ISSN: 2502-2318 (Online)
ISSN: 2443-2911 (Print)
Homepage: http://omega.uhamka.ac.id/
Accredited by RISTEKDIKTI, Decree No: 14/E/KPT/2019

Omega: Jurnal Fisika dan Pendidikan Fisika **5** (1), 7 - 14 (2019)
(*Journal of Physics and Physics Education*)

The Potential of Gamification in Developing Pre-Service Physics Teachers' Critical and Creative Thinking Skills

Saprudin[1,4,*], Liliasari[1], Ary Setijadi Prihatmanto[2], Andhy Setiawan[3]

[1] *Program Studi Pendidikan Ilmu Pengetahuan Alam, Sekolah Pascasarjana, Universitas Pendidikan Indonesia*
Jl. Dr. Setiabudhi No. 229, Bandung 40154, Indonesia

[2] *Sekolah Teknik Elektro dan Informatika, Institut Teknologi Bandung*
Jl. Ganesha 10 Bandung 40132, Indonesia

[3] *Program Studi Fisika, Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia*
Jl. Dr. Setiabudhi No. 229, Bandung 40154, Indonesia

[4] *Program Studi Pendidikan Fisika, Fakultas Keguruan dan Ilmu Pendidikan, Universitas Khairun*
Jl. Pertamina Kampus II Gambesi, Ternate 97719, Indonesia

(Received 12 March 2019; published 6 July 2019)

Abstract

This article is a part of the research related to the development of gamification models to improve critical and creative thinking skills of pre-service physics teachers (PPTs). This case study is a preliminary research to describe the potential of gamification in physics experiments that was involved 25 PPTs at one of the universities in Bandung. The potential of gamification was analyzed from the results of observations, and the monitoring of the physics experiment activities assisted by WhatsApp social media. Through the implementation of gamification, physics experiments can be designed like gameplay so that it was expected to motivate PPTs to be more actively involved in physics experiment activities. Besides that, the presence of gamification can create an atmosphere of physics experiments to be more enjoyable.

Keywords: gamification, physics experiment, critical thinking skills, creative thinking skills

DOI: 10.31758/OmegaJPhysPhysEduc.v5i1.7

*Corresponding author. E-mail address: saprudin@unkhair.ac.id

Introduction

The Fourth Industrial Revolution is a phrase has its roots in early analysis of technological evolution. The first industrial revolution emerged in the 1780s which was characterized by the use of water and steam power toward more systematic and efficient forms of manufacturing. The second industrial revolution (1860 to 1900 period), that is associated with new manufacturing technologies based on electricity. The third Industrial Revolution (1980s and 1990s), that is generally attributed to computerization and web-based interconnectivity. The fourth industrial revolution is often described as the result of integration and the combined effects of multiple "exponential technologies" such as artificial intelligence, biotechnology, and nanomaterials [1, 2].

The industrial revolution is both a challenge and an opportunity especially for higher education to prepare competent human resources according to

the demands of the era. In the 2016 World Economic Forum report states that there are 10 skills that are most needed in priority workers in 2020, which are; complex problem solving, critical thinking, creativity, people management, coordinating with others, emotional intelligence, judgment and decision making, service orientation, negotiation, and cognitive flexibility [1]. Only superior and competent human resources who can compete so that they can exist in the fourth industrial revolution.

Based on the process, some of the skills mentioned earlier is included in the level of complex thinking called higher order thinking skills (HOTS) such as critical thinking, creative thinking, problem solving, and decision making [3]. Critical thinking is reasonable and reflective thinking focused on deciding what to believe or do [4]. Creative thinking skills are skills to develop or invent original ideas, aesthetic, constructive, related to perceptions as well as concepts, emphasize aspects of intuitive and rational thinking especially in using information and materials to bring up or explain with the original perspective of thinkers [5].

The use of information and communications technology (ICT) has been widely used in an effort to improve the effectiveness of physics learning. The use of ICT in physics learning includes the use of animation [6], educational video [7, 8], interactive simulation [9, 10], interactive multimedia [11–13], virtual laboratory [14,15], digital games [16, 17], augmented reality [18], e-learning [19], and mobile learning [20, 21].

In the context of physics learning, the successful use of ICT in improving critical thinking skills has been carried out through the use of animation [22,23], interactive simulations [24,25], virtual laboratory [26], and e-learning [7]. While success related to the improvement of creative thinking skills has been done through the use of interactive multimedia [27] and digital games [28].

