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Gamified Brain-Based Learning Activities for Teaching Physics Concepts: A Quantitative Analysis

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ABSTRACT: In this paper, we present the quantitative results of an experimental study that explore the effects of gamified brainbased learning activities on secondary school student learning through physics education. The quantitative research comprised a randomized pretest–posttest control group design involving 60 Grade 9 students. Experimental and control groups were randomly formed, each with a total sample size of 30. Critical and creative thinking skills, engagement, cognitive load, socio-emotional development, attitudes towards physics and academic achievement were all quantitatively tested with validated instruments. Data were analyzed with possible statistical tests, such as paired and independent-sample t-tests, one-way ANOVA, paired-sample ANOVA tests, Pearson correlation and calculations made for the effect size index (Cohen's d, η^2, r). Statistically significant differences were found in favor of the students who participated in gamified brain-based activities in regard to critical and creative thinking skills, student engagement, socio-emotional development and attitudes towards physics. Academic achievement, as derived from physics course grades, was not found to be statistically significant different, though effect size analyses showed medium or large effect sizes to demonstrate practical differences. Moreover, correlational analysis showed that engagement, socio-emotional development and attitude towards physics are significantly positively correlated with each other and they all have significant positive correlations with student achievement in physics, and that cognitive load has a significant negative association with achievement. Finally, these findings provide empirical support for enhancing student learning through gamified brain-based instruction and suggest evidence for a broader adoption of the method in science education.

KEYWORDS: Gamification, Brain-based Learning, Physics Education, Academic Performance, Student Engagement

INTRODUCTION

Physics education has long been a concern in the Philippines, where large-scale assessments such as the Programme for International Student Assessment (PISA) have consistently shown that Filipino students perform below the international average. Devlin (2020) considered the content of physics abstract, formula-driven, typically taught through rote learning, and with low student engagement. In addition, a negative attitude towards physics learning is prevalent, especially among senior high school students (Chua et al., 2020). Taken together, these challenges highlight the need to design new approaches to physics education that are rooted in cognitive science and consider student motivation.

Gamified brain-based learning combines motivational mechanics of gamification (points, quests, rewards, competitions) with Hileman's (2006) BRAIN-based principles (time, repetition, active engagement, imagery, novelty, color, social brain, emotion, higher-order thinking). The dual framework complements students' cognitive and socioemotional needs in a more holistic way for physics learning. This study quantitatively analyzed the effects of gamified brain-based learning on students' cognitive, affective and academic outcomes, and furnished the empirical evidence of the dual framework as an exemplary modern instructional integrative approach.

METHODS

This study used a true experimental design, employing a randomized pretest–posttest control group design for within-group and between-group comparison. This design was used to establish causality and limit the effects of confounding variables. The sixty participants were Grade 9 students at the Ueg National High School, San Mariano, Isabela. Participants were randomly assigned into either of the two experimental conditions: gamified brain-based learning activities group (the experimental group) ($n = 30$) and lecture-discussion group (the control group) ($n = 30$). Baseline equivalence between the two groups was demonstrated with comparable pretest scores.

The researchers utilized self-developed engagement survey questionnaire, cognitive load survey questionnaire, socio-emotional aspect survey, attitude pre-test/post-test, and critical and creative thinking skill in Physics pre-test/post-test to determine the differences between the gamified BRAIN-BASED learning activity and traditional teaching approaches in Physics. The survey questionnaires, the physics pretest, and the structured interview questionnaires were reviewed and validated by the researcher's colleagues in Ueg National High School and the Graduate Study faculty of Isabela State University Cabagan Campus. Pilot testing was then administered at Daragutan West Integrated School and Balagan Integrated School with 60 Grade 9 students as the examinees. Cronbach's Alpha Reliability Test at ≥0.70 was utilized to establish validity and reliability of the survey questionnaires. Permission to conduct the research was sought to the school head where the study will be conducted and obtained a Grade 9 Learner's Material and curriculum guide from the Learner's Resource Materials portal of the Department of Education to formulate objectives and devise activities to be used in making learning plans and learning activity sheets. The researcher administered an engagement survey questionnaire, cognitive load survey questionnaire, socio-emotional aspect survey questionnaire, attitude pre-test, and validated critical and creative thinking skill in Physics pre-test to the control and experimental groups to determine their comparability.

