

Improvement in Mathematical Critical Thinking Ability Following Gamification-Based Learning on Fraction Material among Sixth-Grade Students

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Abstract: Mathematical critical thinking is a core competency in primary education, and fraction learning provides a demanding context for developing it. Previous research has documented the benefits of gamification for motivation, engagement, and mathematics performance, while less attention has been directed toward indicator-level changes in critical thinking within fraction learning. This study aims to examine changes in sixth-grade students' mathematical critical thinking ability following gamification-based learning, measured through Facione's interpretation, analysis, evaluation, and inference indicators. A descriptive quantitative approach with a one-group pretest-posttest design was applied to 10 students selected through random sampling. The intervention incorporated points, a leaderboard, simple rewards, explanation of solution procedures, and peer feedback. Data were analyzed using Hake's normalized gain. The combined mean normalized gain was 0.25 (low). Interpretation showed the highest gain (0.35, moderate), followed by evaluation (0.26), analysis (0.24), and inference (0.15), all in the low category. The findings are exploratory because the design lacked a comparison group and involved a small sample.

Keywords: Gamification; Mathematical Critical Thinking; Fractions; Normalized Gain; Elementary School.

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INTRODUCTION

Critical thinking is widely regarded as a core educational outcome. Abrami et al. (2015) describe it as purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference, together with explanations of the considerations behind that judgment. Their meta-analysis of 341 effect sizes reported a weighted mean effect of $g^+ = 0.30$ and indicated that dialogue, exposure to authentic problems, and mentoring were associated with positive effects on critical thinking skills. Primary mathematics provides opportunities for students to practice these processes through solving fraction word problems that require interpretation, analysis, evaluation, and inference.

Fractions are a demanding topic within primary mathematics. Siegler et al. (2013) reported that learning fractions requires children to recognize that many properties of whole numbers do not hold for numbers in general, and that accurate representation of fraction magnitudes is crucial for both conceptual understanding and fraction arithmetic. Kärki et al. (2022) noted that rational number knowledge predicts later mathematics achievement and that many students find the transition from natural number to rational number reasoning difficult. Fraction word problems therefore provide a suitable setting in which interpretation, analysis, evaluation, and inference can be observed in students' written work.

Gamification refers to the use of game design elements, such as points, levels, and leaderboards, in learning contexts. Meta-analytic evidence indicates generally positive effects on learning outcomes. Sailer and Homner (2020) reported significant effects on cognitive, motivational, and behavioral outcomes, whereas Li et al. (2023) also found positive overall effects and noted that the effectiveness of *gamification* varied according to discipline, design principles, and intervention duration.

Studies in primary education have reported varied outcomes of gamification. Romero-Rodríguez et al. (2024) reviewed 31 studies and found positive effects on engagement, motivation, and self-efficacy, alongside mixed learning outcomes. Dehghanzadeh et al. (2024) identified motivation, engagement, and competitiveness as key factors associated with gamification in K-12 education. Suárez Caballero (2023) reported positive effects on motivation and mathematics performance in primary mathematics. Fraga-Varela et al. (2021) found improvements in mathematics fluency among primary students using serious games. Kärki et al. (2022) reported a small positive

effect of a digital game on rational number conceptual knowledge among fifth- and sixth-grade students. Hanus and Fox (2015) found negative effects on motivation and satisfaction in a university course, while Wang and Tahir (2020) reported that Kahoot! generally supported learning performance, although some studies found limited effects.

Existing studies have primarily examined motivation, engagement, mathematics performance, fluency, and conceptual knowledge. Research remains limited regarding indicator-level mathematical critical thinking in fraction learning, particularly interpretation, analysis, evaluation, and inference among upper primary students. Preliminary classroom observations indicated that sixth-grade students had difficulty interpreting fraction word problems, selecting solution strategies, and explaining their reasoning. These observations informed the use of gamified activities involving repeated problem solving, procedural explanations, and peer feedback.

This study examines changes in sixth-grade students' mathematical critical thinking ability following gamification-based learning on fractions, using Facione's indicators of interpretation, analysis, evaluation, and inference. It describes normalized gain for each indicator in an Indonesian elementary school context. The study addresses two questions: (1) What is the level of normalized gain in mathematical critical thinking following gamification-based fraction learning? (2) How does normalized gain differ across the four indicators?

METHODS

Research Design

This study used a descriptive quantitative approach with a one-group pretest-posttest design. Students completed a pretest, participated in gamification-based fraction learning, and completed a posttest. Because there was no comparison group, changes cannot be attributed solely to the intervention. Marsden and Torgerson (2012) identified regression to the mean, maturation, history, and test effects as potential influences on single-group pre-post results. Figure 1 presents the research flow.



Figure 1. Research Method Flow Diagram

Participants and Sampling

Participants were ten sixth-grade students from a public elementary school in Surabaya, Indonesia. They were selected through probability sampling from the available classes, so that each student had an equal chance of being included. Random selection was used to reduce selection bias.

