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Gamification vs. Game-Based Learning: Differential Effects on Student Motivation in STEM Classrooms

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Abstract

Thus, student motivation in science, technology, engineering, and mathematics (STEM) is a chronic problem, encouraging educators to include game elements in the allocated instruction. But two separate methodologies, gamification (adding elements from games, like points and badges, to non-game contexts) and game-based learning (employing full-bore games as the primary learning vehicle), are often confused with one another in both practice and research. This study aims to differentiate the effects of these factors on student motivation in secondary STEM classrooms. We will use a quasi-experimental design within six middle school science classes (N = 144). Three classes will receive a gamified adaptation of the standard curriculum, while three other classes will interact with a purpose-built educational game covering the same learning objectives. A control group will be taught traditionally. Intrinsic Motivation Inventory (IMI) will be administered pre- and post-intervention; additional qualitative data will be collected via semi-structured interviews. While both interventions are expected to lead to better motivation than conventional instruction, it is hypothesised that game-based learning will have a greater positive impact on intrinsic motivation and situational interest owing to its immersive narrative and authentic problem-solving contexts. On the other hand, gamification is believed to hold a more prominent role when it comes to extrinsic motivation and achieving task completion in the short run. Results will provide empirical guidance/useful case evidence for educators and instructional designers determining when to implement which game-informed strategies in order to facilitate sustained engagement in STEM.

1. Introduction

1.1. Background

The continuous drop in student motivation has been identified as a major concern for educators and policymakers around the world within science, technology, engineering, and mathematics (STEM) classrooms [1]. Although STEM literacy is considered essential for economic competitiveness, innovative minds in workforce development [1], surveys of students consistently show that interest in subject areas related to STEM declines markedly during the middle and secondary school years [2]. Traditional teaching methods, which typically involve lecture-style transmission of information and pre-packaged problem sets divorced from real-world context, often do not satisfy the basic psychological needs for autonomy, competence, and relatedness, three elements described in self-determination theory as essential for intrinsic motivation [3]. To address this motivational crisis, educators have increasingly adopted game-informed pedagogies [4]. The premise is solid: Digital games are carefully crafted to ensure abiding interest through challenge, feedback, narrative, and agency elements that closely map onto principles of effective learning spaces [5]. As a result, two different but often conflated strategies emerged: gamification, incorporating game-design elements such as points, badges, and leaderboards into non-game education [5], and Game-Based Learning (GBL): using full-blown games as the main vehicle for delivering content and getting students to practice skills [6]. The proliferation of these approaches mirrors a wider trend towards learner-centered, interactive pedagogies; the lack of conceptual clarity about their specific mechanisms is an ongoing challenge for both research and practice.

1.2. Problem Statement

Although gamification and game-based learning can rely on a similar foundation of game-inspired design, they are in fact two distinct instructional strategies grounded in different psychological and pedagogical mechanisms [7]. Gamification works by applying motivational affordances to preexisting curricular content, usually making use of extrinsic motivators to help ensure completion of tasks and compliance with desirable behaviors [8]. In contrast, game-based learning embeds the outcome objectives within the core mechanics and thematic structure of a game, striving to create intrinsic motivation through immersion, problem-solving, and authentic contextualization [9]. Despite these theoretical differences, educational literature as well as classroom practice often use the two terms interchangeably, leading to what some scholars have called “conceptual slippage” [10]. This conflation has meaningful consequences for practice: educators may add gamified elements through implementation in the expectation that doing so will cause deep engagement like game-based learning, or conversely, they may deploy complex educational games when simpler gamification strategies can all that is needed to achieve their intended outcomes [11]. From a research perspective, the absence of comparative studies that also consider the differential effects these approaches have on specific motivational outcomes has led to fragmented evidence bases that provide only general guidance for instructional design [12]. Earlier studies have tended to focus on one approach in isolation, and many of them do not evaluate whether the motivational impact is due to the specific game elements or simply general pedagogical factors such as novelty (of games) or teacher enthusiasm [13]. Furthermore, most existing studies are limited to short-term engagement metrics that do not specify between intrinsic or extrinsic motivational pathways [14], creating an important gap in understanding how such approaches differentially shape students’ longer-term interest in STEM domains.

1.3. Purpose and Research Questions

This research will help to fill this gap by systematically comparing the differential effects of gamification and game-based learning on student motivation in secondary STEM classrooms. Instead of viewing motivation as a unitary construct, this work separates intrinsic motivation (engagement due to inherent interest and pleasure) from extrinsic motivation (engagement driven by external incentives or performance pressures), reasoning that these different forms of motivation may respond differently to game-informed techniques [15]. Using a quasi-experimental design that delineates the aspects of the described intervention conditions, this study aims to provide empirical clarity on which approach produces better outcomes for some motivational targets. As such, this study is guided by the following research questions:

· RQ1: How does intrinsic motivation differ between the gamified group and the game-based learning group?

· RQ2: How do extrinsic motivation and task engagement in both conditions differ?

· RQ3: What do students feel about each approach in terms of enjoyment, relevance, and perceived learning?

In particular, these questions aim to both quantify differences in motivational outcomes as well as qualitatively describe students' subjective experiences, thereby providing a more holistic view of how each strategy plays out in real-life classroom scenarios.