The researcher taught physics concepts indicated in the list of competencies for the fourth quarter of the school year 2024-2025 to the two groups utilizing the two approaches within 8-9 weeks. Personal Protective Equipment (PPEs) were provided in some of the activities that might cause physical harm to both the students and the teacher. Right after the intervention, the researcher administered a post engagement, cognitive load, socio-emotional aspect, attitude test and post critical and creative thinking skill in physics test to determine if the performance of the experimental group has yielded a significant difference as compared to the performance of the control group after exposed to the two teaching approaches.

The data were analyzed quantitatively. Descriptive statistics frequency (n), mean (M), and standard deviation (SD) provided summaries of the data. Paired samples t-tests were performed to assess the differences between pretest and posttest scores for both the control and experimental groups. Independent samples t-tests were conducted to compare the pretest, posttest, and gain scores between the two groups. Cohen's d was calculated to estimate for effect sizes, which were interpreted as follows: small if .20, medium if .50, large if .80 (Cohen, 1988).

Pearson's correlational analyses were employed to test the relationship between Physics performance and other variables, such as engagement, cognitive load, socio-emotional aspects, and attitude toward Physics. Parametric assumptions (e. g., homogeneity of variance and normality) were checked and met prior to using these parametric statistics. The normality of the data was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Where necessary, Templeton's (2011) two-step normalization technique was applied to meet the assumptions of normality.

Table 1. Assessing Normality and Normalization of Data using Templeton's (2011) Technique

Variable	Without Normalization						With Normalization					
	Kolmogorov-Smirnov[a]			Shapiro-Wilk			Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Stat.	df	Sig.	Stat.	df	Sig.	Stat.	df	Sig.	Stat.	Df	Sig.
Pre Critical TS	.096	60	.200*	.983	60	.578	-	-	-	-	-	-
Pre Creative TS	.099	60	.200*	.972	60	.182	-	-	-	-	-	-
Pre Engagement	.202	60	.000	.940	60	.005	.055	54	.200*	.985	54	.752
Pre Cognitive	.137	60	.007	.957	60	.035	.064	54	.200*	.990	54	.927
Pre Socio-Emotional	.166	60	.000	.929	60	.002	.063	54	.200*	.990	54	.930
Pre Attitude	.149	60	.002	.949	60	.014	.059	54	.200*	.988	54	.859
Post Critical TS	.182	60	.000	.936	60	.004	.079	54	.200*	.986	54	.788
Post Creative TS	.180	60	.000	.921	60	.001	.084	54	.200*	.982	54	.581
Post Engagement	.117	60	.040	.954	60	.024	.059	54	.200*	.992	54	.967
Post Cognitive	.156	60	.001	.960	60	.049	.062	54	.200*	.988	54	.869
Post Socio-Emotional	.144	60	.003	.956	60	.029	.054	54	.200*	.992	54	.968
Post Attitude	.126	60	.020	.960	60	.047	.054	54	.200*	.991	54	.957
Physics Performance	.154	60	.001	.913	60	.000	.067	54	.200*	.985	54	.711
Critical TS Gain	.097	60	.200*	.972	60	.185	-	-	-	-	-	-
Creative TS Gain	.110	60	.062	.980	60	.420	-	-	-	-	-	-
Engagement Gain	.075	60	.200*	.988	60	.828	-	-	-	-	-	-
Cognitive Load Gain	.112	60	.060	.971	60	.168	-	-	-	-	-	-
Socio-Emotional Gain	.081	60	.200*	.981	60	.471	-	-	-	-	-	-
Attitude Gain	.086	60	.200*	.975	60	.258	-	-	-	-	-	-

