The Eastasouth Journal of Learning and Educations
Vol. 4, No. 02, July 2026, pp. 107-120
ISSN: 3025-2504, DOI: 10.58812/esle.v4i02

The Effect of Digital Gamified Learning on Fifth Graders' Critical Thinking in Fraction Arithmetic: A Motivation-Based Moderation Study

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Article Info

Article history:

Received Jun, 2026
Revised Jun, 2026
Accepted Jul, 2026

Keywords:

Critical Thinking;
Digital Gamified Learning;
Elementary Mathematics;
Fraction Arithmetic;
Learning Motivation

ABSTRACT

Elementary students' limited critical thinking in fraction arithmetic remains a persistent concern, particularly when mathematics instruction emphasizes procedural computation rather than reasoning, justification, and evaluation. Digital gamified learning offers a promising alternative, yet its effectiveness may depend on students' motivational characteristics. This research aimed to examine the effect of digital gamified learning on fifth graders' critical thinking in fraction arithmetic and to determine whether learning motivation moderated this effect. A quantitative quasi-experimental design with a non-equivalent pretest–posttest control group and a 2 × 2 factorial structure was employed. The participants were 89 fifth-grade students from four public elementary schools in Cepogo District, Boyolali Regency, Central Java, Indonesia. The experimental group received digital gamified learning using Wayground, whereas the control group received PowerPoint-based instruction. Data were collected using a critical thinking test and a learning motivation questionnaire, both of which demonstrated acceptable validity and reliability. The results showed that students in the experimental group achieved a higher mean gain score than those in the control group. Factorial ANCOVA further revealed significant effects of instructional media, learning motivation, and their interaction on students' posttest critical thinking scores. Students with high learning motivation benefited most from digital gamified learning, although low-motivation students also showed meaningful improvement. These findings imply that digital gamification can serve as an effective instructional strategy for enhancing mathematical critical thinking when it is pedagogically aligned with reasoning-based tasks, immediate feedback, and motivationally responsive learning support.

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1. INTRODUCTION

Mathematics learning in elementary schools is increasingly expected to develop not only procedural fluency but also students' ability to reason, justify, evaluate strategies, and make mathematically sound decisions [1]. This expectation is urgent in Indonesia, where international assessment data still indicate a substantial gap in mathematical literacy. In PISA 2022, Indonesian students obtained an average mathematics score of 366, far below the OECD average of 472, and only 18% of Indonesian students reached at least Level 2 proficiency in mathematics compared with 69% across OECD countries [2]. National data also show that, although the proportion of elementary students reaching minimum numeracy competence improved from 39.04% in 2022 to 52.48% in 2024, nearly half of elementary students were still below the expected numeracy threshold [3].

This problem becomes more critical when mathematics learning is connected to higher-order thinking and critical reasoning. PISA 2022 creative thinking results show that only 31% of Indonesian students reached baseline proficiency, compared with the OECD average of 78%, and only 5% were classified as top performers, compared with 27% across OECD countries [4]. Although creative thinking and critical thinking are not identical constructs, both require students to interpret information, evaluate possibilities, and generate reasoned solutions rather than merely recall procedures. These data suggest that Indonesian students need learning environments that systematically strengthen reasoning-oriented mathematical activity from the elementary level, especially before students encounter more abstract mathematics in later grades [5].

Fraction arithmetic is a particularly important domain for addressing this issue because it functions as a bridge between basic arithmetic and more advanced mathematical reasoning [6]. Prior longitudinal evidence shows that elementary students' knowledge of fractions and division uniquely predicts later algebra knowledge and overall mathematics achievement, even after controlling for general intellectual ability, working memory, and family background. At the same time, fractions remain one of the most difficult topics for elementary learners because students often struggle to interpret part-whole relations, compare fractional quantities, connect numerators and denominators conceptually, and move beyond algorithmic manipulation [7]. In the Indonesian elementary context, recent literature has also identified weak foundational numeracy, low learning motivation, and procedural teaching approaches as major contributors to students' difficulties in understanding fractions [8].

Recent educational technology research has positioned digital gamified learning as a promising approach for improving mathematical engagement, motivation, and learning performance [9]. Meta-analytic evidence indicates that digital game-based learning in school contexts has a positive effect on overall learning outcomes, with reported effects on cognitive outcomes and affective-motivational outcomes [10]. A more recent meta-analysis on game-based learning in mathematics also found a positive effect on students' mathematical higher-order thinking skills, although the effect size was small and influenced by moderator variables such as educational level, type of thinking skill, control treatment, and intervention duration [11]. Similarly, research on gamification shows that gamified learning can enhance intrinsic motivation and students' perceptions of autonomy and relatedness, although the magnitude of effects varies across designs and learner characteristics [12].

