

# Optical Gamification (OG); Serial Versus Random Model to Improve Pre-Service Physics Teachers' Concept Mastery

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**Abstract**—Optical Gamification (OG) is an information and communication technology (ICT)-based gamification-application that applies the elements of game design in a serious context of optics. Through setting for the variations in pre-service physics teachers' (PPTs) access to the sub-topics presented in this application, two OG application models are generated, namely: 1) serial model; designed to facilitate PPTs who study sequentially, and 2) random models; designed to facilitate PPTs who study randomly depends on their choices. This research is quasi-experimental with pretest-posttest nonequivalent multiple group design involving 48 PPTs enrolled in wave and optics course, specifically on the topics of interference and diffraction. The results of this research indicate that there is no significant difference in the improvement of PPTs' concept mastery in the serial and random groups. Both of these models can be used as references in designing ICT-based gamification-applications for a more effective and efficient learning in the future.

**Keywords**—Optical Gamification (OG), Serial Model, Random Model, Concept Mastery.

## 1 Introduction

Gamification is the use of game design elements in non-game contexts [1, 2, 3]. The implementation of gamification has had a positive impact in various sectors of society such as transportation [3, 4, 5, 6, 7, 8], healthcare [9, 10, 11, 12], economics and business [13, 14, 15, 16], disaster risk management [17], parenting [18], and the education sector [19, 20, 21, 22, 23, 24].

In the education sector, previous research found a successful implementation of gamification in blended learning [21, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37]. Other research indicates a similar success in conventional learning [38, 39], e-learning [40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50], and learning through massive open online courses [51, 52, 53, 54, 55, 56, 57, 58, 59].

In general, research related to the implementation of gamification in learning are more focused on the research of how the impact of gamification in changing student behavior, so they are motivated to learn [27, 35, 50, 60, 61, 62, 63, 64, 65, 66, 67], and more engaged in learning activities [20, 21, 25, 28, 31, 32, 60, 62, 63, 65, 68, 69]. Through the improvement in motivation and engagement, student learning outcomes was proven empirically to be improved [70, 71]. One of the learning outcomes is the students' concept mastery.

A concept is a mentality that represents one class of stimulus [72]. Concept can also be interpreted as labeling of objects, symbols, or events with the same characteristics or important attributes [73]. Concept can be acquired in two ways, namely: a) concept formation; acquisition of concepts before students learn about material in a formal education situation, and b) concept assimilation; acquisition of concept during and after learning in a formal education [74]. The theory of meaningful learning by Ausubel states that meaningful learning is a process of relating new information to relevant concepts that already exist in a person's cognitive structure [74]. The most optimal concept development can take place if the most general or inclusive elements of a concept are introduced first, then the more detailed and more specific elements of the concept are given afterward [72, 74]. Therefore, to develop a good curriculum, concept analysis is needed. Certain relationships between the concepts are analyzed so that the most general and the more specific concepts can be identified [72, 75]. In contrast to learning in universities, the population in this research are PPTs over 18 years old, where they can be categorized as an adult [76, 77, 78]. Some assumptions used in adult education (andragogy) include, 1) self-concept; the shift from a person who is dependent on others towards an independent person, 2) experience; humans accumulate a lot of experiences they have acquired so that they become a source of learning that develops, 3) readiness for learning; humans are increasingly oriented to the task of developing the social role they carry, and 4) orientation towards learning; the perspective of time changes from knowledge with delayed application to knowledge with immediate application, and changes in learning orientation from learning-centered to problem-centered [76]. One implication of these assumptions is that in learning andragogy, students should be involved in diagnosing their learning needs. Students will feel engaged and motivated to learn if what will be learned is in accordance with their learning needs. [76].

