The Effects of Gamification on Engineering Lab Activities

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***Abstract*— The aim of this study was to explore the effects of gamification on engineering lab activities by providing empirical evidence of the effect of gamification on students working in an engineering lab. Although gamification has been applied in several contexts including business, marketing, corporate management, and online communities and social networks, little research has been conducted on the application of gamification to engineering lab activities, nor is there empirical evidence to support the effectiveness of gamification at motivating and engaging students. For this study, two types of websites were created to collect data from students who enrolled an undergraduate introduction to human factors course taught at The Pennsylvania State University in the fall of 2015 semester. The two types of websites were Gamification (GM) and Non-Gamification (NG). While the GM website included game elements such as a Badge System, Score, Avatar, Leaderboard, Level, and Feedback (Notification), the NG website was a traditional website without game elements. In these websites, students could create their own multiple-choice questions (MCQs) and answer questions authored by classmates. The results suggest that the gamification of engineering lab activities had a positive effect in terms of motivation, engagement, and performance, indicated by the higher number of students who joined the GM website, the number of answers submitted by the GM group, the number of distinct days of participation, and the score of exam for the GM group. Thus, we can conclude that a positive effect of gamification on student learning in engineering lab activities was ultimately found.**

***Keywords*— gamification; learning; engineering education**

I. INTRODUCTION

Gamification can be defined as the use of game elements and mechanics as well as game design techniques in non-game contexts [1]. It is no surprise that in recent years the application of gamification has encouraged people to engage in desired behaviors in business, marketing, corporate management, and online communities and social networks [2-5].

Lee and Hammer theorized that gamification can also be applied to the education field as a tool to increase student engagement and motivate students to learn [6]. Further, they suggested that the most important factor in applying gamification is to understand under what circumstances game elements can drive learning behavior. Therefore, understanding gamification's impact on the emotional and social aspects of students' lives is the key to engaging them. Lee and Hammer [6] expected that gamification could change the rules, students' emotional experiences, and students' sense of identity and social positioning. Several researchers have also suggested applying gamification to increase student motivation by providing students with clear, achievable goals [7], providing immediate and frequent feedback [8], making a narrative context around a task [9], encouraging competition [10], and showing visual display of progress [8, 11].

While numerous studies on gamification have been conducted to explore its impact on students' learning, there is little empirical evidence to support the effectiveness of gamification at motivating and engaging students [12-16]. Especially, little research has been conducted on the application of gamification to engineering lab activities [14].

The overall goal of an engineering education is to prepare students to practice engineering and, in particular, to deal with the forces and materials of nature. As such, lab activity is essential to an education in engineering. Beyond gaining theoretical knowledge in the classroom, vital practical knowledge and experience can only be obtained in the lab. Lab activity also improves teamwork among students, as they must work in groups while dealing with real data and case studies [17].

Thus, the purpose of this study is to explore the effects of gamification on engineering lab activities by providing empirical evidence of the effect of gamification on students working in an engineering lab.

II. METHODOLOGY

Two types of websites were created to collect data from students who enrolled an undergraduate introduction human factors course (IE327) taught at The Pennsylvania State University in the fall semester of 2015. This course is a first-level junior course required for all baccalaureate students in the Department of Industrial and Manufacturing Engineering and was selected for this study because it includes a lab activity with more than 100 students. The course has 6 lab sections in which the maximum number of students is 24. In the first week of lab activity, we introduced the background and purpose of this study as well as the research question and data-collection websites. Only students who wanted to participate in this study were then asked to join the websites and practice the activities. They were also to take the general knowledge test. This study received institutional review board (IRB) approval from Pennsylvania State University.