The state of the art therefore suggests that gamification is no longer viewed simply as the addition of points, badges, leaderboards, or rewards, but as a pedagogical design that can structure challenge, feedback, progression, autonomy, and meaningful engagement around learning objectives [13]. In mathematics education, this shift is important because students need opportunities to explore strategies, receive immediate feedback, test conjectures, and revise errors in a low-risk environment. When aligned with fraction arithmetic, digital gamified learning may help transform fraction tasks from routine computation into interactive problem-solving experiences that invite comparison, justification, and evaluation [14]. However, the effectiveness of such learning environments depends on whether gamification is pedagogically integrated with mathematical reasoning rather than used as superficial entertainment.

Despite these developments, several research gaps remain. First, many studies on gamification and game-based learning in mathematics focus primarily on achievement, engagement, or motivation, while fewer studies examine critical thinking as the central learning outcome in elementary fraction arithmetic [15]. Second, existing meta-analytic findings show positive but varied effects, which indicates that learner characteristics and instructional conditions may influence whether gamified learning produces meaningful cognitive gains [16]. Third, learning motivation is often treated as an outcome of gamification, but less frequently examined as a moderating variable that may strengthen or weaken the effect of digital gamified learning on students' critical thinking [17]. These gaps are particularly relevant for fifth-grade students because they are developmentally positioned at a critical stage where fraction understanding becomes more complex and reasoning demands increase.

The problem addressed in this study is that fifth graders' critical thinking in fraction arithmetic remains insufficiently developed under conventional mathematics instruction, while current evidence does not adequately explain whether digital gamified learning improves critical thinking equally across students with different levels of learning motivation. This study assumes that students' motivational profiles may shape how they respond to challenge, feedback, competition, progress indicators, and repeated problem-solving opportunities in a gamified digital environment [18]. Therefore, examining motivation as a moderating factor is necessary to determine whether digital gamified learning functions as a universally effective intervention or whether its impact varies according to students' readiness and willingness to engage in mathematical reasoning.

The urgency of this research lies in its potential contribution to both theory and practice in elementary mathematics education. Theoretically, the study extends gamification research by shifting the focus from general achievement and engagement toward critical thinking in a specific mathematical domain, while also testing learning motivation as a conditional factor. Practically, the findings may guide teachers, curriculum designers, and educational technology developers in designing gamified fraction learning that supports reasoning, not only enjoyment. In a broader policy context, this study responds to Indonesia's continuing need to strengthen elementary numeracy and higher-order thinking by identifying an instructional strategy that is digitally relevant, motivationally responsive, and pedagogically aligned with 21st-century mathematics learning.

2. METHODS

2.1 Research Design

This study employed a quantitative quasi-experimental research design to examine the effect of digital gamified learning on fifth graders' critical thinking skills in fraction arithmetic. A quasi-experimental approach was considered appropriate because the participants were drawn from intact classroom groups in existing elementary schools, making random assignment at the individual student level impractical. The study used a non-equivalent pretest–posttest control group design embedded within a 2 × 2 factorial framework. This design enabled the researcher to examine not only the main effect of learning media on students' critical thinking, but also the main effect of learning motivation and the interaction effect between learning media and learning motivation.

The independent variable in this study was the type of instructional media, consisting of digital gamified learning using Wayground and conventional digital presentation media using PowerPoint. The moderating variable was students' learning motivation, categorized into high and low motivation levels. The dependent variable was students' critical thinking ability in the topic of fraction arithmetic, specifically addition and subtraction of fractions. The factorial design was used to determine whether the effect of digital gamified learning on critical thinking differed across students with different levels of learning motivation.

Table 1. Factorial Design of the Study

Learning Media	High Learning Motivation	Low Learning Motivation
Digital gamified learning using Wayground	A1B1	A1B2
PowerPoint-based learning	A2B1	A2B2

In this design, A1 represents digital gamified learning, A2 represents PowerPoint-based learning, B1 represents students with high learning motivation, and B2 represents students with low learning motivation. The use of this factorial structure allowed the study to identify whether digital gamification functioned as an effective instructional intervention across motivational profiles or whether its effectiveness depended on students' initial motivation to learn mathematics.