OpticalGamification (OG) is an ICT-based gamification-application that applies elements of game design in a serious context of optics. This application is intended for a wave and optics course, especially on the topic of interference and diffraction. This topic was chosen because it is one of the topics that is still lacking in competency achievement [79]. The setting of variations in PPTs' access to sub-topics of interference and diffraction material is intended to facilitate the diverse ways of learning. For example, PPTs' can study in sequence or randomly. ICT-based gamification-

application allows learning to be presented without the constraints of space and time, performs an automatic assessment, provides an opportunity to do an unlimited number of evaluations, allows the setting of PPTs' freedom to access, and records the history of PPTs' exploration while participating in learning through the application. The impact of variations in PPTs' access to learning sub-topics presented in the OG application towards PPTs' concept mastery is an interesting study. Variations in PPTs' access are closely related to PPTs' behavior when studying the sub-topics presented in the OG application. Studies like this are still rarely found in previous studies. The lack of research on the matter comes a big question related to whether the variations in PPTs' learning behavior that studies the sub-topics presented in the OG application will affect PPTs concept mastery.

OG consists of nine sub-topics and three evaluations, each sub-topic is designed into levels that must be passed by PPTs. Each sub-topic is presented through a virtual laboratory designed in the form of a dependent experimental quiz; which is a quiz that can only be done well if PPTs conduct the experiments through virtual simulations. Meanwhile, the evaluation contains questions in the form of multiple choices. Each level and evaluation has a minimum score limit to get stars as rewards. OG is presented in three sessions, each session consists of three levels and one evaluation. OG is also presented in two models, which are serial and random models. In the OG with serial model, PPTs can learn more than one sub-topic sequentially in the same order of work arrangements for each session. Whereas in the OG with random model, PPTs can learn several sub-topics in random order at each session, they can learn several sub-topics by cross-session randomly of their choosing.

This article aims to discover the empirical evidence related to the comparison of the usage of OG applications in serial and random models towards the PPTs' concept mastery on the topics of interference and diffraction. Empirical evidence found in this research is expected to be used as a reference in designing ICT-based gamification-applications for future research.

## 2 Methodology

### 2.1 Research Design and Research Method

The research used quasi-experimental method with a pretest-posttest nonequivalent multiple group design [80].

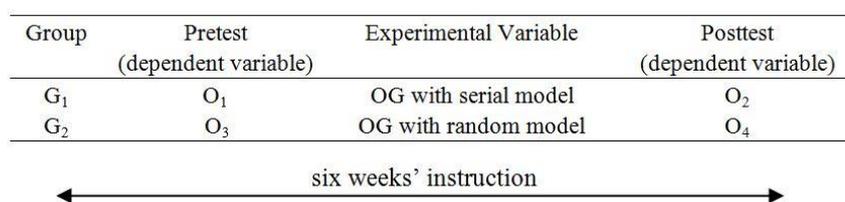


Fig. 1. Research Design

## **2.2 Participant**

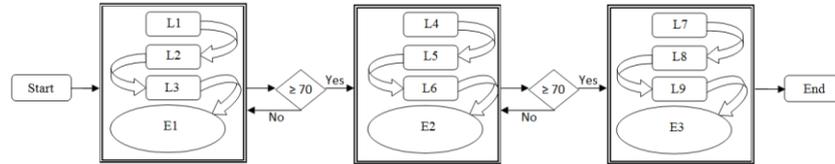
This research involved 48 PPTs enrolled in the course of waves and optics, especially on the topics of interference and diffraction. Participants were divided into two groups without randomization, experiment group 1 (total = 26 PPTs, M = 6, F = 20, average age = 19 years old) and experiment group 2 (total = 22 PPTs, M = 6, F = 16, average age = 19 years old). The characteristics of participants in this research have low motivation and are less engaged in the learning process. Most PPTs stated that majoring in physics department was the second choice when they took the college entrance selection test.