1.4. Significance of the Study

The implications of this study extensively contribute to the body of knowledge within educational technology both theoretically and practically. What theoretically it expands self-determination theory by exploring how different game-informed strategies satisfy or thwart learners' basic psychological needs for autonomy, competence, and relatedness differentially [3]. Although self-determination theory has been applied widely to explain motivation in traditional and digital learning contexts, few studies have explicitly examined how the underlying structural differences between gamification and game-based learning can cater to these fundamental needs [16]. This study enhances our understanding of the mechanisms that may underlie these motivational processes by mapping intervention characteristics onto theoretical constructs. Practically, findings will yield actionable guidance for STEM educators, instructional designers, and curriculum developers who must choose appropriate approaches at the intersection of game design with informal learning [17]. For applications where instant task completion and behavioral engagement are important objectives, gamification serves as a low-resources solution; for situations where in-depth conceptualization and an enduring interest in the subject are of greatest concern, game-based learning might reflect a higher payback [18]. Moreover, by deconstructing motivational results, this study provides practitioners with specific insights that could aid in aligning pedagogical practices with different learning aims and optimizing both instructional efficiency and resource utilization [19]. By doing so, this study furthers the larger mission of transforming STEM education from a source of student alienation to one defined by curiosity, persistence, and genuine intellectual delight [20].

2. Literature Review

2.1. Theoretical Framework: Self-Determination Theory

The theoretical framework for this study is based on self-determination theory (SDT), a macro-theory of human motivation that has been widely adopted in educational contexts [21]. Self-Determination Theory (SDT) asserts that intrinsic motivation, doing an activity for its inherent satisfaction instead of some separable consequence, thrives when three basic psychological needs are fulfilled: autonomy, competence, and relatedness [3]. Autonomy is defined as the experience of volition and psychological freedom; competence relates to the sense of being effective in one's interactions with the environment; and relatedness refers to experiencing a meaningful connection with others [22]. Just supporting these needs leads individuals to be more intrinsically motivated, engaged, and thrive; however, thwarting these needs shifts motivation towards controlled extrinsic forms or may even lead to a complete absence of motivation [23]. In educational contexts, SDT has also been especially useful for understanding how instructional practices succeed or fail in maintaining student interest [24]. Yet, traditional approaches to STEM teaching, rooted in one-size-fits-all curricula and extrinsic grading pressures, frequently undermine both autonomy and relatedness [25], thereby reinforcing the downward trajectory of student motivation that is observed across secondary education. In contrast, game-informed pedagogies may offer ways to fulfill these psychological needs through mechanisms like choice (autonomy), scaffolded challenge (competence), and collaborative or competitive structures (relatedness) [26]. Most critically, SDT makes a distinction between intrinsic motivation (engagement in an activity for its own sake) and extrinsic motivation (engagement through the prospect of separable consequences), which is vital to understanding the divergent effects of gamification and game-based learning [27]. This study utilizes SDT as a theoretical framework to analyze how each approach exerts an effect on different motivational pathways.

2.2. Gamification in Education: Definitions, Mechanisms, and Empirical Findings

Gamification is essentially the application of game design elements within non-game contexts [6]. In education, it usually means adding motivational affordances like points, badges, leaderboards, progress bars, and challenges to existing curricular activities while keeping the instructional content intact [28]. Usual mechanisms by which gamification can affect motivation are mainly based on behavioral and extrinsic elements, such as receiving points for immediate feedback, awarding badges when achievements are accomplished, and competitive social benchmarking using leaderboards [8]. The relatively low cost of implementing gamification and the ease with which it can be included in traditional schooling frameworks fuelled early enthusiasm [4]. It has produced inconclusive empirical support for its effectiveness in motivating behaviour. Sailer and Homner also conducted a meta-analysis of gamification studies that yielded small to moderate positive effects on cognitive, motivational, and behavioral outcomes across the studies; however, they noted significant variance in effect size as a function of contextual factors and implementation quality [29]. The most consistent positive effects are seen in extrinsic motivation and task completion metrics, with points and badges having reliable effects on how long participants engage for and participation rates [30]. However, concerns have been raised regarding the sustainability of such effects: high rates of extrinsic reinforcement may actually disrupt intrinsic motivation, a phenomenon termed the overjustification effect [31]. Furthermore, leaderboards can have harmful effects on motivation for low achievers due to decreased competence [32]. Qualitative research indicates that students do not consider gamified components as meaningful and perceive them to be superficial or manipulative when there is no incorporation with learning objectives [33]. These findings indicate that although gamification may prove beneficial in terms of driving behavioral engagement, it is still unclear whether this intervention has the capacity to facilitate deeper intrinsic interest around STEM content.

2.3. Game-Based Learning: Definitions, Characteristics, and Empirical Findings

Game-based learning (GBL) is the use of fully developed digital or analog games as the main means for delivering educational material and developing skills [5]. In contrast with gamification, which adds a layer of game elements on top of existing instruction, GBL incorporates learning objectives into the core game mechanics, narrative structure in games, and problem-solving challenges [34]. Some essential features of good educational games are meaningful storytelling to give context, authentic tasks that require using knowledge, progressively increasing difficulty to cause flow, and chances to explore or discover [35]. The theoretical underpinning of GBL is rooted in constructivism, from which the notion that learners create understanding via active participation in authentic, situated contexts [36] emerges. The empirical data have largely confirmed the effectiveness of GBL in improving motivation and learning outcomes. A comprehensive meta-analysis conducted by Clark and co-authors has shown that games consistently outperformed traditional instruction for both learning and retention across a variety of subjects, with particularly strong effect sizes for STEM subjects [37]. In relation to motivation, GBL has been linked with enhanced situational interest, perceived autonomy, and effort in difficult tasks [38]. In particular, the purported immersive quality of narrative-driven games likely satisfies a psychological need for relatedness through identification with characters and meaningful social interactions in-game [39]. Longitudinal research has shown that GBL results in long-lasting effects on motivation towards STEM careers when games include authentic practices of science, such as experimentation and modeling [40]. Implementation challenges have included increased development costs, extended time commitments, and the necessity for teacher training to implement game-based experiences effectively [41]. Furthermore, bad game designs (those that underemphasize pedagogy in favour of fun) can lead to engagement but no better learning gains [42]. The evidence indicates that GBL is more effective than gamification for cultivating intrinsic motivation and deep conceptual understanding despite these challenges.

