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The effect of gamified flipped learning on Malaysian fifth-grade students' academic achievement and learning experience in science

El efecto del aprendizaje invertido gamificado en el rendimiento académico y la experiencia de aprendizaje en ciencias de los estudiantes de quinto grado en Malasia

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ABSTRACT

This study investigated the effect of gamified flipped learning on the academic achievements and learning experiences of fifth-grade students. A quasi-experimental design was employed, with a control group receiving conventional instruction and a treatment group engaging in gamified flipped learning. Forty fifth-grade students were randomly selected, with 20 students in each group. Data were collected through pre- and post-tests, along with interviews, and analysed using descriptive statistics and the Quade-ANCOVA non-parametric test. The results revealed a significant improvement in the academic achievement of the gamified flipped learning group ($p < 0.05$) with a large effect size (partial eta squared = .626) compared to the control group. Interview data further indicated that students in the treatment group experienced enhanced learning, reporting increased excitement, focus, and ease of understanding through gamified activities. These findings underscore the potential of gamified flipped learning to not only improve academic performance but also create engaging and effective learning environments tailored to the needs of Generation Z students. This study contributes valuable insights into the role of gamified flipped learning in primary science education, emphasizing its capacity to transform traditional pedagogies and better support student learning outcomes.

KEYWORDS Gamification; flipped learning; gamified flipped learning; primary school education; academic achievement.

RESUMEN

Este estudio investigó el efecto del aprendizaje invertido gamificado en los logros de los estudiantes de quinto grado. Se utilizó un diseño cuasi-experimental, con un grupo de control que recibió el aprendizaje convencional y un grupo experimental que participó en el aprendizaje invertido gamificado. Se seleccionaron aleatoriamente cuarenta estudiantes de quinto grado, con 20 estudiantes en cada grupo. Los datos se recopilaron mediante pruebas previas y posteriores junto con entrevistas, y se analizaron utilizando estadísticas descriptivas y la prueba no paramétrica Quade-ANCOVA. El análisis reveló una mejora significativa en los logros del grupo de aprendizaje invertido gamificado ($p < 0.05$) con un tamaño de efecto grande (eta cuadrado parcial = .626) en comparación con el grupo de control. Los datos de las entrevistas indicaron que los estudiantes en el grupo experimental tuvieron experiencias de aprendizaje positivas, informando un aumento en la emoción, el enfoque y la facilidad de aprendizaje a través de actividades gamificadas. Estos hallazgos sugieren que integrar la gamificación con el aprendizaje invertido puede mejorar el logro y el compromiso de los estudiantes, y se recomienda que los educadores continúen incorporando elementos gamificados en el aprendizaje invertido para satisfacer mejor las necesidades de aprendizaje de los estudiantes de la Generación Z.

PALABRAS CLAVE Gamificación; aprendizaje invertido; aprendizaje invertido gamificado; escuela primaria; experiencia de aprendizaje.

1. INTRODUCTION

Primary school science education plays a critical role in shaping students' attitudes toward science and building foundational problem-solving skills. Research suggests that interdisciplinary learning, especially with technology integration, positively influences students' attitudes toward science (Zhou & Lin, 2024). However, many primary school students struggle with science, often perceiving it as difficult, which has led to a search for more engaging and relevant teaching strategies to improve students' scientific inquiry skills (Ortiz & Aliazas, 2021). Challenges in science education stem from outdated teaching methods (Marcourt et al., 2022), limited exposure to science careers (Kang et al., 2023), and teachers' limited pedagogical content knowledge, all of which hinder students' interest in learning science (Solis-Foronda & Marasigan, 2021).

In Malaysia, data from the Trends in International Mathematics and Science Study (TIMSS) study (1999-2019) reveals a concerning decline in students' science performance, with a drop in the percentage of students meeting advanced benchmarks and average scores falling below the international average (Phang et al., 2021). Despite students' initial interest in science, their confidence wanes over time due to traditional teaching approaches, assessment issues, and limited opportunities to explore science-related careers. To address these challenges, experts recommend curriculum adaptation (DeBarger et al., 2017), pedagogical innovation (Iwuanyanwu, 2019), and the integration of technology into science education, such as the use of games (Yilmaz, 2023).

Game-based learning (GBL) and flipped learning have been identified as promising solutions to these challenges. A meta-analysis by Lei et al. (2022) of 41 studies comparing GBL to traditional methods found that GBL enhances students' understanding of complex scientific concepts, increases engagement, and improves academic outcomes in science learning, particularly in quizzes and exams. Fahdiran et al. (2021) observed improved science learning outcomes in 6th-grade students when the flipped classroom approach incorporated active learning strategies.

Gamification, the integration of game elements into non-gaming contexts, has also gained attention in educational research for its potential to enhance student engagement and motivation (Majdoub & Heilporn, 2024; Rodrigues et al., 2022). Studies suggest that gamification can foster positive learning experiences (Klock et al., 2018) and improve social interaction (Gaonkar et al., 2022). However, gamification is not without its challenges; for instance, poorly designed gamified activities can lead to frustration, reduced engagement, or a focus on extrinsic rewards rather than intrinsic learning goals (Buckley & Doyle, 2016).