At present, the challenge of using ICT in physics learning is how users (students) can be bound to the system, and optimizing the development of critical and creative thinking skills simultaneously during the learning process. Previous research has shown that the use of ICT in learning physics is still focused on developing one type of thinking skill, for example focusing on critical thinking skills or creative thinking separately.

Gamification has the potential to optimize the use of ICT in physics learning. Gamification is the use of game design elements in non-game contexts [**?**]. In other literature, gamication refers to a process of enhancing a service with affordances for gameful experiences in order to support user's overall value creation [32]. In practice, gamification has been implemented in the conventional learning [33], e-learning [34], Massive Open Online Courses [35], and blended learning [36].

This article describe the results of a case study related to the implementation of gamification concept in a physics experiment, namely free fall motion experiment (FFME) which aims to determine the acceleration due to gravity that is assisted by the application of physical phone experiments (Phyphox) on smartphones. This application was developed by RWTH Aachen University [37]. Phyphox is an application program that integrates various sensors in modern smartphones, such as accelerometers, gyroscopes, and pressure sensors, as the basis for various experimental measurements [38]. This application can be downloaded and installed for free from Google Play (Android) or App Store (iOS).

The design of the FFME assisted by Phyphox smartphone application was chosen because generally pre-service physics teachers (PPTs) at the research location were accustomed to using smartphones. In addition, the duration of free fall of objects recorded by the sensor acoustic stopwatch on the Phyphox application can be exported in excel format, making it easier to share via Bluetooth, email, BBM, Share-it, Wi-fi, or WhatsApp. With this convenience, the opportunity to implement gamification in the FFME becomes possible.

Research Method

Design, Subject, and Research Instrument

This research is a pre-experimental reseach with a one-shot case study design. In this study, one group of subject of the research, namely 25 PPTs in one of the Universities in Bandung, was subjected to treatment in the form of implementation of gamification in the FFME assisted by Phyphox smartphone application, then after that, PPTs responses to the treatment were measured. Data related to PPTs activities were collected through observation sheets and activity monitoring during the implementation of physics experiments assisted by WhatsApp social media. While data related to PPTs responses were collected through questionnaires. Data analysis techniques were carried out using quantitative descriptive analysis techniques.

FFME Procedure

The FFME procedure used is a modification of the procedure demonstrated by Staacks [39]. The purpose of this experiment is to determine the magnitude of the acceleration due to gravity (g). Materials/ apparatus needed include: retort stand, wooden rod (150 cm long), ruler (100 cm long), balloon, several masses of different weights (can be replaced by pad lock with difference weights), measuring tape, wire, needles, clear tape, double tape, smartphone that has installed phyphox application. The procedures to conducting FFME are as follows;

1. Download the phyphox application through Playstore on the smartphone
2. Install the phyphox application on the smartphone
3. Open the phyphox application and choose Acoustic Stopwatch
4. Set the threshold value to 0,5 a.u and minimum delay at 0,1 s
5. Inflate 3 balloons
6. Prepare 3 masses with different weights and write down each mass (m_1, m_2, m_3)
7. Hang the masses with different weight on the balloon and put it on the circular wire attached on the retort stand as pictured in Figure 1
8. Press Play button on the Acoustic Stopwatch. This sensor will record the duration of a free fall through the detection of noise. The initial time recording indicator is the explosive sound of the balloon, while the final time indicator is the sound of the weight hitting the floor.
9. Explode the first balloon by pricked a needle
10. Read the recorded the duration of a free fall on the Acoustic Stopwatch on your smartphone
11. Export the experimental data to excel format then share it through the WhatsApp group
12. Repeat steps 8 to 11 for the second and third balloon.
13. Download the experimental data from the WhatsApp group including the experimental data which made by other groups, so that each group gets more experimental data. The experimental data from other groups can be used as a comparison.
14. Calculate the magnitude of the acceleration due to gravity (g) using Equation (1),

$$g = \frac{2y}{t^2} \tag{1}$$

where g is the acceleration due to gravity, y is the height, and t is the duration of a free fall.