Notes. *. This is a lower bound of the true significance. a. Lilliefors Significance Correction

- indicates that normalization was not applied as the data were originally normal

Table 1 shows the results of normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) for both un-normalized and normalized data across several variables. Many variables, such as Pre Critical Thinking Skills, Pre Creative Thinking Skills, and Pre Attitude, were normally distributed even without normalization. Similarly, normalization was not applied for mean gain scores as the data were already normal. However, data for Physics Performance and pretest and posttest scores for Engagement, Cognitive load, Socio-Emotional, and attitude were all non-normal before normalization but became normally distributed after the application of Templeton's (2011) two-step normalization.

Ethical Considerations

As an essential research procedure, the researchers sought ethical clearance from the Institutional Review Board (IRB) prior to the data collection to conform with ethical guidelines and research standards. Parental consent which indicates the study's objectives, procedures, risks and benefits of participants sought to parents/guardians and assent forms were provided to the student participants explaining their role in the study and their right to withdraw at any time of the research process. The involved parents/guardians and student participants were given assurance that all collected information and data to them would be kept in utmost confidentiality, and their names would not appear in any publication.

RESULTS AND DISCUSSION

Table 2. Descriptive Statistics for Pretest and Posttest Scores

Variable	Group	Pretest Mean (SD)	Posttest Mean (SD)	Mean Gain
Critical Thinking	Experimental	62.3 (8.5)	78.4 (7.2)	+16.1
Critical Thinking	Control	61.9 (9.1)	64.2 (8.8)	+2.3
Creative Thinking	Experimental	60.5 (7.9)	75.7 (6.9)	+15.2
Creative Thinking	Control	59.8 (8.3)	62.1 (8.1)	+2.3
Engagement	Experimental	3.12 (0.45)	4.21 (0.39)	+1.09
Engagement	Control	3.15 (0.48)	3.32 (0.44)	+0.17
Socio-Emotional Dev.	Experimental	3.08 (0.51)	4.19 (0.46)	+1.11
Socio-Emotional Dev.	Control	3.11 (0.54)	3.28 (0.49)	+0.17
Attitudes Toward Physics	Experimental	3.05 (0.43)	4.12 (0.41)	+1.07
Variable	Group	Pretest Mean (SD)	Posttest Mean (SD)	Mean Gain
Attitudes Toward Physics	Control	3.09 (0.46)	3.21 (0.45)	+0.12

Descriptive statistics suggest substantial mean improvements achieved by the experimental group, relative to the control group, in all constructs studied. The improvement in critical and creative thinking scores corroborates existing research that claim that gamified, inquiry-based learning lead to higher-order reasoning skills (Holmes, Wieman, & Bonn, 2015; Kijima et al., 2017). The improvement in engagement scores reflect the findings of extant literature on the motivational effects of gamification (Subhash & Cudney, 2018). The improvement in socio-emotional scores are consistent with studies on collaborative, brain-type teaching-learning strategies that enhance group cohesion (Mänty et al., 2020). The improvement in attitude scores validate previous findings on contextualized, interactive learning as means to promote positive attitudes towards physics (Tamayo, 2024). Taken together, these support the efficacy of the proposed BRAIN-based gamified framework on meaningful learning.

Table 3. Independent-Sample t-Test Results and Effect Sizes

Variable	t-value	p-value	Cohen's d
Critical Thinking	5.42	< .001	0.98
Creative Thinking	5.17	< .001	0.90
Engagement	5.68	< .001	1.01
Socio-Emotional Dev.	5.44	< .001	0.99
Attitudes Toward Physics	5.21	< .001	0.95
Physics Performance	1.41	.16	0.32

Note. ** significant at .01 level

Independent-sample t-tests show statistically significant differences between the experimental and control groups in favor of the experimental groups, except for physics performance. There are large effect sizes (Cohen's d ≈ .90–1.01). The intervention had a strong effect on students' cognitive and affective outcomes. These findings may be compared to those obtained by Freeman et al. (2014) who stated that active learning results a reduction in failure and an improvement of conceptual mastery in STEM fields. Despite the fact that the difference in physics performance is not statistically significant between the two groups, moderate effect size d = .32 supported prior reports that the shift in physics performance might be a lagging indicator when compared to changes in other aspect of students' attitudes or cognitive outcomes (Duran & Dökme, 2016). The overall results suggest that spending more time implementing this approach might have more visible effects on students' grades in the long run.