Integrating gamification into flipped learning addresses these challenges by enhancing engagement during out-of-class activities and improving overall flipped learning effectiveness. For instance, Huang et al. (2018) found that gamification improved engagement and performance in a flipped course, while Lo and Hew (2018) reported that gamified flipped learning enhanced academic performance and cognitive engagement compared to traditional approaches. However, challenges such as designing effective gamified components and overcoming technological barriers remain (Gündüz & Akkoyunlu, 2020).

Recent research, including Mulyanti et al. (2023), demonstrates the effectiveness of gamified flipped learning in improving fifth-grade students' science achievement. However, their focus on general science leaves gaps in understanding its impact on specific topics, such as *Machines*, and its applicability in contexts like Malaysia. Additionally, while evidence supports the academic benefits of gamified flipped learning, less is known about its effects on students' learning experiences.

These findings underscore the potential of flipped learning across diverse subjects and settings. However, integrating digital games into this model remains underexplored. This gap highlights the need for further research on how GBL can complement and enhance flipped learning to improve both academic outcomes and student experiences.

2. LITERATURE REVIEW

2.1. Flipped Learning

The concept of flipped learning, introduced by Bergmann and Sams (2012), has transformed traditional teaching methods by reversing classroom activities. Students complete preparatory tasks outside of class and engage in more interactive, teacher-guided activities during in-class sessions. This approach fosters a student-centred learning culture, encouraging deeper engagement with content. In the digital era, flipped learning incorporates synchronous (live, online, real-time) and asynchronous (delayed, not in real-time) learning tasks to maximise flexibility and accessibility.

Recent studies emphasise the adaptability of flipped learning across disciplines and educational levels (see Table 1). For example, Ranoptri et al. (2022) and Erkan and Duran (2023) demonstrated how inquiry-based, and Science, Technology, Engineering, and Mathematics (STEM-integrated) flipped models improved science outcomes and creativity in junior high and primary school students. Similarly, Cheng (2023) found gains in critical thinking, problem-solving, and creativity through STEM-integrated flipped learning. These studies highlight flipped learning's potential to develop higher-order thinking skills. However, the extent to which these benefits are sustained across different contexts requires further exploration.

Flipped learning approaches vary in design and outcomes. Da Silva et al. (2022) and Lee et al. (2021) investigated dialogic and cooperative flipped models, respectively, reporting improvements in science achievement and motivation. While these studies showcase the strengths of flipped learning, they focus primarily on its structural elements, neglecting the role of motivational strategies that could enhance engagement in pre-class tasks. This gap is particularly concerning given challenges such as the lack of student participation in at-home activities, as noted by Maxwell (2024).

TABLE 1. Critical analysis of research gaps in Flipped Learning

No.	Researchers	Samples	Learning Approaches	Findings
1.	Ranoptri et al. (2022)	7th grade of junior high school students	Inquiry web-based learning multimedia	Improvement of learning outcome in science
2.	Erkan and Duran (2023)	4th grade of primary school students	STEM activities with flipped learning	STEM activities with flipped learning model improved scientific creativity and perceptions
3.	Cheng (2023)	Primary school	STEM activities with flipped learning	Enhancement of critical thinking, problem-solving, and creativity skills
4.	Flores-Gonzales & Flores-Gonzales (2022)	High school students	Virtual learning environment	Enhancement of students' comprehensive learning process in science with increased completion of activities and higher-grade point averages
5.	Da Silva et al. (2022)	High school students	Flipped learning with dialogic strategies	Promotion of student protagonism in science
6.	Lee et al. (2021)	High school students	Cooperative flipped learning (CFL)	CFL showed higher science achievement and motivation than simple flipped learning
7.	Rudoft (2021)	Secondary school students	Flipped learning with interactive video	Significant improvement in understanding mathematical concepts
8.	Fahdiran et al. (2021)	6th grade primary students	Flipped classroom approach with active learning	Improvement of learning outcome in science

2.2. Gamification

Gamification and GBL are increasingly recognised for their potential to enhance student engagement. Unlike GBL, which uses fully immersive games tailored for educational purposes, gamification incorporates game elements such as points, levels, and rewards into traditional educational tasks, fostering motivation without altering the core learning activities (Al-Azawi et al., 2016; Maratou et al., 2023;). This approach has demonstrated success in improving student motivation, engagement, and knowledge retention across various educational contexts (Nipo et al., 2023; Lim et al., 2024). For instance, Nilubol (2023) showed that gamified strategies particularly benefited students with high intrinsic motivation, while Mulyanti et al. (2023) observed enhanced science learning outcomes in fifth-grade students. These findings suggest that gamification could address challenges in flipped learning, such as student disengagement during pre-class tasks, yet successful implementation requires careful alignment of gamified elements with the educational goals (Guerrero-Quinonez et al., 2023).