## **2.3 Procedure**

The OG application consists of nine sub-topics designed in the form of nine levels and three evaluations. Each sub-topic at each level is presented through a virtual laboratory designed in the form of a dependent experimental quiz. Evaluations are presented in the form of multiple-choice questions. The OG with serial and random models are presented in three sessions, each consisting of three levels and one evaluation. Evaluation 1 (E1) contains material from level 1 (L1), level 2 (L2) and level 3 (L3). Evaluation 2 (E2) contains material from level 4 (L4), level 5 (L5), and level 6 (L6). Evaluation 3 (E3) contains material from level 7 (L7), level 8 (L8), and level 9 (L9). Rewards in the form of stars will be obtained by PPTs if the score obtained is  $\geq 70\%$  of the ideal score for each level and evaluation. L1 presents the sub-topic of lightwave characteristics (ideal score = 75; time = 15 minutes; red star reward). L2 presents the sub-topic of the principle of superposition of waves (ideal score = 25; time = 25 minutes; orange star reward). L3 presents the sub-topic of double slit interference part 1 (ideal score = 75; time = 75 minutes; yellow star reward). L4 presents a sub-topic of double slit interference part 2 (ideal score = 40; time = 40 minutes; green star reward). L5 presents the sub-topic of multiple slit interference (ideal score = 40; time = 40 minutes; blue star reward). L6 presents the sub-topic of single slit diffraction (ideal score = 50; time = 50 minutes; indigo star reward). L7 presents the sub-topic of circular aperture diffraction (ideal score = 115; time = 115 minutes; violet star reward). L8 presents the sub-topic of diffraction grating (ideal score = 95; time = 95 minutes; white star reward). L9 presents the sub-topic of resolving power (ideal score = 55; time = 55 minutes; black star reward). For each evaluation has an ideal score of 100.

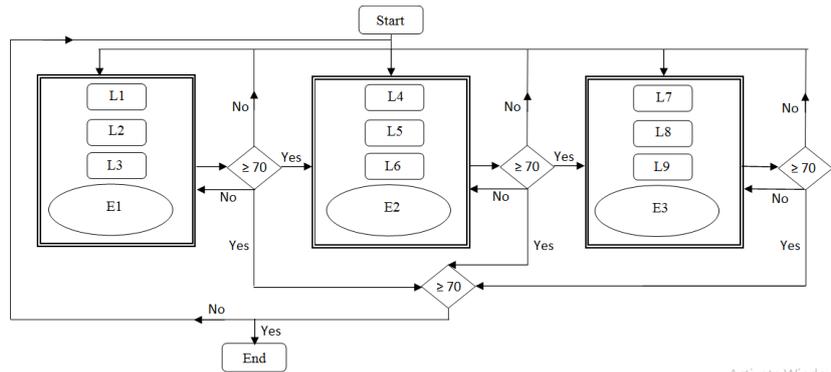
In the OG with serial model, the learning material is divided into three sessions. Each session consists of three levels (sub-topics) and one evaluation. In the first week, all PPTs followed the pretest and explanation related to the learning mechanism through the OG application. In the second week, PPTs take part in learning session 1 which consists of L1, L2, L3, and E1. Each level can only be done once, while each evaluation can be done repeatedly and become a prerequisite for entering the next session. PPTs conduct learning in sequence with each session. PPTs are required to pass evaluation 1 with a minimum score of 70 to be able to proceed to the next session. The second and third sessions were carried out using the same mechanism as in the first session. PPTs can proceed to the third session when they passed the first and

second sessions. After completing the learning process through the OG application, PPTs may take posttest.



**Fig. 2.** OG with Serial Model

In the OG with random model, PPTs can learn several levels (sub-topics) in random order on each session and PPTs are also allowed to do cross-sessions. PPTs are also given the freedom to choose the level or evaluation in any session of their choosing. PPTs are successful in following all learning process through the OG application when PPTs can get scores of  $\geq 70$  for all evaluations.



**Fig. 3.** OG with Random Model

The learning program using OG application is carried out within six weeks with one face-to-face session each week. The design of the learning setting uses blended learning model as shown in Table 1.