15. Data analysis can be done using Microsoft Office Excel or through manual calculations

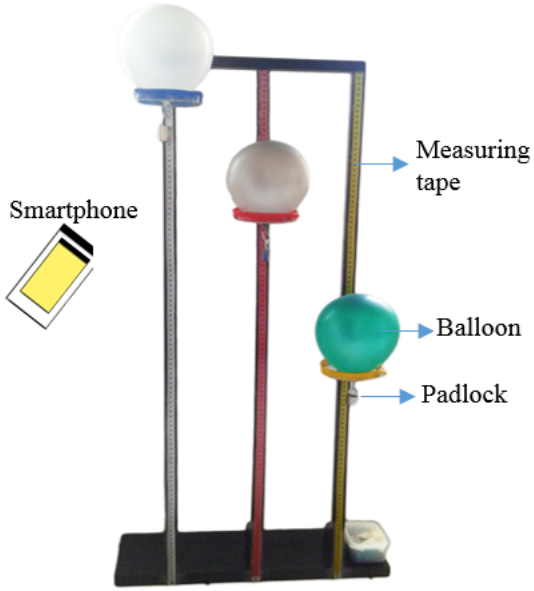

Figure 1: The design of media on FFME.

Results and Discussion

The Potential of Gamification in Developing Critical and Creative Thinking Skills

The potential of gamification in developing critical and creative thinking skills can be seen by analyzing the steps in implementing gamification on FFME based on observations and online monitoring through the WhatsApp group. PPTs are divided into small groups (number of groups depends on the number of PPTs and the availability of tools and materials). Each group was given a challenge to produce a number of the experimental data related to FFME which is the duration of a free fall (t) from different heights (y). The measurement of the duration of a free fall (t) recorded by the sensor acoustic stopwatch on the phyphox application are exported in excel format which is then shared through the WhatsApp group. Each group is required to download data of experiment results from the other groups, so that there are more data owned by each group. Data from other groups is used as a comparison. Each group analyzes data and criticizes data obtained from other groups. The results of data analysis are shared through WhatsApp groups which can be in the form of excel files or photos as a result of data processing and conclusions. Each group was given the opportunity to criticize the results of data analysis and conclusions from other groups. In addition, each group was given the opportunity to be able to reflect on the experimental activities they had carried out.

For more details, the steps to carry out FFME by implementing gamification can be shown in Figure 2.

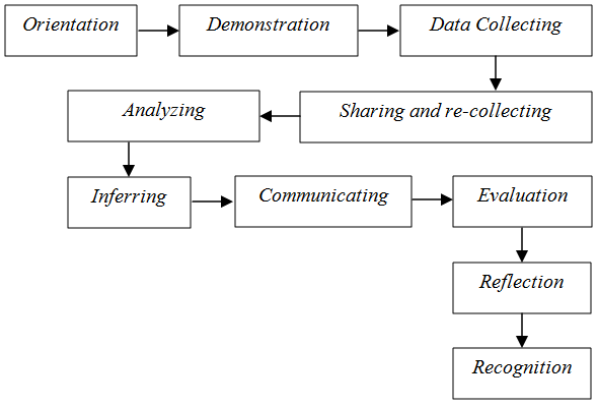

Figure 2: The implementation of gamification on the FFME.

1. Orientation; PPTs in groups are given problems/ challenges in the form of assignments to determine the magnitude of the acceleration due to gravity, create a WhatsApp group, download and install the phyphox application on a smartphone. This step has the potential to develop problem solving skills, critical and creative thinking skills.

2. Demonstration; the lecturer shared a demonstration video of the FFME through WhatsApp group, PPTs downloaded the video, watched the video, and discussed in groups to plan the FFME. This step has the potential to develop critical and creative thinking skills.

3. Data Collecting; PPTs in groups are required to obtain a number of experimental data of FFME, export the experimental data on the phyphox smartphone application into the excel format so that its can be shared through WhatsApp groups. This step has the potential to develop critical and creative thinking.

4. Sharing and re-collecting; each group is required to share the experimental data and download the it from the other groups through the WhatsApp group, so that each group is expected to get more experimental data. Data from other groups can be used as a comparison. This step has the potential to develop creative thinking skills.

5. Analyzing; PPTs are conducting classification, tabulation and interpretation of data, applying the concept/ principle of free fall motion experiment to determine the magnitude of the acceleration due to gravity, comparing the result that was obtained from the other groups. This step has the potential to develop critical thinking skills.

6. Inferring; PPTs are required to produce conclusions that are can get the value of the acceleration due to gravity. This step has the potential to develop critical thinking skills.

7. Communicating; PPTs communicate the results of data processing and conclusions through the WhatsApp group. PPTs can present the results of data processing and conclusions in the form of photos, excel files or presentations video related to the results of data processing and conclusions. This step has the potential to develop creative thinking skills.

8. Evaluation; each group downloads the results of data processing and conclusions from other groups, then evaluates based on their respective abilities. This step has the potential to develop critical thinking skills.