Yu and Yu's (2023) meta-analysis of gamified flipped classrooms (GFCs) reveals positive effects on academic achievement, motivation, and satisfaction, especially in Asian and African contexts, where cultural and technological factors amplify the benefits of gamified learning. However, most existing studies have primarily focused on secondary and higher education, leaving a significant gap in understanding the potential of GFCs for primary school students. Integrating gamification into flipped learning combines the principles of flipped classrooms with game design elements to boost student engagement. Gamification addresses the key challenge of engaging students in pre-class activities by providing immediate feedback, rewards, and a sense of progression (Toda et al., 2019). This approach creates a synergy, where flipped learning offers a structured framework for independent and collaborative activities, while gamification enhances engagement and motivation throughout the learning process. Research by Guerrero-Quinonez et al. (2023) and Yu and Yu (2023) highlight the potential of this combined approach, particularly in science education.

Despite its potential, the integration of gamified flipped learning in primary education remains underexplored, as most research treats flipped learning and gamification as separate strategies. This gap is particularly significant in primary education, where gamification has the potential to sustain student motivation and engagement during pre-class activities. The current study seeks to address this gap by examining how gamified flipped learning can enhance primary students' academic achievement and learning experiences, with a specific focus on the science topic of *Machines*. According to Sayeski et al. (2015), the effectiveness of flipped learning is often hindered when students fail to engage with pre-class tasks. By incorporating gamification, this study aims to determine whether such integration can address these challenges and improve the overall flipped learning experience. This investigation is crucial, as existing literature provides limited exploration of gamification as a complementary strategy within the flipped learning model, particularly at the primary school level.

3. THEORETICAL UNDERPINNING OF GAMIFIED FLIPPED LEARNING

The theoretical foundation of gamified flipped learning combines the flipped learning model by Bergmann and Sams (2012) and gamification elements by Toda et al. (2019), offering a framework for integrating gamification into flipped classrooms.

3.1. Foundational pillars of flipped learning

Bergmann and Sams (2012) introduced four foundational pillars of flipped learning: flexible environment, learning culture, intentional content, and professional educator.

- **Flexible environment:** This pillar emphasises both synchronous and asynchronous learning, allowing students to learn at their own pace. In a gamified flipped classroom, this flexibility is enhanced through elements like progress tracking and levels to enable students to navigate their learning journey more dynamically.
- **Learning culture:** The flipped model promotes a student-centred culture, where learners take responsibility for their education. Gamification supports this by encouraging active participation through points, levels, and rewards to reinforce positive behaviours.

- **Intentional content:** Educators select content carefully to suit both independent study and collaborative activities. Gamification helps by breaking content into smaller, engaging segments, often linked to levels or progress indicators to keep students motivated.
- **Professional educator:** Educators play a key role in designing and managing a gamified flipped classroom. They ensure that gamified elements align with learning goals and provide personalised support for students.

By integrating these pillars with gamification, educators can create a more engaging and effective flipped learning environment that addresses the needs of diverse learners.

3.2. Gamification Sub-Elements

Toda et al. (2019) identified several gamification sub-elements that enhance learning engagement and motivation. These elements, when integrated with flipped learning, create a synergistic effect that supports academic achievement and positive learning experiences:

- **Acknowledgement:** Recognising student achievements through badges, trophies, or medals provides extrinsic motivation and encourages active participation.
- **Level:** Offering levels or skill hierarchies motivates students to progress through increasingly challenging tasks, which align with the adaptive nature of flipped learning.
- **Progress:** Progress bars, maps, or steps provide visual feedback on students' advancement, helping them stay on track in both independent and collaborative activities.
- **Points:** Assigning points for completed tasks or correct answers gives students immediate feedback and fosters a sense of accomplishment.
- **Time pressure:** Countdown timers or time-limited challenges encourage focus and efficiency, particularly during in-class activities designed to apply learned concepts.
- **Novelty:** Introducing surprises or unexpected elements within tasks keeps students engaged and prevents monotony, which is an essential aspect of sustaining attention in flipped learning environments.
- **Chance:** Incorporating elements of luck, such as random rewards or outcomes, adds excitement and unpredictability that make the learning experience more engaging.

The integration of Bergmann and Sams' (2012) flipped learning model with the gamification sub-elements proposed by Toda et al. (2019) creates a robust theoretical foundation for gamified flipped learning. This approach not only enhances the structural flexibility and engagement of the flipped classroom but also aligns with modern pedagogical goals, fostering motivation, active learning, and student-centred experiences.

4. RESEARCH CONTEXT, OBJECTIVES, AND QUESTIONS

This study focused on fifth-grade students and investigated the implementation of gamified flipped learning activities to understand their impact on students' academic achievement and learning experiences. The objectives of this study were as follows:

i. To examine the effects of digital gamified flipped learning activities on the academic achievement of Malaysian fifth-grade students.
ii. To explore the learning experiences of fifth-grade students participating in gamified flipped learning activities.