2.2 *Participants*

The population of this study consisted of all fifth-grade students enrolled in public elementary schools in Cepogo District, Boyolali Regency, Central Java, Indonesia, during the second semester of the 2025/2026 academic year. The district consisted of 34 public elementary schools with a total of 508 fifth-grade students. From this population, four public elementary schools were selected using purposive sampling. This sampling technique was used because the study required schools with comparable grade levels, relevant curriculum implementation, available fifth-grade classes, and the feasibility to conduct digital learning interventions.

The total sample consisted of 89 fifth-grade students from four public elementary schools. The experimental group consisted of students from SDN 1 Cepogo and SDN 1 Jelok, while the control group consisted of students from SDN 1 Paras and SDN Randu. Students in the experimental group received instruction using digital gamified learning through Wayground with interactive video features. Students in the control group received instruction using PowerPoint-based learning on the same topic.

The use of intact school groups helped preserve the natural classroom context and minimized disruption to regular school activities. Although individual randomization was not applied, the use of pretest data allowed the researcher to examine the initial condition of students' critical thinking ability before the intervention. This procedure strengthened the internal validity of the study by providing a baseline for comparing students' development after the instructional treatment.

2.3 *Instruments*

Two main instruments were used in this study: a critical thinking test and a learning motivation questionnaire. The critical thinking test was developed to measure students' ability to analyze, interpret, evaluate, and solve problems related to addition and subtraction of fractions. The test items were aligned with the fifth-grade mathematics curriculum and designed to assess students' reasoning processes rather than merely their procedural computation skills. The indicators of critical thinking included identifying relevant information, selecting appropriate solution strategies, justifying mathematical reasoning, evaluating solution accuracy, and drawing logical conclusions from fraction arithmetic problems.

The learning motivation questionnaire was used to classify students into high and low motivation categories. The questionnaire measured students' motivational orientation toward mathematics learning, including attention, persistence, confidence, interest, effort, and willingness to engage in mathematical problem-solving activities. Students' motivation scores were then used to determine their motivational category for the factorial analysis. The classification of high and low motivation may be conducted using a median split, percentile-based grouping, or another statistically justified criterion, depending on the final distribution of motivation scores.

To ensure the quality of the instruments, both the critical thinking test and the learning motivation questionnaire should undergo expert validation before being administered in the main study. Content validation may involve mathematics education experts, elementary education experts, and assessment specialists to evaluate the relevance, clarity, cognitive level, and curriculum alignment of each item. A pilot test should also be conducted to examine item difficulty, item discrimination, and reliability. The reliability of the critical thinking test may be estimated using Cronbach's alpha or another appropriate reliability coefficient, while the questionnaire reliability should also be examined to ensure internal consistency.

The inclusion of supporting documentation and observation notes was intended to strengthen the interpretation of the quantitative findings. These supporting data helped ensure that differences in students' critical thinking outcomes were related to the instructional treatment rather than uncontrolled classroom implementation differences.

2.4 *Data Collection Process*

The data collection process was conducted in several stages. First, the researcher obtained permission from the relevant schools and coordinated with classroom teachers to determine the research schedule, instructional procedures, and technical requirements for implementing the digital gamified learning intervention. At this stage, the researcher also prepared the learning materials, Wayground activities, interactive video content, PowerPoint materials, critical thinking test, and motivation questionnaire.

Second, students in both experimental and control groups were given a pretest to measure their initial critical thinking ability in fraction arithmetic. The learning motivation questionnaire was also administered before the treatment to identify students' motivation levels. The pretest and motivation data served as baseline information for comparing the experimental and control groups and for classifying students into high and low motivation categories.

Third, the instructional treatment was implemented. The experimental group learned addition and subtraction of fractions through digital gamified learning using Wayground. The learning activities included interactive video, game-like tasks, immediate feedback, progress-based participation, and structured problem-solving activities. These features were intended to encourage active engagement, sustained attention, and reasoning-oriented participation. In contrast, the control group learned the same topic through PowerPoint-based instruction. The control treatment used teacher explanation, visual presentation, worked examples, and practice exercises without gamified digital features.

Fourth, after the instructional treatment was completed, students in both groups were given a posttest to measure their critical thinking ability in fraction arithmetic. The posttest was designed to assess the same critical thinking indicators as the pretest, with equivalent difficulty and content coverage. The posttest scores were then compared across learning media groups and motivation categories to examine the effect of digital gamified learning and the moderating role of learning motivation.