9. Reflection; reflection is carried out after PPTs have finished conducting the experiment. Reflection is carried out by retelling the experience of conducting FFME in the form of intergroup discussions so that there is mutual exchange of experiences between students. Lecturers act as facilitators and supervisors. This step has the potential to develop reflective thinking skills.

10. Recognition; after the assessment is complete, the lecturer ranks the position of each group (makes the leaderboards) and announces it through the WhatsApp group. The best groups were given reward in the form of certificates and prizes.

The results of monitoring PPTs' activities using WhatsApp on the implementation of FFME are shown in Table 1 and Figure 3. In Table 1, it can be seen that the implementation of gamification has the potential to develop critical and creative thinking skills. In addition, the reflection phase can provide opportunities for PPTs to develop reflective thinking skills. Through the application of gamification, critical and creative thinking skills make it possible to be trained simultaneously during the conduct of experiments.

For further research, it is necessary to find empirical evidence regarding the effectiveness of gamification to improve critical and creative thinking skills. Beside, a design of a gamification system that can integrate assessment / assessment automatically is needed, so that PPTs can get feedback immediately. With the existence of this system, it is expected that the system can increase the effectiveness of learning and can facilitate lecturers in assessing both products and processes. On the other

hand, PPTs' thinking style is need to pay attention in designing a model of gamification [40, 41]. By knowing PPTs' thinking styles, we can design a model of gamification that is suitable for all PPTs' thinking styles. That way, it is expected that the development of PPTs' critical and creative thinking skills can develop more optimally.

Table 1: Monitoring the activities of lecturers and PPTs.

Time (GMT+7)	Data Source	Activities	Notes	The potential to improve thinking skills
14:00	Lecturer & PPTs	Make a WhatsApp group	Communication and activity monitoring facilities	
14:10	Lecturer & PPTs	• Delivering the objectives of FFME • Download and install the phyphox application on the smartphones • Sharing a demonstration video of FFME • Perform a demonstration of FFME	• PPTs browse the source of the phyphox application provider • PPTs download, watch, and discuss the demonstration video	Critical and creative thinking
14:15	PPTs	Conducting FFME (planning experiments, making observations, collecting data)		Critical and creative thinking
14:24	Group I	• Presenting data in excel format • Sharing the 1st experimental data	File; excel	Creative thinking
14:27	Group III	• Presenting data in excel format • Sharing the 1st experimental data	File; excel	Creative thinking
	Group II	• Presenting data in excel format • Sharing the 1st experimental data	File; excel	Creative thinking
14:30	Group III	• Presenting data in excel format • Sharing the 2nd and 3rd experimental data	File; excel	Creative thinking
14:31	Group I	• Presenting data in excel format • Sharing the 2nd and 3rd experimental data	File; excel	Creative thinking
14:32	Group II	• Presenting data in excel format • Sharing the 2nd and 3rd experimental data	File; excel	Creative thinking
15:01	Group IV	• Presenting data in excel format • Sharing the 1st experimental data	File; excel	Creative thinking
15:04	Group IV	• Presenting data in excel format • Sharing the 2nd and 3rd experimental data	File; excel	Creative Thinking
15:07	Group II	Sharing the results of data processing and conclusions (data analyzed manually with calculator)	Photo of data analysis table and conclusion	Critical and creative thinking
15:15	Group III	Sharing the results of data processing and conclusions (data analyzed with Microsoft office excel)	File; excel	Critical and creative thinking
15:16	Group I	Sharing the results of data processing and conclusions (data analyzed with Microsoft office excel)	Photo of data analysis table and conclusion	Critical and creative thinking
15:21	Group IV	Sharing the results of data processing and conclusions (data analyzed with Microsoft office excel)	Photo of data analysis table and conclusion	Critical and creative thinking
15:30	Group II	Sharing revision of data processing after discarding the data that are considered inaccurate (data analyzed with Microsoft office excel)	File; excel	Critical and creative thinking
15:40	Lecturer	Sharing the result of assessment (order of achievement score of each group)	Photo of leaderboard	
15:45	Lecturer & PPTs	Reinforcement and reflection		reflective thinking
15:45	Lecturer & PPTs	Distribution of certificates and prizes for the best group		
16:00	Lecturer	Closing		