To achieve these objectives, this study addressed the following research questions:

i. What are the effects of digital gamified flipped learning activities on the academic achievement of Malaysian fifth-grade students?
ii. What are the learning experiences of fifth-grade students participating in gamified flipped learning activities?

5. METHOD

5.1. Research Design

This study utilised a mixed-methods approach, employing a quasi-experimental design for the quantitative component and interviews for qualitative data collection. The quasi-experimental design was chosen for its appropriateness in assessing the effectiveness of a digital game-based flipped classroom approach in enhancing student academic achievement on the topic of *Machines*, compared to conventional teaching without flipped learning activities. Specifically, a pre-test and post-test control group design was used. Participants in both the treatment and control groups had similar characteristics but were not randomly assigned due to predetermined group allocations by the school.

To control for potential confounding variables, particularly prior knowledge, a pre-test was administered to both groups before the intervention. The Quade-ANCOVA analysis was then employed to evaluate the effect of the pre-test on post-test scores, using the pre-test scores as a covariate. This approach helped address any pre-existing differences in baseline knowledge between the groups.

This study's data collection process spanned four weeks, comparing a control group and a treatment group in a quasi-experimental design. In Week 1, both groups began with a pre-test to assess their prior knowledge on the science topic of *Machines*. Following the pre-test, the treatment group engaged in five digital games created using Wordwall, which were hosted on a website designed with Google Sites. These games served as the flipped learning component and allowed students to explore the topic asynchronously during Week 2. The control group, meanwhile, did not participate in these pre-class digital activities.

In Week 3, both groups engaged in in-class teaching and learning activities, led by the same teacher to ensure consistency. After completing the in-class sessions, both groups took a post-test in Week 4 to measure knowledge acquisition on the *Machines* topic. In addition, the treatment group participated in interviews to discuss their experiences with the gamified flipped learning activities. Figure 1 illustrates the data collection process involving both the treatment and control groups.

FIGURE 1. Data collection process

Week	Control Group ↓	Treatment Group ↓
Week 1	Pre-test ↓	Pre-test ↓
Week 2	↓	**Five Digital Games (Wordwall)** ↓
Week 3	In-class teaching and learning activities ↓	In-class teaching and learning activities ↓
Week 4	Post-test	Post-test Interviews

5.2. Samples

For this study, a school in the Kulai district of Malaysia was purposively selected based on the following criteria:

- The school possessed appropriate technological facilities.
- Accessibility for data collection purposes by the researcher.
- The basic background of the involved students could be identified by the researcher.

The study involved a sample of 40 fifth-grade students, selected through cluster random sampling from two classes at a public primary school in the Kulai district. All participants were learning science, focusing on simple machines and their functions. Class 5b was randomly assigned as the treatment group, which experienced the flipped classroom model incorporating digital GBL, while Class 5a, the control group, followed conventional teaching methods. Both groups were taught by the same Science teacher to ensure consistency in instructional quality. To gain deeper insights into the students' experiences with the gamified flipped learning approach, six students from the treatment group were randomly selected for interviews, providing a more thorough understanding of their engagement and learning outcomes.

5.3. Research Instruments

The research instruments included pre- and post-test questions adopted by expert teachers from validated exam questions in the Ministry of Education's Standardised Primary School Evaluation Test, with a focus on the *Machines* topic. These questions assessed students' understanding of the functions of simple machines in various devices. The test consisted of 34 identical subjective questions, each worth one point, for a total score of 34 points, and was administered during both the pre-test and post-test phases. Based on the Examination Division of the Ministry of Education, the questions were designed to evaluate academic achievement at Bloom's Taxonomy levels of understanding, application, and analysis. To ensure scoring objectivity, all responses were graded by the classroom teacher and verified by an independent teacher using the standardised answer scheme validated by the Ministry, achieving an inter-rater agreement of 82.5%.

While the test items were based on Ministry-approved question banks, which have undergone construct validity checks for the *Machines* topic, additional validation specific to this study's context would have further enhanced their appropriateness for the target age group and topic. A pilot test was conducted with 10 fifth-grade students to check the appropriateness of the test questions, and content validity was established through reviews by two primary science teachers. Additionally, the reliability of the test was confirmed through a test-retest analysis, yielding a high Spearman correlation coefficient of 0.85.

In addition to the test, individual interviews were conducted by the classroom teacher with students in the treatment group to explore their learning experiences during the gamified flipped learning activities. These interviews followed a structured protocol with open-ended questions aimed at capturing students' feelings and perceptions about learning through digital games, their preferences for learning activities, and their views on the effectiveness of the games in supporting their learning. Before data collection, the interview protocol was reviewed and validated by two expert primary school teachers to ensure the questions were appropriate for the fifth-grade level.

5.4. In-class Teaching and Learning Activities

The in-class teaching and learning activities covered the same scope as the five gamified learning activities, including subtopics such as simple machines, complex machines, and the importance of creating tools sustainably. The teaching method used in both groups was a tutorial-based approach within a conventional classroom setting. The same teacher who instructed the treatment group also delivered the content to the control group, ensuring consistency in instructional delivery across both groups. The only difference was that the treatment group engaged with the digital games prior to the in-class activities, providing them with a gamified flipped learning experience before interacting with the conventional instructional content.