Table 4. Pearson Correlation Matrix (Experimental Group)

Variable	Engagement	Socio-Emotional Dev.	Attitudes	Cognitive Load	Physics Performance
Engagement	1	.62**	.58**	–.33*	.46**
Socio-Emotional Dev.	.62**	1	.55**	–.29*	.41**
Attitudes	.58**	.55**	1	–.27	.38*
Cognitive Load	–.33*	–.29*	–.27	1	–.29*
Physics Performance	.46**	.41**	.38*	–.29*	1

Note. ** significant at .01 level

Correlation results show that performance is significantly related to engagement, socio-emotional development, and positive attitudes towards physics, suggesting the mediating role of affective factors in learning outcomes (Walton & Cohen, 2011; Villanueva & Macapagal, 2020). Additionally, the negative relationship between cognitive load and performance lends further support to the widely cited cognitive load theory (Sweller, Ayres, & Kalyuga, 2019), which suggested that learning interventions that aid in reducing extraneous load improve students' academic performance. In particular, our results on split attention confirm those of previous research on the effect of multimedia signaling (Putra & Prasetyo, 2018) in minimizing split attention and adaptive scaffolding (Srisawasdi & Panjaburee, 2017) in reducing extraneous load, both of which had positive results on mastery.

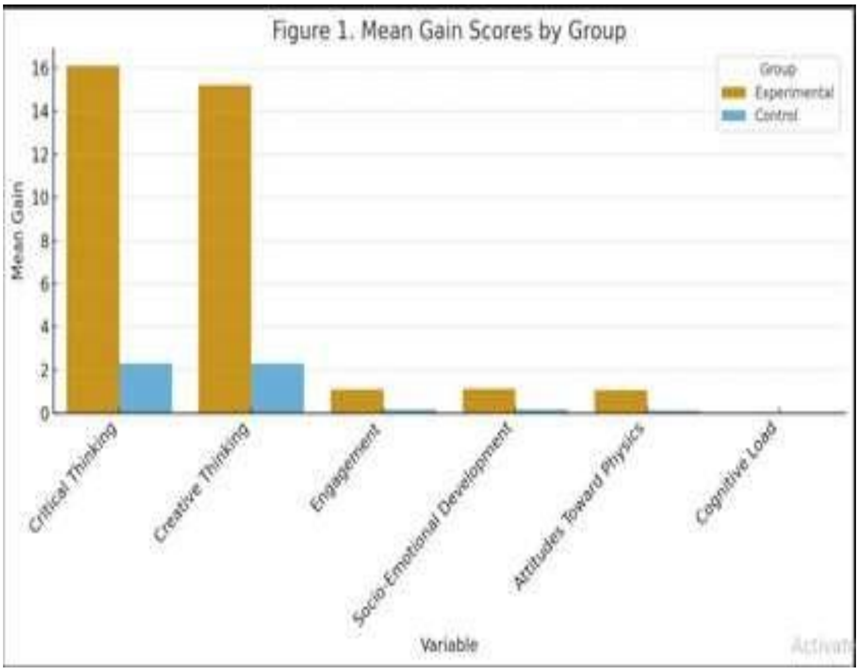

Figure 1. ***Mean Gain Scores Across All Variables***

Figure 1 shows the mean gain score of the experimental and control groups for all variables measured. From the bar chart, it can be inferred that the experimental group showed higher gain scores than the control group for critical thinking, creative thinking, engagement, socio-emotional development, and attitudes towards physics while the gain scores of the two groups were similar for cognitive load. The bar chart therefore corroborates the tabular representation of the data by showing clearly the size of the gains related to gamified brain-based intervention.