## 2.4 Data gathering and data analysis technique

Data related to PPTs' concept mastery on the topic of interference and diffraction were collected through tests consisting of 50 multiple-choice questions. The improvement of PPTs' concept mastery is calculated by determining the score of normalized gain  $\langle g \rangle$  [81]. Normalized gain is interpreted to be in the high category if  $\langle g \rangle \geq 0.70$ , the medium category if  $0.70 > \langle g \rangle \geq 0.30$ , and the low category if  $\langle g \rangle < 0.30$ . An inferential statistical test is performed to discover the presence or absence of significant differences in the improvement of PPTs' concept mastery in using OG with serial and random model.

## 3 Finding and Discussions

### 3.1 Profile of PPTs' concept mastery

The results of the pretest and posttest of the PPTs' concept mastery on the topics of interference and diffraction that have been processed using SPSS 16.0 is shown in Table 2.

**Table 2.** The Mean, Standard Deviation, and Statistical Test Results from Pretest and Posttest Scores of PPTs' Concept Mastery

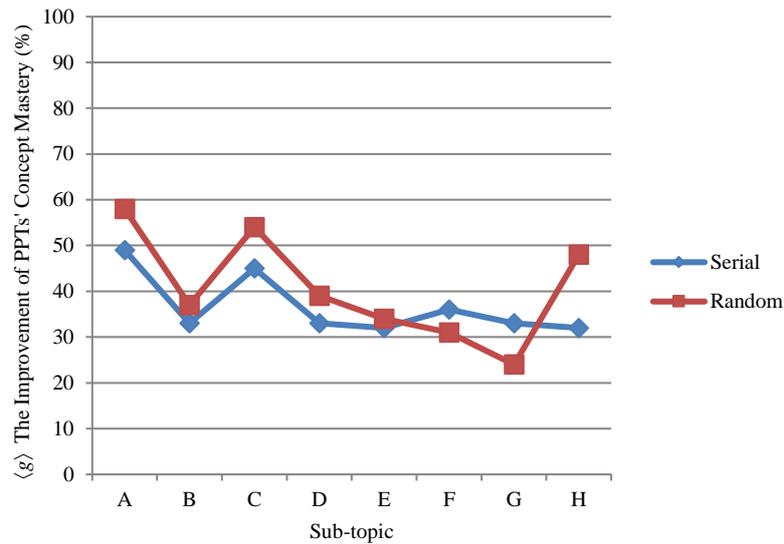
Statistical Test	Pretest		Posttest	
	Serial Group	Random Group	Serial Group	Random Group
Ideal Score	54.00	54.00	54.00	54.00
Mean	5.04	7.50	22.85	26.64
Deviation Standard	2.44	2.69	5.79	5.11
One-Sample Kolmogorov-Smirnov Test (Sig.)	0.412	0.577	0.811	0.361
Test of Homogeneity of Variances	F = 11.054; Sig.= 0.812		F = 5.672; Sig.= 0.639	
t-test (Independent Sample Test)	t = -3.325; Sig.= 0.002		t = -2.381; Sig.= 0.021	

Table 2 shows that the PPTs' concept mastery has improved in both serial and random groups. The t-test results showed that before participating in the learning process, the PPTs' concept mastery between serial and random groups was significantly different. Similar with the PPTs' concept mastery after participating in the learning process. To compare the improvement of PPTs' concept mastery in the two groups, the mean score of normalized gain  $\langle g \rangle$  in the two groups can be used for that purpose [81].

### 3.2 Comparison of OG with serial and random model on the improvement of PPTs' concept mastery

The improvement in the PPTs' concept mastery for each interference and diffraction sub-topics both in serial and random groups is shown in Figure 5. In general, there is no significant difference in the improvement of PPTs' concept mastery on the

topic of interference and diffraction between PPTs who take part in the learning process by using OG with serial and random model. Statistical test results related to differences in PPTs' concept mastery in the two groups are shown in Table 3.