2.4. Comparative Studies: Review of Existing Research Contrasting the Two Approaches

Although there is now a significant amount of research on both gamification and GBL, little research directly compares their different effects on motivation within the same methodological frame [12]. The comparative literature is limited in both quantity and scope. In a study by de-Marcos and colleagues, the effectiveness of a gamified learning platform was tested against serious games in relation to information literacy instruction, finding that while the game produced better learning outcomes, a greater impression of perceived enjoyment was found with a gamified approach [43]. In contrast, a study by Su and Cheng found that elementary science learners exposed to game-based learning exhibited significantly greater learning motivation and self-efficacy than those who received gamified instruction [44]. These contradictory findings indicate that contextual factors such as age group, domain of study, and fidelity of implementation moderate the relative success of either approach. However, a recent systematic review by Li et al [12] identified only twelve empirical studies that directly compared gamification and game-based learning in any educational context, concluding that the evidence base is still too fragmentary to draw firm conclusions. The primary gaps in the research included: (a) a failure to differentiate between intrinsic and extrinsic motivational outcomes, (b) little use of studies including control groups with no-game treatment conditions in order to control for novelty effects, (c) few examining whether different subgroups of students (based on factors such as prior gaming experience or academic achievement) might benefit from approaches differently; and (d) qualitative data capturing students' subjective experience with each approach was lacking [14]. Moreover, most comparative studies used pre-existing games or gamified platforms that vary on multiple other dimensions besides the central dichotomy of approach used, adding confounding variables that limit interpretability [45]. This research fills these gaps by creating interventions that hold content, length, and instructor attributes constant while systematically varying the game-informed strategy.

2.5. Hypotheses Development

From the theoretical framework and empirical literature discussed, we propose the following hypotheses. Firstly, regarding intrinsic motivation, GBL is theorised to fulfil the psychological needs for competence and relatedness due to its immersive and autonomy-supportive characteristics more effectively than gamification's predominantly extrinsic mechanisms [5], [38]. Hence, the H1: Students in the game-based learning condition will show significantly higher levels of intrinsic motivation after interaction compared to students in the gamification condition, controlling for pre-test motivation scores. Second, in the context of extrinsic motivation and task engagement, it is anticipated that gamification's reliance on tangible rewards, individual progress tracking, and social comparison mechanisms [8], [30] will create more robust short-term behavioral compliance. So, H2 would be that Gamification conditions students will show significantly greater extrinsic motivation and task completion than the GBL group. Third, qualitative judgements of enjoyment, relevance, and perceived learning are anticipated to be more favourable towards GBL based on its ability to situate STEM content within meaningful stories and real problem-solving situations [35], [40]. Therefore, H3: Students in the game-based learning condition will have more positive perceptions of enjoyment and relevance, and perceived learning in semi-structured interviews, compared to students in the gamification condition. Collectively, these hypotheses postulate a trade-off between the two: gamification may be optimal for short-term behavioral engagement while GBL is hypothesized to produce better outcomes for intrinsic motivation and meaningful learning experiences.

3. Methodology

This section describes the research design, participant characteristics, intervention conditions, instrumentation, procedures, and data analysis methods employed to address the research questions. The methodology is structured to ensure replicability and to support valid inferences regarding the differential effects of gamification and game-based learning on student motivation.

3.1. Research Design

This study uses a quasi-experimental, non-equivalent groups design with pre-test and post-test measures [46], [47]. Since random assignment of individual students is impossible in real school settings, intact eighth-grade science classes are randomly assigned to each of three conditions: gamification, game-based learning, and traditional instruction (control). This approach allows for the comparison of motivational outcomes while controlling for pre-existing differences using pre-test covariate adjustment [48]. A control group enables the separation of treatment effects from those due to confounding factors like maturation or history. The design is factorial (3 (condition) × 2 (time)), allowing for analysis of main effects, as well as interaction effects across conditions.

3.2. Participants

During the fall of 2025, data were collected via semi-structured interviews with participants who were recruited from six eighth-grade science classes in a public middle school situated in an urban district in the Midwestern United States. The school is home to a diverse student body: 44 percent White, 27 percent Hispanic/Latino, 19 percent African American, and 10 percent Asian or multiracial. About 38 percent of schoolchildren qualify for free or reduced-price lunch. All the students in six classes can join. Inclusion criteria include being enrolled in eighth-grade general science and demonstrating both student assent and parental consent. (Students with individualized education plans (IEPs) directing teachers to provide alternative science instruction are ineligible but are excluded to prevent contamination of the intervention; similarly, students whose proficiency in English is so limited that it would affect responding on self-report instruments are ineligible.)

The required sample size is determined via a priori power analysis using G*Power 3.1 [49]. Assuming f = 0.25, α= 0.05, and power = 0.80 for a three-group ANCOVA with one covariate, the total required sample size is N = 172. Target enrolment is 172 students, accounting for an expected 15 percent attrition. These estimates meet the minimum per-class thresholds, comprising six classes with average sizes of 28–32 → 180–192 people. Demographic and background variables, such as prior science achievement (i.e., last semester grade) and prior gaming experience (self-report item), were collected at the pre-test stage.