A. Websites

For this study, we established websites of two types in which students could create their own multiple-choice questions (MCQs) and answer the questions authored by classmates, as based on a previous study [13]. The two types of websites were Gamification (GM) and Non-Gamification (NG). While the GM website included game elements including a Badge System, Score, Avatar, Leaderboard, Level, and Feedback (Notification), the NG website was a traditional website without game elements. Several previous studies showed that having students create their own questions is an effective learning technique that also helps students to develop self-regulating skills [18, 19]. Furthermore, according to Bloom's revised taxonomy, to have students create their own questions requires them to employ the most advanced step in the learning process, "Creating," which involves designing, constructing, planning, producing, inventing, devising, and making [20]. Examples of the websites as seen by the students are shown in Fig. 1. In these websites, when the students created questions, they had to also provide an explanation for the correct answer in their own words. These explanations appeared with the correct answer whenever other students submitted their own answers. When students answered the questions authored by their classmates, they also had to provide their opinion about whether they agreed with the correct answer or not, evaluate the difficulty and quality of the question, and write comments about the question in their own words. They also needed to decide whether to "follow" the author of the question or not. The "follow" function enables students to view the questions created by specific authors in the first row among the unanswered questions.

The game elements were only available in the GM website. Scores for students in this website were calculated by an algorithm based on the number of questions authored as well as the number of answers given and the feedback provided by other students. This score was then used to determine level and ranking for competition between the students. The GM website included two more pages, called "View my badges" and "Leaderboard." Samples of these two pages are shown in Fig. 2. In the "View my badges" page, students could identify what they earned from the activity. A total of 27 kinds of badges were available. Examples of the badges with their descriptions are shown in Table 1. In the "Leaderboard" page, students could see where they ranked on the website in relation to their classmates. They could also see information about specific rankings such as Username, Level, Score, the number of earned badges, questions, and answers.

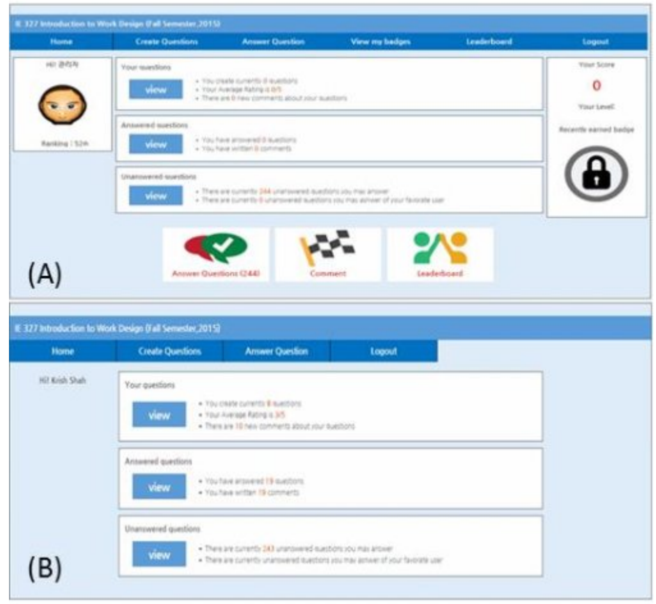

Fig. 1. The main menus of the two websites: (A) Gamification (B) Non-Gamification