**Fig. 5.** Comparison of the Improvement of PPTs' Concept Mastery in Serial and Random Group

**Table 3.** The Test Results of Normality, Homogeneity, and t-test between Serial and Random Groups

Sub-Topic	One-Sample Kolmogorov-Smirnov Test (Sig.)		Levene's test (Sig.)	t-test (df = 46)	
	Serial Group	Random Group		t	Sig.
Sub-Topic A	0.393	0.279	0.768	-.974	0.335
Sub-Topic B	0.398	0.462	0.815	-.544	0.589
Sub-Topic C	0.608	0.827	0.841	-1.317	0.194
Sub-Topic D	0.073	0.569	0.621	-.610	0.545
Sub-Topic E	0.513	0.560	0.424	-.385	0.702
Sub-Topic F	0.725	0.315	0.903	.577	0.567
Sub-Topic G	0.837	0.468	0.483	1.748	0.087
Sub-Topic H	0.822	0.721	0.195	-2.074	0.044
Topic	0.679	0.596	0.819	-1.496	0.141

On sub-topic A (lightwave characteristics), PPTs are asked to; 1) compare and contrast the characteristics of light and sound waves, 2) define terms related to the characteristics of light and sound waves, and 3) employing and reacting to fallacy labels related to the characteristics of light and sound waves. The improvement of PPTs' concept mastery in serial group ( $\langle g \rangle = 0.49$ ) and random group ( $\langle g \rangle = 0.58$ ) can be

categorized as "medium". The improvement of PPTs' concept mastery in the random group is greater than the serial group, but the results of the t-test shows that this difference is not significant.

On sub-topic B (the principle of superposition of waves), PPTs are asked to; 1) compare and contrast the phases of a two-wave propagation graph, 2) provides a reason to why a constructive interference occurs in two interfering coherent waves, 3) mention the examples of points where constructive interference occurs from a graph of two-wave superposition, and 4) employing and reacting to fallacy labels related to the frequency and amplitude of the results of two-wave superposition. The improvement of PPTs' concept mastery in serial group ( $\langle g \rangle = 0.33$ ) and random group ( $\langle g \rangle = 0.37$ ) can be categorized as "medium". The improvement of PPTs' concept mastery in the random group is greater than the serial group, but the statistical test results show that this difference is not significant.

On sub-topic C (double slit interference), PPTs are asked to; 1) develop ideas related to the concept of interference and the path difference of the two-wave that can produce constructive interference, 2) provides reasons related to the path difference of the two-wave so that constructive interference can occur, 3) generalize the relationship between the distance of two sequenced bright fringes with the distance between two slits, 4) determine logical actions to enlarge the distance between two adjacent bright or dark fringes, and 5) apply the principle of double slit interference to determine the distance between two adjacent bright fringes and determine the magnitude of the wavelength used in double slit interference. The improvement of PPTs' concept mastery in serial group ( $\langle g \rangle = 0.33$ ) and random group ( $\langle g \rangle = 0.37$ ) can be categorized as "medium". The improvement of PPTs' concept mastery in the random group is greater than the serial group, but the statistical test results show that this difference is not significant.

On sub-topic D (multiple slit interference), PPTs are asked to; 1) generalize mathematical models to determine the total number of secondary maxima and minima between two adjacent primary maxima, 2) give various interpretations of the intensity graph ( $I$ ) to the magnitude of the angle ( $\theta$ ). The improvement of PPTs' concept mastery in serial group ( $\langle g \rangle = 0.33$ ) and random group ( $\langle g \rangle = 0.39$ ) can be categorized as "medium". The improvement of PPTs' concept mastery in the random group is greater than the serial group, but the statistical test results show that this difference is not significant.