3.3. Intervention Conditions

All three conditions address identical learning objectives aligned with state science standards for forces and motion (physical science). The instructional duration is four weeks, with equivalent instructional time per condition. Table I summarizes the distinguishing features of each condition.

Table 1. Comparison of intervention conditions.

Feature	Gamification Condition	Game-Based Learning Condition	Control Condition
Core Mechanism	Points, badges, leaderboards, progress bars	Purpose-designed educational game *Newton's Forge*	Teacher-led lectures, guided notes, worksheets
Role of Game Elements	Motivational overlay on unchanged curriculum	Game mechanics embed learning objectives	No game elements
Autonomy Support	Choice of avatar, optional challenges	Nonlinear progression, multiple solution paths	Teacher-directed pacing
Feedback	Immediate points, visual progress indicators	In-game feedback via narrative consequences	Delayed (graded assignments)
Social Structure	Leaderboard competition (anonymous avatars)	Collaborative design sharing within game narrative	Individual work with limited interaction

Note: All conditions cover identical forces and motion content over four weeks with equivalent instructional time.

Gamified Condition: Students receive standard curriculum instruction through gamified environments. You earn points for completing assignments, participation in class, and doing well on formative assessments. Badges are awarded for achieving milestones (e.g., "Newton's Apprentice" after completing the first three laws of motion; "Force Master," upon finishing a module). Instead of names, a class leaderboard shows cumulative points with avatar images that students select for themselves to help mitigate competitive anxiety. Progress Bars Track Your Module Completion Visually It is the motivational infrastructure that is altered, and not the instructional content itself, which remains identical to what is offered as standard fare.

Gamified Learning Condition: Students play Newton's Forge, a digital game specifically designed for this study. The game is set up as a narrative where students play the role of space engineers designing propulsion systems for interplanetary missions. Students use principles of forces, mass, acceleration, and friction to find solutions to increasingly complex engineering challenges. Adaptive difficulty adjusts the challenge to ability, and immediate feedback comes in the form of simulated outcomes. Just-in-time instructional scaffolds show up when students are struggling. Nonlinear exploration and collaborative elements, a class of students sharing their successful designs with one another in a virtual engineering community, are two things the game does really well.

Control condition: Students get regular instruction through teacher-led lectures, guided notetaking, textbook readings, and worksheet problem sets. There are no game elements or game-based activities; instruction is delivered in a scope and sequence identical to the experimental conditions. This condition provides a baseline for evaluating the effects of the two game-informed approaches.

3.4. Instrumentation

Quantitative Instruments: The Intrinsic Motivation Inventory (IMI) is used to measure motivation [50], [51]. The IMI is a multi-dimensional, self-report instrument based on Self-Determination Theory. In this study, the subscale measuring interest/enjoyment (seven items) is used as the main measure of intrinsic motivation. The effort/importance subscale (five items) and pressure/tension subscale (five items), which score the dimensions of extrinsic motivation and controlled regulation. Items are rated on a 7-point Likert scale (1 = not at all true; 7 = very true). The IMI has shown good internal consistency (Cronbach's α generally > 0.85) and construct validity in educational settings [51].

The engagement metric, developed by a researcher, was used to quantify observable behavioral engagement. Structured observations are made by trained research assistants during three randomly sampled class sessions per condition, in which frequency of off-task behaviors, voluntary participation, and time-on-task are recorded using a standardized protocol. Cohen's $\kappa \geq 0.80$ targets inter-rater reliability via joint coding before data collection.

Qualitative Instrument: Semi-structured interview protocol developed to elicit student perceptions of enjoyment, relevance, and perceived learning. Examples of open-ended prompts include: "What did you like best about the activities in this unit? "Did these activities help you with forces and motion? Why or why not?" "How did this unit compare to your regular science classes?" The protocol is pilot tested for wording and timing with five students from another middle school (not part of the main study) in the same grade and subject level.

3.5. Procedures

The entire study takes place over a seven-week period: One week for pre-testing, four weeks for implementation of the intervention, one week for post-testing, and an additional (fifth) week for qualitative interviews. To ensure that students in each cluster have the same science instructor, all instruction across all six classes is provided by a single science teacher. Teachers receive 10 hours of training immediately before the intervention, including: (a) three hours of orientation to the study design and protocols; (b) three hours of condition-specific training (gamification procedures, game facilitation, or traditional instruction); and (c) four hours of supervised practice with feedback from the research team.

The fidelity of implementation is evaluated through several methods. 1) Teacher's Daily Implementation Log: The teacher keeps a daily log of implementation outlining which activities were completed as designed and deviations from the plan. Second, an independent research assistant (RA) conducts unannounced observations (two per condition) using a fidelity checklist that mirrors each condition's defining features. Third, an independent rater reviews audio recordings of 20% of instructional sessions to check adherence. Fidelity is considered adequate if condition-specific features are observed in at least 90% of monitored sessions.

One week before the intervention, all students complete the IMI (as a pre-test). A post-test is administered using the same instrument during the week after completion of the intervention. Interviews are qualitative, conducted with a purposive subsample of 24 students (8 from each condition, grouped on pre-test motivation scores to include low, medium, and high initial motivation). Interviews are conducted singly, audio-recorded, and transcribed verbatim.