Finally, all collected data were organized, coded, and prepared for statistical analysis. Students' critical thinking scores were tabulated based on group membership, school, type of learning media, and motivation category. Data screening was conducted to check completeness, scoring accuracy, outliers, and assumption requirements before inferential statistical analysis was performed.

2.5 *Data Analysis*

Data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics, including means, standard deviations, minimum scores, and maximum scores, were calculated to provide an overview of students' critical thinking performance across groups.

Prior to hypothesis testing, assumption tests were conducted to ensure compliance with parametric statistical requirements. Normality was examined using the Shapiro–Wilk test, while homogeneity of variance was assessed using Levene's Test. Only data meeting these assumptions were subjected to further inferential analysis.

The primary analysis employed a Two-Way Analysis of Variance (Two-Way ANOVA) to examine: The main effect of instructional media on critical thinking skills; The main effect of learning motivation on critical thinking skills; The interaction effect between instructional media and learning motivation. The statistical model can be represented as:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk}$$

where:

a. Y_{ijk}= critical thinking score,
b. μ= grand mean,
c. A_i= effect of instructional media,
d. B_j= effect of learning motivation,
e. $(AB)_{ij}$= interaction effect,
f. ε_{ijk}= random error.

When significant interaction effects were identified, post-hoc comparisons were conducted to determine specific group differences. All analyses were performed using statistical software with a significance level of α = .05.

To strengthen interpretability, effect sizes (η^2) were also calculated to determine the magnitude of the observed effects and provide a more comprehensive understanding of the practical significance of digital gamification in enhancing critical thinking skills among elementary school students.

3. RESULTS AND DISCUSSION

3.1 *Data Analysis*

The dataset consisted of 89 fifth-grade students, comprising 39 students in the control group and 50 students in the experimental group. The control group received PowerPoint-based instruction, whereas the experimental group received digital gamified learning using Wayground. Based on the motivation classification recorded in the dataset, the control group consisted of 22 students with high learning motivation and 17 students with low learning motivation, while the experimental group consisted of 29 students with high learning motivation and 21 students with low learning motivation. The students' critical thinking scores were reported on a 0–100 scale for both the pretest and posttest.

Table 2. Participant Distribution and Motivation Profile

Group	Instructional Treatment	N	High Motivation	Low Motivation	Motivation Mean	SD
Control	PowerPoint-based learning	39	22	17	81.70	8.41
Experimental	Digital gamified learning using Wayground	50	29	21	82.05	9.40

Group	Instructional Treatment	N	High Motivation	Low Motivation	Motivation Mean	SD
Total		89	51	38	—	—

The instrument validation results showed that both instruments met acceptable psychometric criteria. The learning motivation questionnaire consisted of 20 items, with Aiken's V values ranging from 0.800 to 0.933 and a mean value of 0.847. The critical thinking test consisted of 6 items, with Aiken's V values ranging from 0.800 to 0.900 and a mean value of 0.833. All items reached the minimum validity criterion of V ≥ 0.800. The reliability analysis also showed acceptable to very strong internal consistency. The learning motivation questionnaire obtained a Cronbach's alpha coefficient of 0.812, while the critical thinking test obtained a Cronbach's alpha coefficient of 0.935.

Table 3. Validity and Reliability of the Research Instruments

Instrument	Number of Items	Aiken's V Range	Mean Aiken's V	Cronbach's Alpha	Interpretation
Learning motivation questionnaire	20	0.800–0.933	0.847	0.812	Valid and reliable
Critical thinking test	6	0.800–0.900	0.833	0.935	Valid and highly reliable

The descriptive statistics of the critical thinking scores showed an increase from pretest to posttest in both groups. In the control group, the mean pretest score was 57.26 with a standard deviation of 8.69, and the mean posttest score increased to 65.38 with a standard deviation of 11.44. The mean gain score in the control group was 8.12. In the experimental group, the mean pretest score was 55.83 with a standard deviation of 9.07, and the mean posttest score increased to 77.67 with a standard deviation of 12.84. The mean gain score in the experimental group was 21.83. A preliminary comparison of the pretest scores showed no statistically significant difference between the experimental and control groups, $t(87) = -0.75$, $p = .454$.