On sub-topic E (single slit diffraction), PPTs are asked to; 1) mention some alternative actions to enlarge the distance of two adjacent dark fringes in a single slit diffraction experiment, 2) mention the similarities and differences between Fraunhofer and Fresnel diffraction, 3) develop or enrich the ideas of others related to the concept of a single slit diffraction, and 4) express many ideas related to efforts to increase the distance between two adjacent dark fringes on the screen, 5) record the data information based on the scheme of single slit diffraction experiment presented, 6) apply the acceptable principle in determining the width of the slit on a single slit diffraction, 7) mention examples and non-examples relating to the phase difference ( $\beta$ ) that produces the minimum intensity, and 8) employing and reacting to fallacy labels related to the result data of the single slit diffraction experiment. The improvement of PPTs'

concept mastery in serial group ( $\langle g \rangle = 0.32$ ) and random group ( $\langle g \rangle = 0.34$ ) can be categorized as "medium". The improvement of PPTs' concept mastery in the random group is greater than the serial group, but the results of the t-test shows that this difference is not significant.

On sub-topic F (circular aperture diffraction), PPTs are asked to; 1) develop or enrich other people's ideas related to the concept of circular aperture diffraction, 2) generalize the mathematical models to determine the magnitude of the first dark ring radius on a circular aperture diffraction, 3) apply the acceptable principle to determine the radius of the dark ring based on the results of practicum data, and 4) apply the concept or principle to determine the magnitude of the wavelength used in a circular aperture diffraction experiment. The improvement of PPTs' concept mastery in serial group ( $\langle g \rangle = 0.36$ ) and random group ( $\langle g \rangle = 0.31$ ). The improvement of PPTs' concept mastery in the serial group is greater than the random group, but the statistical test results shows that this difference is not significant.

On the sub-topic G (diffraction grating), PPTs are asked to: 1) give reasons related to the colors that are most strongly stretched and the reasons why the central color spectrum is white if polychromatic light is passed on a grating, 2) formulate alternative solutions to enlarge the distance between two adjacent dark fringes and determine which diffraction grating can be used to separate the sodium doublet in a particular order, 3) employing and reacting to fallacy labels related to the data of experiment results on the diffraction grating, 4) record the data based on the sketches of diffraction grating experiment presented, and 5) determine the magnitude of the grating constant and the number of bright fringes captured on the screen in the diffraction grating experiment. The improvement of PPTs' concept mastery in the serial group can be categorized as "medium" ( $\langle g \rangle = 0.33$ ), while the random group can be categorized as "low" ( $\langle g \rangle = 0.24$ ). The improvement of PPTs' concept mastery in the serial group is greater than the random group, but the results of the t-test shows that this difference is not significant.

On the sub-topic H (resolving power), PPTs are asked to; 1) provides various interpretations of a graph of experiments related to Rayleigh criteria, 2) develop ideas related to the concept and mathematical models of resolving power, 3) determine the maximum distance of two objects that can still be separated by the observer's eye at a certain distance, 4) determine the maximum distance of the observer so that the two objects can still be separated by the eye at a certain distance, and 5) employing and reacting to fallacy labels related to the phenomenon of separating two spectral lines from different isotopes using a spectrometer. The improvement of PPTs' concept mastery in the serial group ( $\langle g \rangle = 0.32$ ) and random group ( $\langle g \rangle = 0.48$ ) can be categorized as "medium". The improvement of PPTs' concept mastery in the random group is greater than the serial group. The PPTs' concept mastery in the random group was significantly increased compared to the serial group.

### 3.3 Discussion

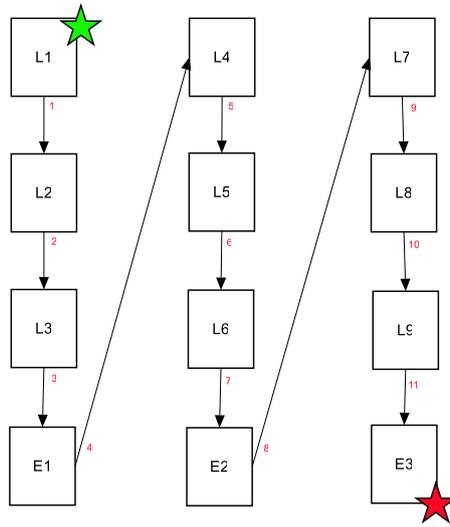
In the serial group, all PPTs have the same learning behavior in studying the sub-topics of interference and diffraction presented in the OG application. PPTs begin