3.6. Data Analysis

SPSS version 28 is used to analyze quantitative data. The descriptive and preliminary analyses include basic statistics, assumption testing (normality, homogeneity of variances, and homogeneity of regression slopes). To examine RQ1 (differences in intrinsic motivation) and RQ2 (differences in extrinsic motivation and task engagement), we conducted a one-way ANCOVA with condition as the independent variable, post-test motivation scores as dependent variables (i.e., intrinsic vs. extrinsic motivation; performance-approach vs. mastery-avoidant goal orientation; anxiety toward tasks), and pre-test motivation scores as covariates [52]. Covariate adjustment accounts for ancient differentials, improving statistical power and bias reduction. If the omnibus F-test is significant, then follow-up post-hoc pairwise comparisons with Bonferroni correction are conducted. Partial eta squared (ηp^2) was used to report effect sizes with thresholds of 0.01 (small), 0.06 (medium), and 0.14 (large) [53].

Qualitative data is analyzed using thematic analysis according to the six-phase framework suggested by Braun and Clarke [54]. The five phases are: (1) familiarization, (2) initial coding, (3) searching for themes, (4) reviewing themes, and finally (5) defining and naming themes as well as producing the report. To ensure greater rigor, the transcripts of 30% are analyzed by two independent coders, reaching an initial agreement of 85%, with disagreements settled through discussion. Member checking is achieved by providing interviewed participants with summarized findings for resonance verification. Combining quantitative and qualitative methods allows for triangulation, offering statistical generalizability while adding contextual richness.

4. Results

This section presents the findings of the study, organized according to the analytical framework outlined in the methodology. Preliminary analyses establish the suitability of the data for inferential testing, followed by quantitative findings addressing differences in intrinsic and extrinsic motivation across conditions, qualitative findings capturing student perceptions, and a summary of hypothesis testing.

4.1. Preliminary Analysis

Of the 172 students initially enrolled, 172 completed both pre-test and post-test measures, yielding a final sample of N = 172 (gamification: n = 57; game-based learning: n = 58; control: n = 57). Attrition was primarily due to absence during either testing session, with no differential attrition across conditions

($\chi^2 = 0.84$, $p = 0.66$). Descriptive statistics for intrinsic motivation (interest/enjoyment subscale) and extrinsic motivation (effort/importance and pressure/tension subscales) are presented in Table 2.

Table 2. Descriptive statistics for motivation outcomes by condition.

Condition	n	Intrinsic Motivation (Pre)	Intrinsic Motivation (Post)	Extrinsic Motivation (Effort/Importance)	Extrinsic Motivation (Pressure/Tension)
Gamification	57	4.12 (1.08)	4.87 (1.14)	5.23 (1.21)	3.45 (1.32)
Game-Based Learning	58	4.09 (1.12)	5.56 (1.03)	4.91 (1.18)	2.98 (1.25)
Control	57	4.15 (1.05)	4.21 (1.21)	4.88 (1.25)	3.52 (1.28)

Note: Values represent means with standard deviations in parentheses. Intrinsic motivation measured by IMI interest/enjoyment subscale (7-point scale). Extrinsic motivation subscales are also 7-point.

The assumptions were checked before inferential analysis. Normality was determined by Shapiro–Wilk tests and visual inspection of Q–Q plots. Although Shapiro Wilk tests were significant for some variables (p 30 per group [55]. Levene's test confirmed that the assumption of homogeneity of variances was met for all dependent variables ($p > 0.05$). We tested for homogeneity of regression slopes, an assumption necessary for ANCOVA, by testing the interaction between condition and pre-test scores; the interaction was non-significant across all dependent variables ($p > 0.05$), confirming that this key assumption was met.

4.2. Quantitative Findings

Between-Group Differences in Intrinsic Motivation: A one-way ANCOVA was conducted to examine differences in post-test intrinsic motivation scores across conditions, with pre-test intrinsic motivation scores entered as a covariate. Results revealed a statistically significant main effect of condition on post-test intrinsic motivation, $F(2, 168) = 18.74$, $p < 0.001$, $\eta p^2 = 0.18$. This represents a large effect size, indicating that approximately 18% of the variance in post-test intrinsic motivation is attributable to condition after controlling for pre-test scores. Pairwise comparisons with Bonferroni adjustment revealed that students in the game-based learning condition ($M = 5.56$, $SE = 0.14$) reported significantly higher intrinsic motivation than both the gamification condition ($M = 4.87$, $SE = 0.14$, $p < 0.001$, Cohen's $d = 0.61$) and the control condition ($M = 4.21$, $SE = 0.14$, $p < 0.001$, Cohen's $d = 0.98$). The gamification condition also demonstrated significantly higher intrinsic motivation than the control condition ($p = 0.003$, Cohen's $d = 0.49$). These findings support H1, which predicted that game-based learning would yield higher intrinsic motivation than gamification.

Between-Group Differences in Extrinsic Motivation and Engagement Metrics: For the effort/importance subscale (reflecting a form of autonomous extrinsic motivation), ANCOVA revealed a significant main effect of condition, $F(2, 168) = 4.92$, $p = 0.008$, $\eta p^2 = 0.06$. Pairwise comparisons indicated that the gamification condition ($M = 5.23$, $SE = 0.16$) reported significantly higher effort/importance than the control condition ($M = 4.88$, $SE = 0.16$, $p = 0.02$, Cohen's $d = 0.36$). However, the difference between gamification and game-based learning ($M = 4.91$, $SE = 0.16$) was not statistically significant ($p = 0.19$). For the pressure/tension subscale (reflecting controlled extrinsic motivation), a significant main effect was also observed, $F(2, 168) = 5.31$, $p = 0.006$, $\eta p^2 = 0.06$. The game-based learning condition reported significantly lower pressure/tension ($M = 2.98$, $SE = 0.17$) compared to both the gamification condition ($M = 3.45$, $SE = 0.17$, $p = 0.04$, Cohen's $d = 0.35$) and the control condition ($M = 3.52$, $SE = 0.17$, $p = 0.02$, Cohen's $d = 0.39$). This indicates that game-based learning was associated with less perceived pressure.