Table 4. Descriptive Statistics of Pretest, Posttest, and Gain Scores

Group	Test Phase	N	Mean	SD	Minimum	Maximum
Control	Pretest	39	57.26	8.69	41.67	70.83
Control	Posttest	39	65.38	11.44	50.00	79.17
Control	Gain	39	8.12	4.16	0.00	16.67
Experimental	Pretest	50	55.83	9.07	41.67	70.83
Experimental	Posttest	50	77.67	12.84	58.33	95.83
Experimental	Gain	50	21.83	5.62	12.50	37.50

When the scores were examined according to both instructional treatment and learning motivation level, the highest posttest mean was observed among students in the experimental group with high learning motivation. This group obtained a pretest mean of 62.36 and a posttest mean of 87.93, with a mean gain of 25.57. Students in the experimental group with low learning motivation also showed an increase, from a pretest mean of 46.83 to a posttest mean of 63.49, with a mean gain of 16.67. In the control group, students with high motivation increased from 64.20 to 74.62, while students with low motivation increased from 48.28 to 53.43.

Table 5. Pretest, Posttest, and Gain Scores by Instructional Treatment and Motivation Level

Group	Motivation Level	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gain Mean	Gain SD
Control	High	22	64.20	3.06	74.62	2.19	10.42	2.49
Control	Low	17	48.28	3.91	53.43	5.94	5.15	4.04
Experimental	High	29	62.36	5.51	87.93	4.22	25.57	4.13
Experimental	Low	21	46.83	3.46	63.49	3.93	16.67	2.28

The paired-sample analysis showed that both groups experienced statistically significant improvement from pretest to posttest. In the control group, the increase was statistically significant, $t(38) = 12.19$, $p < .001$. In the experimental group, the increase was also statistically significant, $t(49) = 27.47$, $p < .001$. The magnitude of improvement was larger in the experimental group, as reflected in the mean gain difference between the two instructional treatments.

To examine the effect of instructional media, learning motivation, and their interaction on students' posttest critical thinking scores, a factorial ANCOVA was conducted with pretest scores entered as a covariate. The result showed that the pretest covariate was statistically significant, $F(1, 84) = 70.84$, $p < .001$, partial $\eta^2 = .458$. After controlling for pretest scores, instructional media had a statistically significant effect on posttest critical thinking scores, $F(1, 84) = 355.21$, $p < .001$, partial $\eta^2 = .809$. Learning motivation also had a statistically significant effect, $F(1, 84) = 77.56$, $p < .001$, partial $\eta^2 = .480$. The interaction between instructional media and learning motivation was statistically significant, $F(1, 84) = 6.94$, $p = .010$, partial $\eta^2 = .076$.

Table 6. Factorial ANCOVA of Posttest Critical Thinking Scores

Source	Error df	SS	MS	F	p	Partial η^2
Pretest covariate	84	673.45	673.45	70.84	< .001	.458
Instructional media	84	3376.87	3376.87	355.21	< .001	.809
Learning motivation	84	737.33	737.33	77.56	< .001	.480
Instructional media × learning motivation	84	65.97	65.97	6.94	.010	.076
Error	—	798.56	9.51	—	—	—

The adjusted posttest means showed that, after controlling for pretest scores, students in the experimental group obtained higher estimated posttest scores than students in the control group across both motivation levels. The adjusted mean for the experimental group with high motivation was 84.02, while the adjusted mean for the control group with high motivation was 69.49. For students with low motivation, the adjusted mean was 69.88 in the experimental group and 58.85 in the control group. These results showed that the highest adjusted posttest performance occurred among students who received digital gamified learning and had high learning motivation.

Table 7. Adjusted Posttest Means by Instructional Treatment and Motivation Level

Group	Motivation Level	Adjusted Posttest Mean
Control	Low	58.85
Control	High	69.49
Experimental	Low	69.88
Experimental	High	84.02

3.2 *Discussion*

The findings provide strong empirical evidence that digital gamified learning using Wayground was associated with substantially higher gains in fifth graders' critical thinking in fraction arithmetic than PowerPoint-based instruction. Although both groups improved from pretest to posttest, the magnitude of improvement was clearly different: the experimental group showed a mean gain of 21.83 points, whereas the control group showed a mean gain of only 8.12 points. This pattern indicates that the advantage of the gamified condition was not merely a function of repeated exposure to fraction problems or normal classroom progression [19]. Rather, the result suggests that the gamified learning environment provided additional cognitive and motivational affordances that supported students in engaging more actively with fraction arithmetic tasks [20].