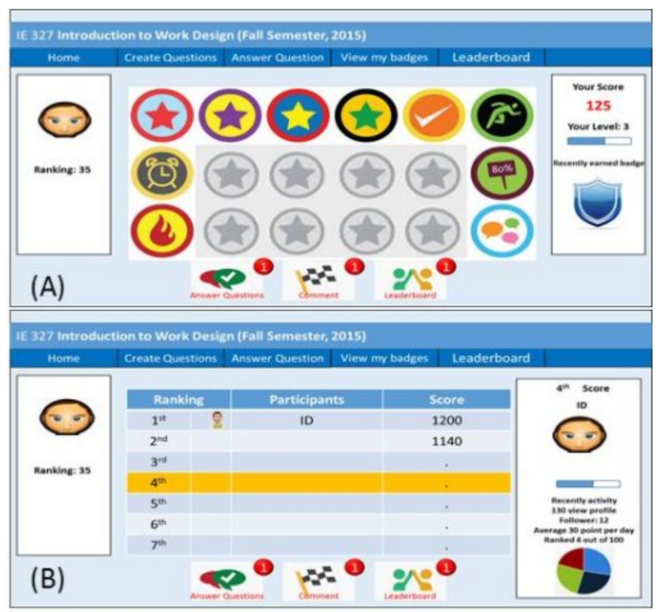

Fig. 2. Samples of the (A) "View my badges" and (B) "Leaderboard" pages

TABLE I. EXAMPLES OF THE BADGES WITH DESCRIPTIONS

Badge Name	Description
1. Author	For contributing your first question on the Website
2. Answerer	For answering your first question on the Website
⋮	⋮
25. Genius	For correctly answering at least 20 questions in a row, on 5 different days
26. Strivers	For answering a questions, on 10 consecutive days
27. Leader	For at least 20 followers

B. Design of experiment

A total of 140 students enrolled in the course and its 6 lab sections in the fall semester of 2015. For the purpose of this study, students who wanted to participate were randomly assigned to the experimental or control groups based on their lab sections. Students in sections 1, 3, and 5 were assigned to the NG group, while students in sections 2, 4, and 6 were assigned to the GM group. The first phase of the study for students who wanted to participate was conducted with Biomechanical Analysis of Lifting and CTD and Screwdriver Design lab materials. All students who participated in the first phase received extra credit amounting to 0.5% of overall course grade and could receive an additional 1% extra credit if they met the minimum requirement of creating 3 questions and answering 18 questions. In the GM group, if students were ranked in the top 5%, they received a further 1% extra credit. In the NG group, students who created every additional five questions or answered 15 questions after meeting the minimum requirement received an additional 0.1% extra credit up to 1%. Since the ranking system was one of the game elements, we gave additional extra credit to the NG group based on the members' effort at creating and answering questions. To balance the GM and NG groups for additional extra credit, the number of questions and answers required for additional extra credit in the NG group was set based on the previous study [7]. In the second phase of this study, all participating students were assigned to the opposite group; students assigned to the NG website in the first phase were assigned to the GM website and vice versa. The second phase for students who wished to participate was conducted with Time Study lab materials. All students participating in the second phase received extra credit via the same method. Fig. 3 shows the timeline on which this study was conducted. To avoid the possibility of students completing all the required contributions in one day, students could not create more than 5 questions per day or answer more than 15 questions per day.

C. Research Question

The research questions used in this study were as follows:

- Would the Gamification system motivate students?
- Would the Gamification system increase students' engagement?
- Would the Gamification system increase students' performance?

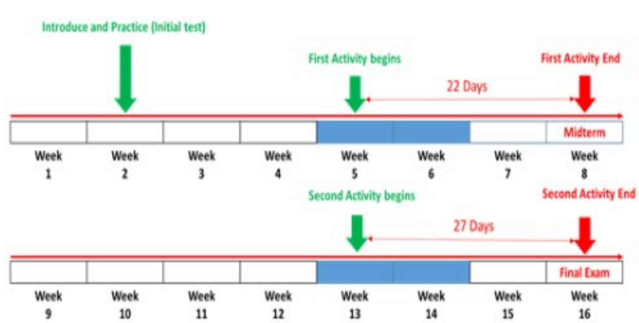

Fig. 3. Timeline of the experiment

III. PREPARE YOUR PAPER BEFORE STYLING

To answer the first research question, frequency analysis was conducted. The numbers of students who joined the websites for each phase are shown in Table 2.

In the first phase, of the 67 students in the GM group and 73 in the NG group, 48 and 50 respectively joined and participated in each website. We observed a higher participation rate in the second phase compared with the first, showing that 61 of 73 in the GM group and 51 of the 67 in the NG group joined the websites. The signup rate for the GM website was 3.1% greater than that for the NG website for the first phase and 7.5 % greater for the second phase compared to lower rates in both phases (68.5% and 76.1% respectively).