studying sub-topics in each level sequentially and ending by an evaluation on each session. PPTs who are categorized as slow learners require a relatively long time to complete the tasks on each session. OG application provides an unlimited opportunity to repeat each evaluation as much as PPTs' choosing so that they can complete the learning program within a predetermined period. For the learning process in the serial group to run well, the lecturer needs to exercise control continuously and keep giving motivation to PPTs so that they want to keep trying and study harder to complete the tasks on each session. PPTs learning behavior is shown in Figure 6(a), which starts from L1 → L2 → L3 → E1 → L4 → L5 → L6 → E2 → L7 → L8 → L9 → E3.

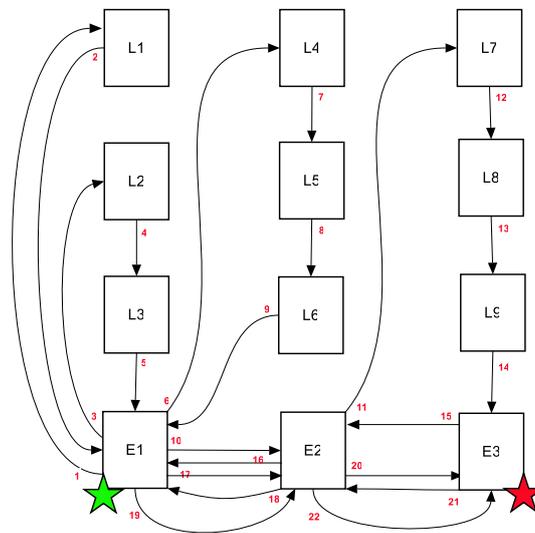
In the random group, PPTs are given the freedom to work on the level and evaluation in any session and cross-sessions are also allowed. The analysis result of the PPTs' exploration history show that the learning behavior in studying the sub-topics of interference and diffraction presented in the OG application is very diverse. Each PPTs has a different way of learning from one another. Figures 6(b), 6(c) and 6(d) show how the three samples of PPTs studied in the random group. The first sample is shown in Figure 6(b) that learns starting from E1 → L1 → E1 → L2 → L3 → E1 → L4 → L5 → L6 → E1 → E2 → L7 → L8 → L9 → E3 → E2 → E1 → E2 → E1 → E2 → E3 → E2 → E3. The second sample is shown in Figure 6(c) that learns starting from L1 → L2 → L5 → E1 → L4 → E2 → E3 → E2 → E3 → E1 → E2 → E3 → L3 → E1 → L6 → L7 → L8 → L9 → E3. While the third sample is shown in Figure 6(d) that learns starting from L1 → L2 → L4 → L5 → L6 → E1 → L7 → L8 → L9 → L3 → E3 → E1 → E2 → E3.

The setting for freedom of PPTs' access at every level (sub-topic) and evaluation has resulted in the OG application with serial and random models. Although PPTs in the two groups show different behaviors in learning the sub-topics presented, all PPTs can complete the learning program within a predetermined time. The analysis showed that there is no significant difference in the improvement of PPTs' concept mastery between two groups.