Instrument

The instrument was an essay test on fractions based on Facione's framework of interpretation, analysis, evaluation, inference, explanation, and self-regulation. Four indicators were measured: interpretation, analysis, evaluation, and inference. The pretest and posttest each contained ten items with equivalent formats and levels of complexity. Responses were scored from 0 (unable) to 4 (very good) for each indicator, and indicator scores were calculated as the mean across the ten items.

Intervention

The intervention was a gamification-based learning sequence on fraction material that used a point system, a leaderboard, and simple rewards. Students also explained their solution procedures to peers and gave peer feedback on each other's answers. The sequence was implemented between the pretest and the posttest.

Data Analysis

Data were analyzed descriptively. For each student and each indicator, normalized gain (N-Gain) was calculated using Hake's (1998) formula:

$$N\text{-Gain} = (\text{posttest score} - \text{pretest score}) / (\text{maximum score} - \text{pretest score})$$

The maximum score was 4. Following Hake (1998), N-Gain values were classified as high (≥ 0.7), moderate (0.3 to less than 0.7), or low (less than 0.3). Mean N-Gain, standard deviation, and student counts for each category were calculated by indicator and for the overall results. No inferential tests were conducted because the study involved one group and ten students.

RESULTS

N-Gain of Each Student

Table 1 reports the N-Gain of every student on each indicator. It is included to show individual results, so that the spread among students can be seen before the class-level

summary is read. The mean and category columns were added to show how each student's overall gain falls within Hake's categories.

Table 1. N-Gain of Each Student by Facione's Indicators

Subject	Interpretation	Analysis	Evaluation	Inference	Mean	Category
S1	0.4	0.5	0.4	0.1	0.35	Moderate
S2	0.4	0.5	0.4	0.0	0.33	Moderate
S3	0.4	0.1	0.1	0.1	0.18	Low
S4	0.2	0.1	0.1	0.0	0.10	Low
S5	0.4	0.3	0.4	0.4	0.38	Moderate
S6	0.3	0.1	0.3	0.3	0.25	Low
S7	0.2	0.2	0.3	0.1	0.20	Low
S8	0.4	0.3	0.4	0.4	0.38	Moderate
S9	0.4	0.1	0.1	0.0	0.15	Low
S10	0.4	0.2	0.1	0.1	0.20	Low
Mean	0.35	0.24	0.26	0.15	0.25	Low

Note. The mean and category columns were calculated from the subject-level values, which are reported to one decimal place. The means are therefore approximate.

Table 1 shows that student means ranged from 0.10 to 0.38. Four students (S1, S2, S5, and S8) reached the moderate category overall, and six students remained in the low category. Interpretation values were the most uniform, since eight students obtained 0.3 or higher. Values for analysis and inference varied more, with a range from 0.0 to 0.5 across students.

Figure 2 presents the same data graphically. It is included to make the differences among students and among indicators visible at a glance, which is difficult to achieve from a table of decimals alone.

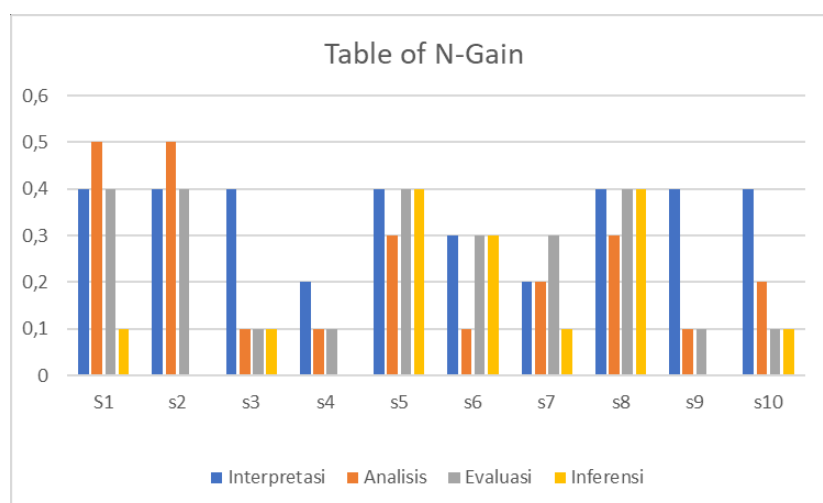


Figure 2. N-Gain Graph per Subject Based on Facione's Indicators

Figure 2 shows that the bars for interpretation are consistently higher than those for the other indicators for most students, while the bars for inference are the lowest, with three students (S2, S4, and S9) at zero.

Summary by Indicator

Table 2 condenses Table 1 into class-level statistics for each indicator. It is included because the research questions concern the level of gain and the differences among indicators. The standard deviation and the number of students per category are added to show how consistently each indicator changed across the ten students.