TABLE II. THE NUMBER OF STUDENTS WHO JOINED EACH TYPE OF WEBSITE FOR EACH PHASE

	1st Phase		2nd Phase	
	GM website	***NG website***	***GM website***	***NG website***
Participants	48 (71.6%)	50 (68.5%)	61 (83.6%)	51 (76.1%)
All	67	73	73	67

The summary of website activities, including the number of questions authored, the number of answers submitted, and the number of distinct days of activity between the two types of websites for each phase are shown in Table 4. Distinct day was defined as the number of days on which a student was considered to be active on the assigned website, either authoring or answering at least one question.

To answer the second research question, a two-sample t-test was conducted to determine the significance of the differences in website activities between the two groups for each phase.

The number of questions authored by students was not significantly different between the two groups for both phases (1st phase: $t(94) = -0.27$, $p = 0.788$; 2nd phase: $t(80) = 0.41$, $p = 0.683$). However, both the quality and difficulty of the questions showed significant differences between the two groups for both phases (Quality: 1st phase: $t(459) = 3.65$, $p = 0.000$, 2nd phase: $t(468) = 12.29$, $p = 0.000$; Difficulty: 1st phase: $t(352) = 2.79$, $p = 0.006$, 2nd phase: $t(556) = 9.29$, $p = 0.000$). The number of answers and comments and the percentage of correct answers were significantly different between the two groups in the first phase (Answer: $t(92) = 2.03$, $p = 0.045$; Comments: $t(468) = 3.50$, $p = 0.001$; Correct Answers: $t(3043) = 2.17$, $p = 0.030$); however, in the second phase those factors were not significantly different between the two groups (Answer: $t(109) = 0.15$, $p = 0.878$; Comments: $t(659) = -1.87$, $p = 0.063$; Correct Answers: $t(5129) = 1.40$, $p = 0.162$). Finally, the number of distinct days showed a significant difference between the two groups for both phases (1st phase: $t(79) = 1.99$, $p = 0.050$, 2nd phase: $t(86) = 2.09$, $p = 0.040$).

TABLE III. THE SUMMARY OF WEBSITE ACTIVITIES BETWEEN TWO GROUPS FOR BOTH PHASES

Activity	Website	1st Phase				2nd Phase			
		N	*Mean*	*StDev*	*P Value*	*N*	*Mean*	*StDev*	*P Value*
The number of Questions	G	48	5.06	6.4	0.788	61	7.3	26	0.683
	N	50	5.4	5.94		51	5.9	10	
The Quality of Questions	G	244	2.291	0.908	**0.000^{***}**	448	2.683	0.562	**0.000^{***}**
	N	270	1.91	1.44		299	1.993	0.855	
The Difficulty of Questions	G	244	1.008	0.287	**0.006^{**}**	448	1.297	0.586	**0.000^{***}**
	N	270	0.87	0.753		299	1.023	0.172	
The number of Answers	G	48	42.3	30.2	**0.045^{*}**	61	49.6	77.1	0.878
	N	50	28.3	37.6		51	47.5	65.7	
The number of Comments	G	244	2.27	3.06	**0.001^{***}**	448	1.38	2.45	0.063
	N	270	1.4	2.49		299	1.72	2.34	
The percentage of Correct Answers	G	2002	0.804	0.397	**$>0.03^{*}$**	3027	0.809	0.393	0.162
	N	1459	0.773	0.419		2426	0.793	0.405	
The number of Distinct Days	G	41	10.54	6.54	**0.050^{*}**	51	14.1	5.57	**0.040^{*}**
	N	47	7.97	5.69		47	11.36	7.21	

* Significant difference at $p<0.05$ ** Significant difference at $p<0.01$ *** Significant difference at $p<0.005$