5.5. Digital Games

Five digital games were developed for this study using the Analyse, Design, Develop, Implement, and Evaluate (ADDIE) instructional design model (Heinich et al., 2002). The process followed these phases:

1. **Analysis phase:** This phase involved analysing the students' prior knowledge, technological familiarity, and the school's resources, such as computer facilities and internet speed, to ensure the games were compatible.

2. **Design and development phase:** The games were designed using gamification elements like points, badges, and leaderboards (Toda et al., 2019). After development, an Educational Technology expert reviewed the games for alignment with educational goals.
3. **Implementation phase:** The games were pilot-tested with a small group of three fifth-grade students to check their functionality, usability, and engagement. Any technical issues were addressed before the games were used in the actual experiment.
4. **Evaluation phase:** The final phase involved collecting data from students' performance and experiences while using the games in the experiment.

Table 2 presents a detailed mapping of the subtopics, digital game elements, learning activities, and technological tools used in the study.

TABLE 2. **Mapping of subtopics, digital game elements, learning activities, and technological tools**

Weeks	Subtopics	Gamification Elements (Toda et al., 2019)	Games	Technology Tools
1	Simple Machines 1	• Progress • Point	Digital game 'Speedy Plane'	• Google Sites • Wordwall App
2	Simple Machines 2	• Acknowledgement • Time pressure	Digital game 'Truth Stage'	
3	Complex Machines 3	• Acknowledgement • Novelty	Digital game 'Danger Maze'	
4	Complex Machines 4	• Point • Chance • Novelty	Digital game 'Bomb It'	
5	The Importance of Sustainable Features in Tool Creation	• Point • Time pressure	Digital game 'The Winner'	

Figures 2 and 3 illustrate examples of the Danger Maze and Bomb It games.

FIGURE 2. **Danger Maze**

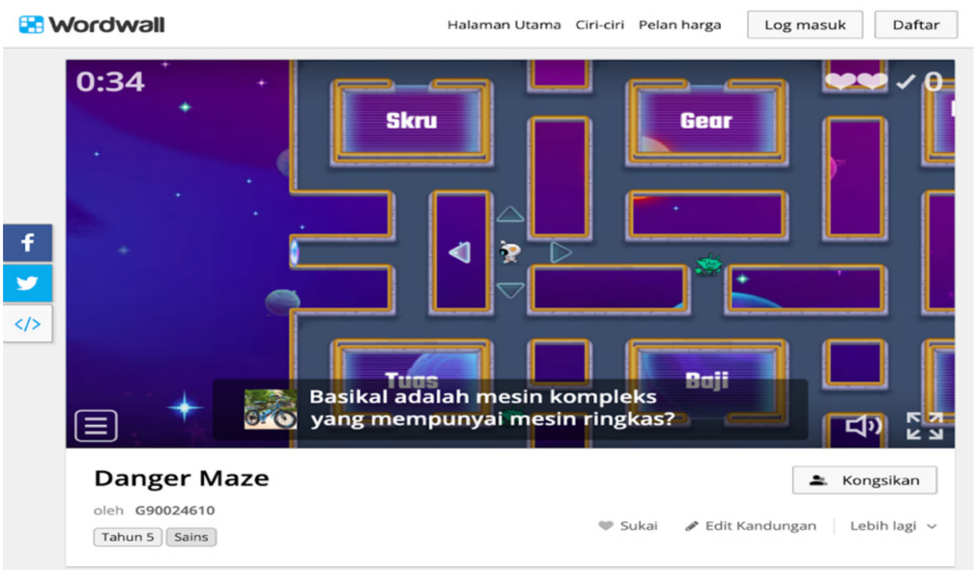
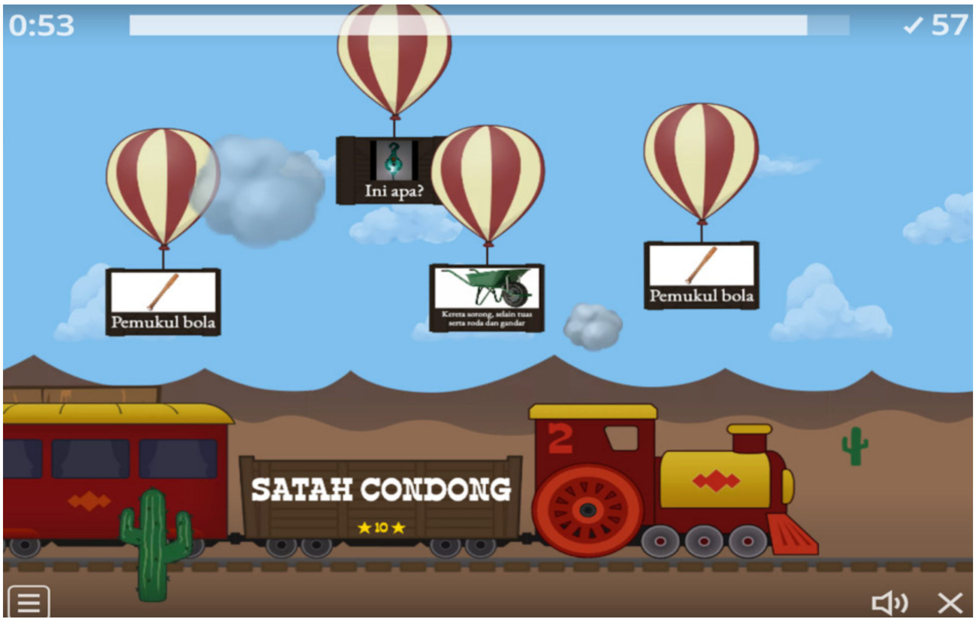