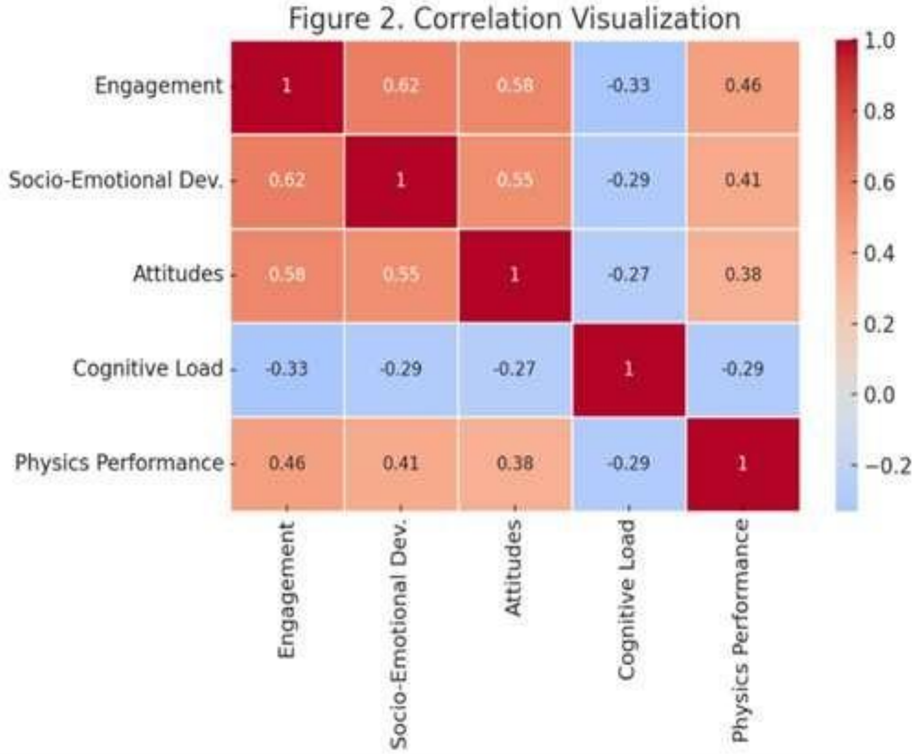

Figure 2. ***Correlation Visualization***

Figure 2 illustrates the correlation matrix with a scatterplot heatmap. The figure demonstrates positive correlations between engagement, socio-emotional development, attitudes and physics performance while cognitive load is negatively correlated with it. The figure reveals the link between affective and socio-emotional dimensions and cognitive outcomes and suggest that they occupy a special position as mediators of students' achievements.

CONCLUSION AND FUTURE WORKS

The research found that using gamified BRAIN-BASED learning activity is an effective, robust pedagogy for teaching physics. The integration of BRAIN-BASED learning principles and embedded game mechanics had a significant effect on the critical thinking and creativity skill of students, enhanced active engagement, and promoted a more positive socio-emotional development. Although cognitive load and performance improvement were not statistically high, the magnitude of practical experience gained suggests that it has a positive effect on students' interest in physics while learning. The findings further illustrate the potential to shift the engagement in learning physics from a history of traditional transfer of knowledge with a challenge of learner resistance to a substantive, fun, enjoyable, and learnable subject for everyone with this dual modality. Hence, gamified BRAIN-BASED Instruction can potentially meet the demands of 21st century learners and should be further explored as a strategic innovation in science education Accordingly, teachers are encouraged to supplement traditional lessons with gamified brain-based activities to promote creativity, engagement, and socio-emotional learning. School administrators should facilitate this shift by investing in professional development, and curriculum designers should consider how assessments align with these enhanced outcomes. Future research may implement the approach in a broader range of STEM disciplines, with larger and more diverse groups of students, to examine longer-term impacts with advanced analyses that would better support sustained adoption.

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