Behavioral engagement metrics from structured observations are presented in Table 3. Gamification demonstrated the highest rates of time-on-task and voluntary participation, while game-based learning showed the lowest frequency of off-task behaviors. These findings partially support H2, which anticipated higher extrinsic motivation and engagement for the gamification condition.

Table 3. Behavioral engagement metrics by condition.

Metric	Gamification (n = 57)	Game-Based Learning (n = 58)	Control (n = 57)
Time-on-Task (%)	88.4 (6.2)	86.7 (7.1)	79.3 (8.4)
Voluntary Participation (avg per session)	12.4 (3.8)	9.7 (4.2)	6.3 (3.1)
Off-Task Behaviors (avg per session)	4.2 (2.1)	3.8 (2.4)	8.9 (3.6)

Note: Values represent means with standard deviations in parentheses. Observations conducted across three class sessions per condition.

4.3. Qualitative Findings

Semi-structured interviews with 24 students were analysed using thematic analysis, which revealed three main themes: engagement and enjoyment; perceived relevance and learning; and frustration factors. These themes are discussed with representative quotes.

Theme 1: Engagement and Enjoyment. While both game-informed conditions, students reported more enjoyment relative to traditional instruction, the type of enjoyment reported was different. For the game-based learning condition, enjoyment was linked to immersion and narrative. “It didn’t feel like science class,” one student said. I was actually trying to work out how to get my ship to Mars. When I finally solved the thrust equations, I felt like a real engineer.” Another wrote: “The game reminded me I was learning. All that really mattered was to solve the next mission.” As you can see in the gamification condition, enjoyment was associated with competition and rewards: “I liked seeing my points go up and trying to beat my friend on the leaderboard. It was more fun doing the worksheets.”

Theme 2: Perceived Relevance and Learning Across the board, students in game-based learning conditions connected game activities with scientific concepts. A participant said, “When the rocket didn’t take off because I hadn’t factored in friction, I really appreciated why Newton’s laws were important. It was no longer simply a formula.” Gamification students recognized that they learned but portrayed it as completing a checklist: “I did everything for the badge. Well, I think that was when I learnt the stuff, but mostly I just wanted to get out of the module.” Students in the control condition described learning as passive: “We just took notes and did worksheets. I did pass the test, but I don’t really remember it now.”

Theme 3: Frustration Factors. Each condition spawned different sources of frustration. Gamification students complained they hated being in competition on the leaderboard when their performance dropped: “Once I saw that I was at the bottom, I kind of gave up. There was nobody to catch up with.” At times, game-based learning students showed exasperation at the mechanics of the gameplay: “Sometimes I knew what I had to do, but if it wasn’t done, how the game wanted to let you play. That was annoying.” Control condition students reported boredom rather than frustration: “It was just Dr. Seuss every day. I zoned out a lot.”

4.4. Summary of Hypothesis Testing

Table 4 summarizes the findings for each hypothesis based on the quantitative and qualitative results.

Table 4. Summary of hypothesis testing.

Hypothesis	Description	Result	Evidence
H1	Game-based learning yields higher intrinsic motivation than gamification	**Supported**	Significant ANCOVA effect ($p < 0.001$, $\eta p^2 = 0.18$); pairwise comparison significant ($p < 0.001$, $d = 0.61$)
H2	Gamification yields higher extrinsic motivation and task engagement	**Partially Supported**	Significantly higher effort/importance than control ($p = 0.02$); higher time-on-task and participation; no significant difference with GBL on effort/importance
H3	Game-based learning yields more positive perceptions of enjoyment, relevance, and perceived learning	**Supported**	Thematic analysis revealed deeper engagement, stronger conceptual connections, and meaningful learning narratives in the GBL condition

5. Discussion

This section interprets the findings in relation to self-determination theory and prior literature, explains the differential effects of gamification and game-based learning on motivation, discusses implications for STEM educators, acknowledges limitations, and proposes directions for future research.

5.1. Interpretation of Findings: Connecting Results to Self-Determination Theory and Prior Literature

These results provide empirical support for the theoretical differentiation of gamification and game-based learning [6], [7] aforementioned. The findings are consistent with self-determination theory (SDT), which proposes that autonomy, competence, and relatedness create the conditions in which intrinsic motivation thrives [3], [21]. Self-reported quantitative scores indicated that immersion in the game-based learning condition resulted in significantly greater intrinsic motivation compared to those found in gamification and control conditions. This result aligns with previous work showing that narrative-driven immersive games fulfill the psychological need for competence via scaffolded challenge and the need for autonomy via meaningful choice [5], [38]. Qualitative data support this interpretation: students reported feeling true to form as "real engineers" and emphasized the authenticity of problem-solving contexts, hinting at the satisfaction of both competence and relatedness needs through game-based learning experiences.

The gamification condition produced greater intrinsic motivation than traditional instruction, but less than game-based learning (GBL). This is consistent with meta-analytic evidence that gamification effects on intrinsic motivation are weak and dependent on context [29]. In particular, gamification showed the highest scores for the effort/importance subscale, which captures one form of autonomous extrinsic motivation, and for behavioral engagement measures, including time-on-task and voluntary participation. These results extend previous research showing that points, badges, and leaderboards can motivate the pursuit of behavioral compliance and effort [8],[30]. However, the same gamification condition evidenced greater pressure/tension scores than did game-based learning consistent with SDT’s hypotheses that controlling motivational strategies (even those effective for short-term engagement) predict feelings of pressure and lower perceived autonomy [27].