The students' performance was compared between the GM group and the NG group for each phase based on the students' scores on the general knowledge test, midterm, and final exam. The difference between the general knowledge score and midterm score was used as the performance data for the first phase of the study, and the difference between the general knowledge score and final exam score was used as the performance data for the second phase. The exams were graded by the course instructor who was not directly involved in the gamification components of the lab exercises. To answer the third research question, a two-sample t-test was conducted to determine the significance of the differences in the exam scores between the groups for each phase, and the results are shown in Fig. 4. The students' performance was significantly different between the two groups for all phases (1st phase: t (83) = 2.12, p = 0.037; 2nd phase: t (83) = 2.20, p = 0.030).

To investigate whether the sequence of students' assignment to the GM and NG groups affected the level of student engagement, we compared the difference in students' activities between the two sequences only for students who participated in both phases using a two-sample t-test. The control group consisted of the students who used the GM system in the first phase and the NG system in the second phase (GM to NG). The treatment group consisted of the students who used the NG system in the first phase and the GM system in the second phase (NG to GM). Fig. 5-7 shows the results in terms of the number of questions authored, answers submitted, and distinct days, respectively. For the number of questions authored, there was no significant difference between the two groups. However, there were significant differences between the two groups for the number of answers submitted and distinct days (Answer submitted: t (78) = -1.98, p = 0.05; Distinct day: t (59) = 2.31, p = 0.024).

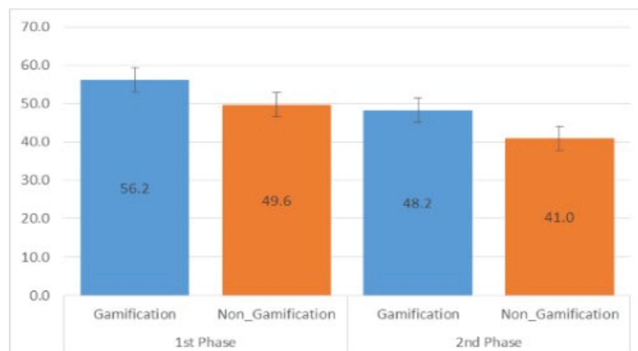

Fig. 4. The difference of exam scores between the two groups for both phases

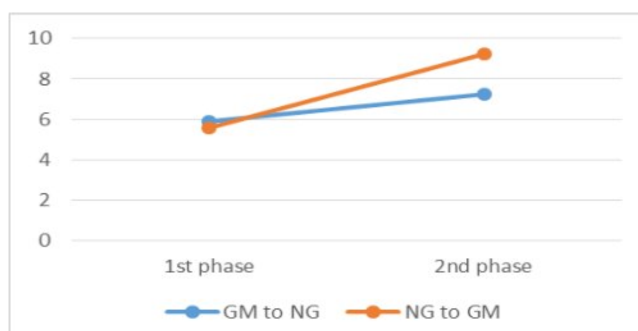

Fig. 5. The difference of the number of questions between two groups (GM to NG, NG to GM)

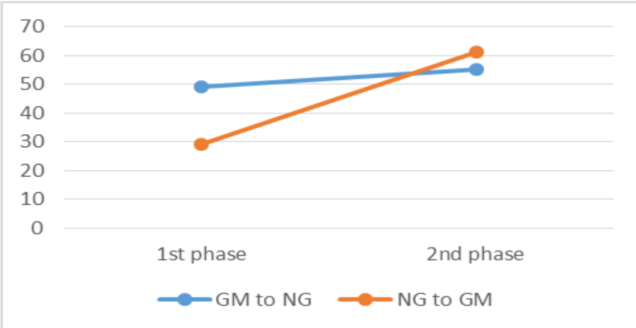

Fig. 6. The difference of the number of answers between two groups (GM to NG, NG to GM)