The significant main effect of instructional media after controlling for pretest scores strengthens this interpretation. The ANCOVA result showed a very large effect of instructional media on posttest critical thinking scores, with partial $\eta^2 = .809$. This effect size indicates that the instructional treatment accounted for a substantial proportion of the explainable variance in students' posttest performance [21]. However, the magnitude should be interpreted carefully because quasi-experimental studies conducted with intact school groups may be influenced by contextual factors such as classroom culture, teacher delivery, school environment, and students' prior exposure to digital tools [22]. Even so, the non-significant pretest difference between the experimental and control groups suggests that the two groups began from relatively comparable levels of critical thinking performance, making the observed posttest difference educationally meaningful.

A key contribution of this finding lies in the cognitive nature of the outcome. Many gamification studies emphasize engagement, motivation, enjoyment, or general achievement, whereas the present study focused specifically on critical thinking in fraction arithmetic. This distinction is important because critical thinking requires more than correct procedural calculation [23]. Students must interpret mathematical situations, select appropriate strategies, justify reasoning, evaluate answers, and draw logical conclusions. The result therefore suggests that digital gamified learning can support not only affective engagement but also reasoning-oriented mathematical performance when game elements are embedded within meaningful problem-solving tasks.

This finding is consistent with recent meta-analytic evidence showing that game-based learning has a positive effect on students' mathematical higher-order thinking skills, including problem-solving, critical thinking, reasoning, and computational thinking [24]. However, the broader literature reports only a small overall effect of game-based learning on mathematical higher-order thinking, with one meta-analysis reporting an overall effect of $g = .134$, while also emphasizing the role of moderator variables such as educational level, intervention duration, type of thinking skill, and control treatment. The stronger effect observed in the present study therefore should not be interpreted as proof that gamification is universally powerful [25]. Instead, it suggests that digital gamified learning may be particularly effective when it is implemented in a focused mathematical topic, supported by structured tasks, and aligned with specific critical thinking indicators.

The fraction arithmetic context also makes the finding theoretically important. Fractions are widely recognized as a difficult domain in elementary mathematics because they require students to move beyond whole-number reasoning and coordinate part-whole relationships, equivalence, magnitude, and operations [26]. A scoping review on fraction learning obstacles emphasizes that fraction learning difficulties are complex and involve diverse student groups, intervention strategies, learning outcomes, and conceptual problems. Longitudinal evidence also shows that competence with fractions contributes to later mathematics achievement, indicating that fraction understanding is not an isolated elementary topic but a foundational component of future mathematical development [27]. Therefore, improving critical thinking in fraction arithmetic is pedagogically significant because it may strengthen students' conceptual readiness for more advanced mathematical learning.

The significant effect of learning motivation further demonstrates that students' motivational characteristics were strongly related to their critical thinking outcomes. Students with high learning motivation consistently achieved higher posttest scores than students with low learning motivation across instructional conditions. This result indicates that motivation was not merely an affective background variable but a meaningful condition shaping students' capacity to benefit from mathematics instruction [28]. In the experimental group, students with high motivation reached the highest posttest mean and the largest gain, suggesting that motivated learners were better able to take advantage of the interactive, feedback-rich, and challenge-based features of Wayground. They may have been more persistent in solving difficult fraction problems, more willing to revise mistakes, and more responsive to immediate feedback [29].

The interaction effect between instructional media and learning motivation is one of the most important results of the study. The statistically significant interaction, with partial $\eta^2 = .076$, indicates that the effect of digital gamified learning was not identical across motivation levels. Students with high motivation benefited most from the gamified intervention, as reflected in the adjusted posttest mean of 84.02, compared with 69.49 for highly motivated students in the control group. Students with low motivation also benefited from digital gamification, with an adjusted mean of 69.88, compared with 58.85 in the low-motivation control group. This pattern shows that gamification had a positive effect across motivational profiles, but its impact was amplified among students who already possessed stronger learning motivation [30].

This result contributes to the literature by positioning learning motivation as a moderating variable, not simply as an outcome of gamification. Recent reviews have shown that gamification can enhance motivation, autonomy, and relatedness, but its effects are often inconsistent and sensitive to design quality [31]. A meta-analysis of gamification and intrinsic motivation found a significant but small overall effect, with Hedges' $g = 0.257$, and noted that students' perceived autonomy, relatedness, and competence are central mechanisms in gamified learning. Another systematic review found that gamification tends to improve motivation, but warned that novelty effects, extrinsic rewards, and prolonged exposure can reduce motivation over time [32]. The present findings support this more nuanced view: gamification appears beneficial, but its effect depends partly on how students motivationally engage with the learning environment.