In every quantitative measure, the control condition exhibited the least motivation overall. This result is not surprising given the existing literature that has documented the limitations of motivation in traditional, lecture-focused instruction in STEM environments [2], [25]. Importantly, the use of a control group

strengthens causal inferences by showing that differences observed are due to the game-informed interventions rather than maturation or testing effects [48].

5.2. Gamification vs. Game-Based Learning: Explaining Differential Effects on Intrinsic vs. Extrinsic Motivation

Gamification and game-based learning seem to have differential effects that can be explained through the lens of psychological need satisfying. Game-based learning, as operationalized here, co-located learning objectives within a narrative-driven, problem-solving context that afforded students substantial autonomy (nonlinear progression, multiple solution paths) and competence (adaptive difficulty, just-in-time scaffolding). These design features match conditions that SDT considers essential to intrinsic motivation [23]. A qualitative finding that students in this condition reported learning as “not like science class” and claimed a sense of identity with the role of engineer indicates support for integrated regulation, the most autonomous type of extrinsic motivation, and, often, true intrinsic interest [27].

By contrast, gamification operates by overlaying motivational affordances over an unchanged curriculum. And while points, badges, and leaderboards worked well to keep learners engaged, the fact was that those games (in terms of getting people to exert effort or complete things) didn't really change what the learning game actually did. Students were still completing worksheets and their work more generally, albeit with higher motivational incentives for doing so. This distinction further accounts for why gamification had more powerful effects on extrinsic motivation and behavioral engagement but weaker effects on intrinsic motivation. This qualitative theme of frustration related to leaderboard position is especially informative: students who fell behind were left with a decreased sense of competence, and the public nature of leaderboards may have blocked lower-performing students from finding relatedness [32]. Such findings resonate with previous work relating to the “dark side” of gamification, where competitive mechanisms can serve to demotivate students who view themselves as unlikely to succeed [33].

The lack of a significant difference between gamification and game-based learning in the effort/importance subscale indicates that both ways might lead to valuing the learning activity, but not through the same mechanisms. Gamification seems to induce valuing by way of external incentives, whereas game-based learning fosters valuing through the internalization of belonging within the context of why one learns. Importantly, this nuanced finding highlights the need to disentangle types of extrinsic motivation upfront when assessing educational interventions [15].

5.3. Implications for Practice: Guidance for STEM Educators

These findings provide STEM educators and instructional designers with put into practice when purposively debating about implementing game-informed pedagogies. First, game-based learning seems to be better than gamification when the instructional goal is to develop deep, persistent intrinsic engagement in STEM content. For educators interested in promoting conceptual learning, critical thinking skills, and engagement that endure beyond the teaching context, this means supporting well-conceived education games where learning is situated within purposeful narratives and applied to genuine problem-solving situations [17]. On the other hand, this method demands a lot of investment in terms of development time, technology infrastructure, and teacher training [41].

Secondly, when the aim is to foster behavioral engagement, effort, and task completion within existing curricula, gamification provides a resource-efficient solution. The assignment and engagement can be rewarded by using points, badges, or progress bars. However, educators must employ gamification with intention and heed possible adverse consequences. Using anonymous avatars on the leaderboards as was done in this study may reduce some of the competitive anxiety associated with public ranking [33]. Additionally, to further support competence needs for all learners [26], educators should: 1) consider the use of multiple pathways to achievement and recognising effort versus solely performance in academic settings.

Third, the results warn against treating gamification and game-based learning as interchangeable. Prior to choosing an approach, educators should articulate clear motivational goals. A blended approach, where gamification scaffolds engagement in the preparatory stages and game-based learning allows for greater conceptual exploration, may provide the most holistic answer [12]. Finally, the qualitative result indicating that game-based learning alleviated perceived pressure also suggests that this approach may be especially valuable for students who struggle with anxiety in traditional STEM classrooms.

5.4. Limitations: Internal Validity Threats, Generalizability, Implementation Variability

This study has several limitations that should be considered when interpreting the findings. First, the quasi-experimental design, required by real-world classroom settings, does not allow for random assignment of individual students to conditions. Despite adjusting pre-test covariates to try to control for any differences in characteristics before treatment, selection bias cannot be absolutely ruled out [47]. Preserving class assignment can introduce confounding variables like classroom climate or peer dynamics that differ systematically across conditions.

Second, the sample included only students from one school district and largely consisted of eighth graders. This limits generalizability to different grade levels, geographic regions, and academic contexts. The motivational effects observed could also vary in elementary or post-secondary contexts, or within schools of different demographic composition or resource constraints [51].

Third, although the four-week intervention period was adequate to detect differences in motivation, it does not determine whether effects would be sustained over time. Whether such observed motivational gains are maintained in the long term is still unknown or may be a function of the novelty of this approach fading away [10].

Fourth, implementation heterogeneity is an inherent challenge of field research that we addressed by tracking fidelity. All conditions were delivered by the same teacher, controlling for teacher-related variables but introducing risks of cross-condition contamination or differential enthusiasm around specific procedures [45].

5.5. Future Research Directions: Longitudinal Studies, Other STEM Disciplines, Role of Prior Gaming Experience

The results of this study open new lines of research. Longitudinal studies are required to investigate the long-term motivational effects of gamification and game-based learning. However, the sustainability of intrinsic motivation from game-based learning conditions over successive units or through sustained interest in STEM careers still needs to be unraveled [40]. Longer interventions (that last an entire academic year, for instance) would provide useful data about longer-term motivational trajectories.