FIGURE 3. Bomb It



5.6. Data Analysis

The data obtained were analysed using descriptive statistical tests, such as the mean and standard deviation, as well as inferential tests, including Quade-ANCOVA. The pre-test was used as a covariate to statistically adjust for initial differences between the treatment and control groups. Given that the data did not follow a normal distribution, Quade-ANCOVA was selected for its robustness against violations of normality assumptions. This method enables comparison of the post-test mean scores between the treatment and control groups while accounting for the effects of the pre-test scores as a covariate.

Additionally, an analysis of student learning experiences in gamified flipped classroom learning was conducted by two expert teachers. This study adapted inductive thematic analysis on the interview data collected, following Braun and Clarke's (2006) six-phase guideline. Since the qualitative data consisted of simple sentences from primary students, themes were identified based on commonalities in the responses provided by the interviewed students. If students expressed similar perspectives regarding the questions asked, those themes were considered stable and significant for highlighting as study findings. The inter-coder reliability between the two teachers was 87.1% agreement.

5.7. Research Ethics

Informed consent was obtained from both the schools and the parents or guardians of the students prior to the study. Participants were assured that their data would remain anonymous, and their privacy would be protected throughout the research process. To ensure that student well-being was not jeopardised, the study was designed with minimal disruption to regular learning activities. Additionally, all participants were informed that their involvement in the study was voluntary, and they could withdraw at any time without consequence. These measures were taken to uphold ethical standards and ensure the safety and privacy of all students involved.

6. RESULTS

6.1. The Effects of Gamified Flipped Classroom Learning Activities on the Academic Achievement of Malaysian Fifth-Grade Students

Table 3 shows the pre-test and post-test means and standard deviations for both the control and treatment groups. The control group had a pre-test mean of 12.25 with a standard deviation of 2.12, indicating less variability in scores compared to the treatment group, which had a pre-test mean of 9.3 with a standard deviation of 2.57. This suggests that the control group's scores were more consistent before the intervention. After the intervention, both groups showed increased variability in their post-test scores, but the treatment group had a slightly lower standard deviation (3.02) compared to the control group (3.12), indicating more consistency in the treatment group's improvement. The treatment group's post-test mean was 26.9 out of a maximum score of 34, while the control group's post-test mean was 17.

TABLE 3. Descriptive analysis of fifth-grade student's achievement

	Control Group (n = 20)	Treatment Group (n = 20)	Levene's test (p value)	Shapiro-Wilk Test (p value)
Pre-Test Mean	12.25	9.3	.010*	-
Post-Test Mean	17	26.9	-	.041**
Pre-Test Standard deviation	2.12	2.57	-	-
Post-Test Standard deviation	3.12	3.02	-	-

**the homogeneity assumption of the variance did not met*
***post-test data not normally distributed*

The results of Levene's test indicated that the homogeneity of variance assumption was not met for the pre-test scores, with a p-value of 0.010 ($p < 0.05$). This suggests that the variance of the pre-test scores differed significantly between the two groups, thereby violating the assumption of equal variances necessary for standard ANCOVA. As a result, the use of a non-parametric alternative, i.e. Quade-ANCOVA, was considered necessary for this analysis.

Additionally, the Shapiro-Wilk test for normality yielded a p-value of 0.041 for the post-test scores ($p < 0.05$), indicating that the post-test data were not normally distributed. This reinforces the need for a robust statistical method that can handle non-normal data distributions.

Given these violations, Quade-ANCOVA was employed to analyse the significance of the differences in post-test scores between the control and treatment groups. Quade-ANCOVA is a suitable alternative to traditional ANCOVA when the assumption of normality is violated or when variances are unequal between groups, as in this case. Unlike parametric ANCOVA, which assumes normally distributed residuals, Quade-ANCOVA adjusts for covariates while accounting for the non-normality in the data, providing more accurate estimates of treatment effects.