The result also challenges a simplistic assumption that gamification automatically solves low motivation. Although low-motivation students in the experimental group improved substantially, their posttest performance remained below that of high-motivation students [33]. This suggests that gamified learning can scaffold engagement but may not fully compensate for motivational disadvantages. Game elements such as points, feedback, progress indicators, interactive video, or challenge sequences may invite participation, but students still need persistence, confidence, and willingness to reason through non-routine mathematical tasks. Thus, for low-motivation learners, gamification should be accompanied by teacher guidance, collaborative support, mastery-oriented feedback, and opportunities for gradual success [34].

The comparison with PowerPoint-based learning is also instructive. The control group improved, indicating that teacher explanation, visual presentation, and practice exercises were not ineffective. However, the smaller gain suggests that presentation-based digital media may remain largely transmissive when students are positioned as recipients of information. In contrast, the gamified environment likely required students to respond, decide, receive feedback, and continue through a sequence of tasks [35]. This difference matters for critical thinking because reasoning develops through active cognitive participation, not through exposure to explanations alone. Therefore, the pedagogical value of Wayground in this study should not be attributed only to its digital or playful format, but to its capacity to structure repeated, feedback-supported mathematical reasoning [36].

Nevertheless, the findings require cautious interpretation. The very large treatment effect is promising, but it also raises methodological questions that must be acknowledged for a high-impact publication. Because the study used purposive sampling and intact school groups, the observed differences may partly reflect school-level or classroom-level characteristics that were not fully controlled. ANCOVA helped adjust for pretest differences, but it cannot eliminate all unmeasured confounds. In future research, stronger designs such as randomized classroom assignment, multilevel modeling, longer intervention periods, delayed posttests, and treatment fidelity checks would strengthen causal inference.

Overall, the study provides meaningful evidence that digital gamified learning can improve fifth graders' critical thinking in fraction arithmetic and that learning motivation conditions the strength of this effect. The findings extend current gamification research by showing that the effectiveness of gamified mathematics instruction depends not only on the presence of game elements but also on the interaction between instructional design, mathematical content, and learner motivation. The study therefore supports a more critical and pedagogically grounded view of gamification: it should not be treated as a decorative layer added to instruction, but as a structured learning environment designed to promote reasoning, feedback use, persistence, and conceptual engagement in mathematics.

4. CONCLUSION

The findings demonstrate that digital gamified learning using Wayground produced a stronger improvement in fifth graders' critical thinking skills in fraction arithmetic than PowerPoint-based instruction. The experimental group achieved a substantially higher gain score than the control group, indicating that gamified digital learning provided a more effective instructional environment for supporting reasoning, evaluation, and problem-solving in the addition and subtraction of fractions. Learning motivation also played an important role, as students with high motivation consistently obtained higher critical thinking scores than those with low motivation.

A significant interaction between instructional media and learning motivation indicates that the effectiveness of digital gamified learning was not uniform across all students. Learners with high motivation benefited most from the gamified environment, but students with low motivation also showed meaningful improvement compared with their counterparts in the control group. These results suggest that digital gamification is pedagogically valuable not only as a tool for increasing engagement, but also as a structured learning approach that can support critical thinking when integrated with meaningful mathematical tasks, immediate feedback, and opportunities for active problem solving.

This study has several limitations. The use of a quasi-experimental design and purposive sampling may limit the ability to establish full causal relationships. In addition, the sample was restricted to four public elementary schools in a single district, which may affect the generalizability of the findings. The intervention was conducted over a relatively short period and focused only on fraction arithmetic, limiting conclusions about long-term effects and broader mathematical competencies. Therefore, the findings should be interpreted within these methodological and contextual constraints.

Future classroom implementation should ensure that gamified learning is designed around clear mathematical objectives rather than merely adding game elements to instruction. Teachers are encouraged to combine digital gamification with scaffolding, reflective questioning, collaborative learning, and mastery-oriented feedback, particularly for students with lower motivation. Further research should involve larger and more diverse samples, longer intervention periods, randomized or multilevel designs, delayed posttests, and more detailed treatment fidelity measures to strengthen causal interpretation and examine the long-term impact of digital gamified learning on students' mathematical reasoning.

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