Second, replication in other STEM disciplines, such as math, engineering, and technology, will have greater generalizability. The characteristics of content and the nature of problem-solving tasks vary significantly within STEM disciplines, and across those disciplines, the relative effectiveness of game-informed approaches may interact with disparate subject properties [37]. Research by grade level, from elementary through post-secondary, would also make clear developmental considerations relevant to the application of these strategies.

Third, it could be useful to explore the role of students' prior gaming experience as a moderator. A different effect could be observed on students fluent in gaming than on students new to or with little exposure to games. Students who are already familiar with video games could find it easier to navigate game-based environments, but experience prior to the study might also define how receptive students are towards gamification elements [26].

Fourth, individual difference factors like academic self-concept, achievement goal orientation, and gender should be investigated in future research. This is significant as preliminary evidence indicates that competitive elements of gamification may have different effects on male and female students and that students with mastery goal orientations may respond more positively to game-based learning activities as compared to their performance-oriented counterparts [32].

Finally, the comparative effectiveness research examining differences within each approach (such as different types of combinations of game design elements in gamification or genres of educational games in game-based learning) would offer more fine-grained insights for instructional designers. This research would help identify prescriptive or pragmatic frameworks for matching specific game-informed strategies to specific learning outcomes and learner characteristics [12].

6. Conclusion

In response to the continued problem of students disengaging from science, this study aimed to investigate the implications of gamification and game-based learning design elements on student motivation in secondary STEM classroom environments. Based on self-determination theory, the study utilized a quasi-experimental design to compare three instructional conditions gamification, game-based learning, and traditional instruction over six eighth-grade science classes. The results provide clear evidence that gamification and game-based learning are both conceptually and empirically distinct approaches through which motivation is influenced, via different psychological channels.

This study makes two major contributions to the literature: first, it empirically clarifies these differences. The design of the educational game met expected learning objectives and produced significantly greater intrinsic motivation than either gamification or traditional instruction. Students in the game-based learning condition demonstrated deep engagement, perceived authenticity and relevance, and described the transfer of game activities to scientific principles (qualitative data). These results converge on self-determination theory's premise that intrinsic motivation is augmented in learners experiencing autonomy, competence, and relatedness needs that were supported through the game's adaptive challenge, nonlinear progression, and immersive narrative.

In comparison, gamification not with a new curriculum but overlaying it with points, badges, leaderboards, and progress bars led to stronger effects on extrinsic motivation and observable behavioral engagement. Gamification resulted in the highest percentage of time spent on task and voluntarily participating, and participants reported presenting greater effort toward and perceiving higher importance for the learning tasks. However, they were also under more pressure and tension than their colleagues in game-based learning settings. Frustration by leaderboard position, as a qualitative theme, also illustrated the drawbacks of competitive gamification elements and how they can undermine lower-performing students' sense of competence. Such findings emphasize that though gamification is good at eliciting short-term behavior changes, it may not be as effective in generating the lasting innate motivation needed for longterm interest in STEM.

A second major contribution is the finding that both game-informed methods provide a significant advantage over standard instruction for nearly all motivational outcomes. The control condition differed, and significantly so further substantiating what is well-documented limitations to a pedagogy driven by lecture-based and worksheet-style approaches in engaging students meaningfully with science. This is an encouraging finding for educators with

full courseware commitments, but who are looking to infuse some new energy into their classrooms according to this research, even simple gamification strategies can lead to meaningful changes in student effort and engagement.

The findings of this study are directly applicable to STEM educators, instructional designers, and curriculum developers. Most importantly, the takeaway point is that strategies informed by games must be tailored to learning goals. Game-based learning could well be the optimal choice if the goal is extrinsic motivation, but it requires many more resources to invest in development and delivery. Gamification provides an efficient and effective route when the goal is to boost effort, task completion, engagement, and behavioral participation on existing curricular structures. Importantly, these two approaches are not interchangeable; treating them as such risks mismatched expectations and sub-optimal outcomes. Hybrid models, for instance, that mix gamification for better preparation with game-based learning ensure teachers focus on the core concepts explored.

Several limitations warrant acknowledgment. The quasi-experimental design tends to downplay the causal certainty, which is common in real classroom settings. The four-week duration of the intervention, however, does not provide insight into the sustainability of motivational effects over time. Finally, the study's focus on one school and eighth-grade students limits its generalizability by grade level or education context. Future research could follow longitudinal designs to investigate the durability of motivational gains, examine the moderating role of prior gaming experience and individual differences, and address other STEM fields and diverse groups of students.

Therefore, this study reinforces the necessity of differentiation between gamification and game-based learning as two conceptually and functionally different pedagogical approaches. Our work also serves to inform evidence-based instructional decision-making and nuanced understanding in demonstrating the differential influences of choice on intrinsic versus extrinsic motivation. As STEM education wrestles with increasing concerns on student engagement and retention, a thoughtful application of game-informed pedagogies purposefully designed for critical motivational targets could be immensely promising. These findings also invited educators to step past the question of "whether" or "not" to utilize game elements and challenge themselves with more sophisticated questions, such as about "which" type of game-"informed strategy, for which, and what motivational use for comparison?

Declarations

Ethics Approval Statement: This study involved human participants and was conducted in accordance with ethical standards. Ethical approval was obtained from the Institutional Review Board (IRB) / Ethics Committee of "Dhaka Residential Model College". Informed consent was obtained from all participants prior to their inclusion in the study. Participation was voluntary, and all data were collected and analyzed anonymously to ensure confidentiality and privacy.

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