By employing Quade-ANCOVA, the study ensures the validity of its findings despite the violations of homogeneity of variance and normality. This robust approach increases the reliability and validity of the results, making it especially well-suited for educational research, where data often deviate from normality and exhibit heteroscedasticity. Therefore, the use of Quade-ANCOVA enhances the robustness of the study's conclusions while addressing the issues identified through the Levene's and Shapiro-Wilk tests.

Based on the Quade-ANCOVA analysis (see Table 4), a significant difference was observed in the mean post-test scores between the treatment and control groups, with a p-value of less than 0.05. The effect size of the treatment on student achievement was substantial, as indicated by an eta squared value of 0.626.

TABLE 4. **The Quade-ANCOVA analysis**

Test of Between – Subject Effects						
Dependent Variable: Unstandard Residual						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	3260.472	1	3260.472	63.737	.000	.626
Intercept	.000	1	.000	.000	1.000	.000
Group	3260.472	1	3260.472	63.737	.000	.626
Error	1943.897	38	51.155			
Total	**5204.368**	**40**				
Corrected Total	**5204.368**	**39**				

*R Squared = .626 (Adjusted R Squared = .617)

6.2. The Learning Experiences of Malaysian Fifth-Grade Students Participating in Gamified Flipped Learning Activities

Based on the thematic analysis of the interview transcripts with students, several learning experiences were identified, as illustrated in Table 5.

TABLE 5. **Thematic analysis of interview transcripts**

No.	Interview Questions	Example	Theme
1.	How do you feel when you learn through flipped learning with games, what are your feelings?	S1: "I feel so excited when doing quizzes." S2: "Happy, later when answering the exam, that question will be easy because I have studied it." S5: "I feel nervous because games involve competition"	Happy, excited, fun, like it Nervous
2.	Do you like playing digital games on the topic of Machines?	S2: "Like it." S6: "I love it"	Like it
3.	When do you play digital games on the topic of Machines?	S3: "At night." S2: "Whenever I'm free"	Anytime
4.	What is your favourite digital game on the topic of Machines? Why?	S2: "Danger Maze because I always play games like that." S4: "Truth Stage."	Speedy Plane, Danger Maze, Truth Stage
5.	How many times do you play each digital game? If more, why do you play more than once?	S3: "Speedy Plane three times, quiz four times, the rest just once or twice. S5: "More than five times."	Many times (more than five times)
6.	Which option do you prefer, continue learning through digital games or using textbooks as usual in class? Why?	S3: " Digital games made me feel excited." S4: "Digital games because I like it."	Digital games Feel excited
7.	Do you think these digital games help you excel as a student? Why?	S6: "It's easy to learn." S5: "Not sure. I need to play games for other topics"	Easy Unsure

7. DISCUSSION AND CONCLUSIONS

The analysis of between-subject effects reveals a highly significant relationship between participation in gamified flipped learning and conventional learning, with a statistical outcome of $F = 63.737$, $p < .001$ (see Table 4). This significance indicates that the treatment group, engaged in gamified flipped learning activities, experienced notably different learning outcomes compared to the control group. This finding corroborates the studies by Lo and Hew (2018) and Jo et al. (2018), which demonstrated that students in gamified flipped classrooms outperform those in traditional or online independent study settings. Elements of gamification, such as ranking systems and word games, have been shown to increase participation rates, competitive spirit, and interest in online preparation activities (Jo et al., 2018), a trend that is not only evident among higher education students but also among primary school students in this study.

The data analysis further indicates that following the intervention with digital games in flipped learning, students' knowledge and understanding of the topic of *Machines* significantly improved compared to their previous levels. The notable increase in scores among the treatment group relative to the control group underscores the effectiveness of integrating flipped learning with digital games. This finding aligns with Gündüz and Akkoyunlu's (2020) research, which established that gamification in flipped learning environments can enhance achievement.

Additionally, the effect size, measured by partial eta squared (0.626), indicates a large effect (Cohen, 1988), suggesting that 62.6% of the variability in students' learning experiences can be attributed to their participation in gamified flipped learning activities. This substantial effect size underscores the robust impact of these innovative educational approaches on enhancing student engagement, motivation, and comprehension of the subject matter.

The findings also align with the research conducted by Tsay et al. (2018), which reported similar results among second-year business students regarding learning through gamification. This study expands upon Tsay's work by demonstrating that these benefits extend to primary school students, indicating that the effectiveness of the gamification approach is applicable across educational levels. Moreover, learning through digital games can enhance motivation and knowledge, even for students who initially lack experience with such games (Divjak and Tomic, 2011). This study enriches the existing research on gamification by illustrating how the integration of flipped learning enhances its impact. The positive effects observed from the gamified approach can be attributed to the use of flipped learning for the topic of *Machines*.

Students demonstrated remarkable improvement when engaging with gamified flipped learning, as they repeatedly played digital games until achieving their desired scores. They expressed a greater interest in self-paced activities through digital games and consistently allocated time to play games related to the topic of *Machines*. This enthusiasm may stem from the engaging elements of digital games, which rely on factors such as the gaming environment, game design, visual presentation, and mechanical technology (Lacovides et al., 2011). Additionally, students found the provided digital games easy to understand for each concept they learned. Key factors contributing to this effectiveness include perceived ease of use, usefulness, and satisfaction, as identified by Guo et al. (2020). Previous studies have also indicated that well-designed games can be highly playable, enjoyable, and immersive, with most students quickly familiarising themselves with the game elements (Yue & Wan, 2015).