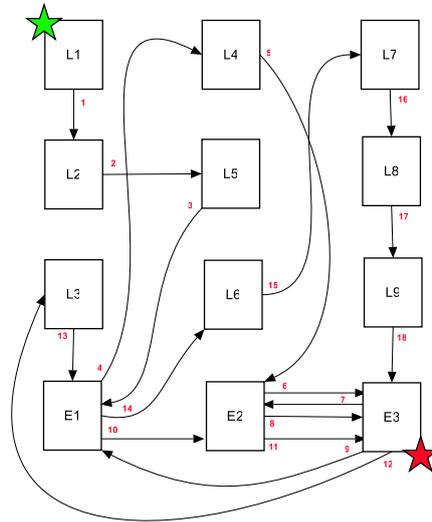
Research with relevant finding was also found in the context of sports education, namely research related to contextual interference (CI) effects on learning outcomes in the psychomotor domain. CI is the memory and performance disruption (i.e., interference) that is resulted from performing multiple skills or variations of skill within the context of practice [82]. There are three variations of the exercise model including the blocked, serial, and random models [83]. Several researches have shown the effect of CI on badminton service skills [83], basketball skills [84], swimming skills [85], and golf skills [84, 86]. The random group showed better performance than the blocked group, and the serial group showed parallel performance with the random group in learning three badminton services [83]. In golf, random model practice can be beneficial for skill acquisition even when the skill or skills to be learned use the same motor programme [86]. The random group also showed a more structured change in mental representation that was more similar to professional golfers compared to the blocked group [87].



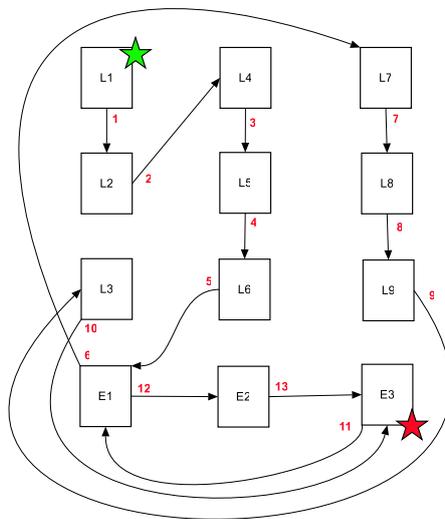
6(a)



6(b)



6(c)



6(d)

**Fig. 6.** PPTs' Learning Behavior in Serial Group (a) and Random Group (b), (c) and (d), Green Star (Start), Red Star (Stop)

The difference between this research and the research in the field of sports education is in the domain of learning outcomes. In the field of sports education, the learning outcome is targeted in the psychomotor domain, which is generally known as skill. There are relatively few skills practiced, so that each session presents the same alternative skills, but only in different order variations, and the learning setting that is designed is also still conventional. While the OG application developed in this research targeted in the cognitive domain, there are quite a lot of concepts that must be mastered by PPTs, so that each session presents a different sub-topic, and the learning setting is designed to be ICT-based so that monitoring and assessment is done automatically.

Based on the posttest results, the PPTs' concept mastery who was using OG application in the serial and random group could still be improved (42% for serial group and 49% for random group). These results are possibly related to the characteristics of PPTs at the research location. Nonetheless, this research has shown that through the setting variations of PPTs' access to sub-topics of interference and diffraction, two ICT-based gamification-application models are found, namely the serial model and the random model. The setting variations of PPTs' access has an impact on the variety of the ways they learn, especially in the random model that is seen as having the potential to develop critical and creative thinking skills while interacting with the OG application. These two skills are very important for the PPTs [88, 89], but to present empirical evidence related to this, further research is certainly needed. For further research, through setting variations of PPTs' access in ICT-based gamification-applications, there may be possibilities that other models besides the serial and random models will be found. In addition, this research has opened new insights in tracing the effect of contextual interference, especially on cognitive domain learning outcomes.

## **4 Conclusion**

The setting variations of PPTs' access for each level and evaluation have resulted in two OG application models, namely the serial and random model. The OG with serial model has succeeded in presenting sub-topics of learning material sequentially in each session. The OG with random model has succeeded in giving PPTs free access to each sub-topic and evaluation so that they can learn these sub-topics randomly in an order of their choosing. There is no significant difference in the improvement of PPTs' concept mastery between the serial and random model. Both of these models can be used as alternatives that can be used in designing ICT-based gamification-applications for more effective and efficient learning in the future.

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