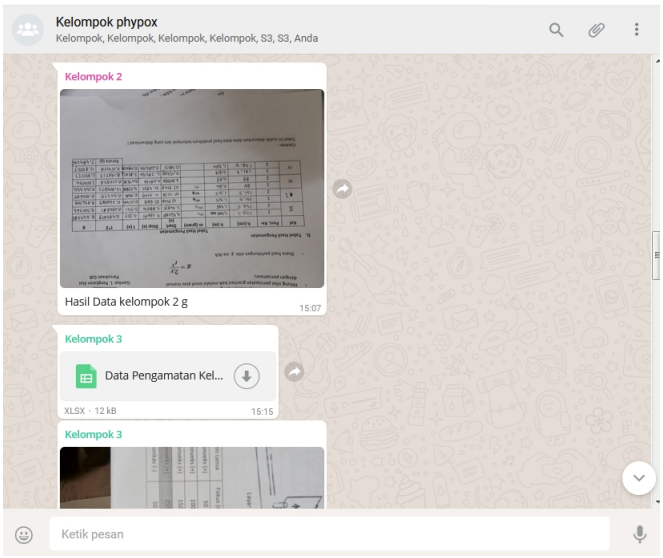

Figure 3: Monitoring of PPTs' activities in the implementation of gamification.

Table 2: PPTs' Responses to the Implementation of Gamification in FFME.

No	Statements	Percentage (%)
1	The interface of media on FFME is interesting	71
2	The media on FFME is easy to operate	80
3	I can download the phyphox application	82
4	The phyphox application is compatible on my smartphone	79
5	There are several sensor on phyphox application features that cannot be installed on my smartphone	60
6	I can run an acoustic stopwatch on my smartphone to support FFME	77
7	I often communicate using WhatsApp	90
8	I have conducted FFME using a smartphone	72
9	The FFME using smartphone is a new experience for me	72
10	The use of smartphones in FFME can increase my motivation to study physics	81
11	The use of social media (WhatsApp) in FFME can increase my motivation to learn	83
12	The use of smartphones in FFME can increase my motivation to take part in physics experiments	81
13	The use of social media (WhatsApp) on FFME can increase my motivation to take part in physics experiments	81
14	This learning media can make it easier for me to conduct FFME	83
15	This learning media can make it easier for me to understand the material of free fall motion	81
16	The existence of game elements in FFME can increase my motivation to be more involved in conducting physics experiments	84
17	The existence of challenges such as determining the acceleration due to gravity, it is an interesting challenge to solve	81
18	I am required to think creatively to determine the acceleration due to gravity through FFME	78
19	From the various results of calculating the acceleration due to gravity, I am required to think critically in producing the best solution	79
20	The point system can increase my motivation to get more experimental data and calculate the acceleration due to gravity as much as possible	77
21	The existence of a point system can increase my motivation to upload and download experimental results through WhatsApp	73
22	The existence of elements of competition can increase my motivation to become a winner by completing FFME and analyzing data correctly	76
23	The presence of game elements in FFME make me stress so that I cannot follow the experiment as a whole	74
Average		78

PPTs' Responses to the Implementation of Gamification in FFME

Overall, PPTs gave a good response to the implementation of gamification in FFME. This is indicated by the total score of 1795 from a maximum score of 2300 (78%). The detailed responses of PPTs can be seen in Table 2.

Conclusion

The implementation of gamification in FFME using ICT is relevant to learning in the era of the fourth industrial revolution. Through the implementation of gamification, physics experiments can be designed like gameplay so they can motivate and bind PPTs to continue to be involved in the activity series of experiment. In addition, the implementation of gamification creates a more joyful atmosphere in physics experiments. The analysis of learning steps was indicated that gamification has the potential to develop PPTs' critical and creative thinking skills simultaneously during the implementation of the experiment. PPTs gave a good response to the implementation of gamification in FFME.

Further research needs to be done by examining empirical evidence related to the effectiveness of gamification in improving PPTs' critical and creative thinking skills. The learning steps presented need to be tested and validated so that it can become a valid model. In addition, it is necessary to design a gamification system that can integrate assessment automatically, so PPTs can get an immediate feedback. The need for a leaderboard that can be seen in real time by PPTs has the potential to motivate them to be more involved in the activities of the experiments carried out.

Acknowledgments

The author would like to express gratitude to; 1) LPDP BUDI-DN that funded this research and as the main sponsor through a scholarship from doctoral education program, 2) PPTs who had participated in this study.

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[41] S. Saprudin, S. Liliasari, A. S. Prihatmanto, and A. Setiawan, Profile of pre-service physics teachers' creative thinking skills on wave and optics course, J. Phys. Conf. Ser. **1157** (3), 032030 (2019).