The findings of this study indicate that students' experiences with flipped learning, enhanced by digital games, are overwhelmingly positive (see Table 5). Participants expressed feelings of happiness, excitement, and enjoyment while engaging with this approach. This positivity can be attributed to the student-centred nature of flipped learning, which promotes active participation in the learning process (Siegle, 2013). Furthermore, the integration of digital games as educational tools creates an enjoyable learning environment, challenging students to excel in these interactive activities (Thomas & Mahmud, 2021).

Students interviewed articulated a clear preference for the gamified flipped learning approach over traditional textbook-based learning. They eagerly embraced digital game activities, often engaging repeatedly until they achieved their desired scores. This behaviour reflects their eagerness to grasp additional information and ensure they do not miss key insights during the gamified learning activities. Additionally, students demonstrated high levels of motivation, actively seeking opportunities to participate in digital GBL.

However, one student expressed a neutral response, reporting nervousness due to the competitive nature of the games. For this student, the element of competition, while motivating for many, created a sense of pressure that made the learning experience somewhat stressful. This highlights the importance of designing gamified activities that balance competition with collaboration to ensure all students feel supported in their learning journey.

Using digital games, students effectively recalled relevant content, accurately identifying key elements such as simple machines, wheels and axles, levers, pulleys, screws, inclined planes, wedges, and gears. This mastery was achieved through self-directed learning, as students repeatedly engaged with the digital games until they attained high scores. Beyond the classroom, the flipped learning method not only enhanced students' comprehension of prior knowledge but also reinforced their understanding of new topics through digital games (Du et al., 2014).

In their interviews, students noted that digital games contributed significantly to their academic success and enjoyment of the flipped learning approach. The application of digital GBL methods effectively captured students' attention, promoting increased engagement and boosting their confidence (Tangkui & Tan, 2020). Overall, students' learning experiences with the gamified flipped learning approach were decidedly positive. These findings align with research by Aidoo et al. (2022), which also highlighted students' positive perceptions of the flipped learning method. However, one student expressed uncertainty, stating, "I need to play games for other topics," suggesting a desire for the broader application of digital games to other subjects. This indicates that while the current approach was engaging, there is potential for further expansion to enhance learning across a wider range of topics.

Moreover, this study builds upon previous research, such as the work by Borit and Stangvaltaite-Mouhat (2020), which found that GBL integrated with flipped classrooms resulted in greater enjoyment, engagement, and perceived learning among students in dental education. This study focuses on learning Science at the primary school level, thus expanding the research conducted by Borit and Stangvaltaite-Mouhat (2020).

In conclusion, the integration of GBL and flipped learning presents a highly effective approach to modern education by enhancing student engagement, motivation, and academic performance. Tools such as Wordwall and Google Sites, along with the development of digital games, provided science educators with innovative resources to diversify their teaching methods. The findings revealed significant improvements in fifth-grade students' academic performance, evidenced by higher post-test scores and positive attitudes toward gamified flipped learning. By combining the interactive and immersive aspects of GBL with the preparatory advantages of flipped learning, students are better equipped with foundational knowledge prior to class and actively engage in deeper learning during in-person sessions. This synergy not only improves comprehension and confidence but also empowers educators with innovative tools to create dynamic and impactful learning experiences, particularly in science education.

7.1. Limitations and future lines of research

Despite the positive findings of this study, several limitations must be acknowledged. First, the research focused specifically on gamified learning related to the topic of *Machines* among fifth-grade students at a single primary school in Malaysia. This narrow scope may limit the generalisability of the results to other contexts or educational levels. Furthermore, the assessment of student improvement in academic achievement was based solely on performance tests, which may not capture the full spectrum of learning outcomes associated with gamified flipped learning, such as critical thinking, creativity, and collaborative skills.

Future studies should consider several recommendations to address these limitations, including conducting research across various educational institutions and regions to assess the effectiveness of gamified flipped learning in different settings and among diverse student populations, which would enhance the generalisability of the findings. Additionally, it would be beneficial to investigate the effectiveness of different gamification elements—competition, reward systems, or specific game mechanics—to identify which elements most effectively enhance student engagement and learning outcomes.

A broader array of assessment methods should be incorporated, including qualitative measures such as observations, student reflections, and peer evaluations alongside quantitative performance tests, to provide a more holistic understanding of the impact of gamified flipped learning on student learning experiences. Furthermore, implementing longitudinal studies could examine the long-term effects of gamified flipped learning on student academic achievement and learning experiences, offering insights into how these methods influence learners over time. Lastly, research should be expanded to include other subjects beyond science, thereby evaluating the applicability and effectiveness of gamified flipped learning across the curriculum.

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