (Fulgosi & Guilford, 1968; Gilhooly et al., 2013; Penaloza & Calvillo, 2012; Sio & Ormerod, 2009) claiming that taking a break in the middle of the performance of an engaging task helps improve success rates.

In addition, results show that incubation duration is insignificantly correlated with IE success rate. Hence, the duration of the incubation did not contribute immensely to the success rate of the players on levels where they took a break.

The positive correlation of the number of potential IE incidences with frustration validates that when students are confronted with an initial failure in an attempt to solve a problem, they tend to repeat their ineffective problem-solving approach again and again in vain. In this situation, a student may feel frustrated (Yoo, Zellner, & Kim, 2005) for not being able to solve the problem. Hence, they turn their attention to something else like going back to the menu, taking a break, or trying out a different level.

In terms of in-game achievement of students in private and public schools, results show that the students' school classification proves to have no bearing to the incidence of both potential-IE and IE-true in PP. This contradicts the previous studies (Bernardo et al., 2015; Carbonaro & Covay, 2010; Chua, 2000; Coulson, 2009; Jimenez et al., 1991, 1988) indicating that students in private schools outperform students in public schools in all levels of achievement, at least, in the context of IE in Physics Playground. Meaning, the IE success rate of students in solving the PP problem has no direct relationship with their school classification.

Aside from contributing to what is known about IEs, the study contributes in the following ways:

First, relatively little has been written in the investigation of IE in computer-based learning environments with fine-grained interaction logs like Physics Playground. Most researches in IE used standard tests to measure fluency and creativity (Baird et al., 2012; Fulgosi & Guilford, 1968; Gilhooly et al., 2013; Sio & Ormerod, 2015), mathematical adeptness (Fulgosi & Guilford, 1968; Segal, 2004; Tan, Zou, Chen, & Luo, 2015), and even memory (Ellwood, Pallier, Snyder, & Gallate, 2009). Most of these researches manually observe, record, and assess test subjects based on task-performance and are scored based on the results produced in the pre- and post-incubation phases. This study, on the other hand, opens the idea of using computer-based learning environments in studying phenomenon of a similar construct with IE since interaction logs of test subjects can be recorded automatically and hence more accurately.

Second, the average success rate of attempts that have incubation is higher than those attempts that do not have and majority of attempts with a break in between resulted to a solved problem. This is an additional evidence to show that incubation can be an effective technique in solving problems (Fulgosi & Guilford, 1968; Gilhooly et al., 2013; Penaloza & Calvillo, 2012; Sio & Ormerod, 2009, 2015) where activities performed during the break are similar or related tasks. It helps students form new, and even creative, ideas that could possibly help generate potential solutions on the succeeding attempts (Penney et al., 2004). This finding can greatly be considered as a pedagogical practice where teachers instruct students who are stuck at a problem to take a break and engage on different tasks with a similar context.

Third, in this study, 84% of the players did relatively similar tasks during incubation. But the study of Gilhooly et al. (2013) claims that an entirely irrelevant activity during the break yields better results at the last IE phase. It is highly recommended that this claim be further investigated.

Lastly, further study is also recommended to determine the factors that might predict whether the incubation would result to a success or not.

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