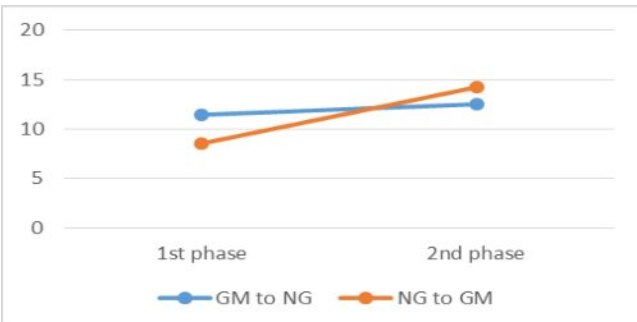

Fig. 7. The difference of the number of distinct days between two groups (GM to NG, NG to GM)

IV. DISCUSSION

Gamification is a fast-growing approach used to encourage user motivation and engagement in non-gaming environments. In a general survey of the literature, Seaborn and her colleagues [21] found that over 750 articles have been written on gamification. With respect to engineering education, Bodnar et al. [22] surveyed 191 papers that used games in engineering classes. The findings of both Seaborn and Bodnar agree that gamification resulted in an overall positive experience for users and students. However, both researchers' findings also concur that the majority of applied work is not grounded in theory and does not use a standard gamification framework. Moreover, from the surveyed literature, only a small subset demonstrated a systematic approach to analytically assessing the benefits of implementing games (or game components) in the classroom [22]. In this context, a major gap exists in that gamification research needs to be improved based on empirical validation of the effectiveness of various gamification methods, which we tried to address by comparing GM and NG groups.

Two types of websites, GM and NG, were created to explore the effects of gamification on engineering lab activities by providing empirical evidence of the effect of gamification on students working in an engineering lab. The results suggest that gamification had a positive effect in terms of motivation, engagement, and performance on engineering lab activities, indicated by the higher number of students who joined the GM website, the higher number of answers submitted to the GM website (in the first phase), and the higher number of distinct days of participation for students in the GM group. Although gamification did not have the impact of increasing the number of questions authored by students in the GM group for either phase, the difficulty and quality of questions authored by students in the GM group were higher than those of the NG group in each phase. These results indicate that the GM group invested greater time and effort in creating questions compared with the NG group.

Despite these differences in participation and engagement, in the second phase the number of answers submitted did not differ significantly between the two groups. One potential reason may be that most students in both groups selected answering questions as the best method for preparing final exam, which had a great impact on their grades. The total number of answers submitted by both groups combined increased by around 2000 in the second phase. The number of questions created by students did not differ significantly between the two groups in either phase. One possible explanation for this is that creating their own questions presented the greatest challenge for students. Each student created only an average of 6 questions for each phase, and this number is only half of the average number of distinct days for all students in both groups. This phenomenon was also found in previous studies [13, 23] and may be due to the fact that creating their own questions requires greater time and effort for students when compared to other activities. Another potential reason is that, since there were one or two lab materials in which students had to create questions, it was difficult to avoid repeated questions.

Additionally, we investigated whether the sequence in which the system was used between GM and NG affected the level of student engagement by comparing two groups, one for each sequence. Since the general trend of decreasing motivation over time is shown in the literature [24-26], we expected that the activity of students in both groups might decrease in the second phase compared with the first phase. However, students' activities did not decrease in either group. Furthermore, the increase in the treatment group was significantly greater than that in the control group. Based on the slope between the two phases for each group, we can explain the effect of gamification on students' motivation, which shows a significant difference in the number of questions submitted and distinct days.

Based on our results, we can conclude that a positive effect of gamification on student learning in engineering lab activities was ultimately found.

Since this is the first and pilot study, it has several limitations. Though our study focused primarily on the effectiveness of gamification on engineering lab activities, future research should consider which elements of gamification had the greatest impact on students' motivation, engagement, and performance. In addition, further research is required to consider real-time evaluation of student behavior by using an eye-tracking system.

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