Table 2. Summary of N-Gain by Indicator

Indicator	Mean	SD	Category	Students in moderate category (<i>n</i>)	Students in low category (<i>n</i>)
Interpretation	0.35	0.09	Moderate	8	2
Analysis	0.24	0.16	Low	4	6
Evaluation	0.26	0.14	Low	6	4
Inference	0.15	0.16	Low	3	7
All indicators combined (student means)	0.25	0.10	Low	4	6

Table 2 shows that interpretation had the highest mean N-Gain (0.35, moderate). Analysis (0.24), evaluation (0.26), and inference (0.15) were in the low category. Evaluation showed individual variation, because six students reached the moderate level even though the class mean was low. The combined mean was 0.25 (low category).

Figure 3 displays the class means from Table 2. It is included to give a direct visual comparison of the four indicators, which supports the second research question on how gains differ across indicators.

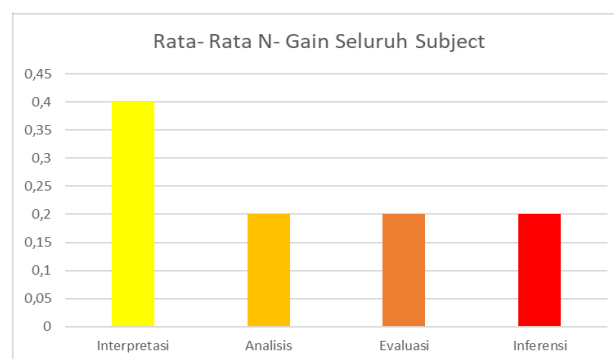


Figure 3. Average N-Gain Graph for the Four Indicators

Figure 3 shows a descending order from interpretation to inference, with evaluation and analysis at similar levels between them.

Illustrative Student Work

The numerical results are complemented by examples of students' written work. Figures 3a to 3d are included because N-Gain values show how much scores changed, and the work samples show what changed in the way students solved the problems. Each figure compares one student's pretest and posttest answers on one indicator.

Figure 4 presents work on the interpretation indicator. In the pretest, the student answered directly without writing the solution steps or elaborating the information in the question, and the answer was incorrect. In the posttest, the student used systematic solution steps that led to the correct answer.

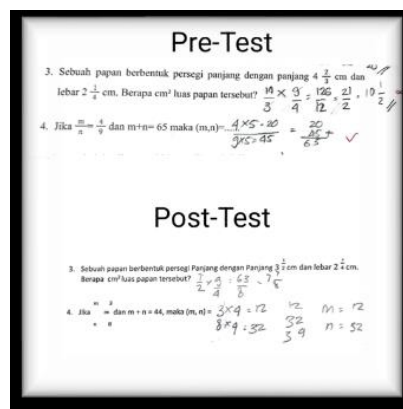


Figure 4. Example of student work, interpretation indicator (pretest and posttest)

Figure 5 presents work on the analysis indicator. In the pretest, the student applied formulas directly and made errors when converting mixed fractions. In the posttest, the student converted mixed fractions into ordinary fractions and calculated step by step to obtain the correct answer.

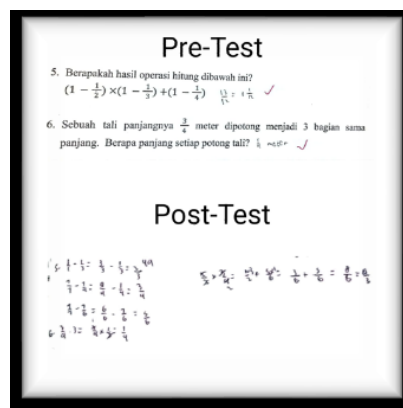


Figure 5. Example of student work, analysis indicator (pretest and posttest)

Figure 6 presents work on the evaluation indicator. In the pretest, the student made calculation errors and did not recheck the result. In the posttest, the student calculated more carefully and obtained correct answers, although the checking remained limited to the final result.

Pre-Test

$$2.) \frac{1}{4} + \frac{2}{5} = \frac{5+8}{20} = \frac{13}{20} \rightarrow \frac{20}{20} - \frac{13}{20} = \frac{7}{20} \checkmark$$

$$3.) 1 \cdot 2 \times \frac{1}{2} = 4 \times \frac{1}{2} = \frac{4}{2} = 2 \checkmark$$

Post-Test

$$2.) \frac{1}{3} + \frac{2}{5} = \frac{5+6}{15} = \frac{11}{15} \rightarrow \frac{15}{15} - \frac{11}{15} = \frac{4}{15} \checkmark$$

$$5.) 5 \times \frac{1}{2} \times 2 \times \frac{1}{4} = \frac{5}{2} \times \frac{1}{2} = \frac{5}{4} \checkmark$$

Figure 6. Example of student work, evaluation indicator (pretest and posttest)

Figure 7 presents work on the inference indicator. In the pretest, the student solved the problem partially and did not draw an appropriate conclusion. In the posttest, the student arranged the solution steps sequentially and reached the correct final result, with a conclusion that remained simple.

Pre-Test

$$5.) \frac{1}{2} \times \frac{2}{3} + \frac{2}{6} + \frac{3}{4} = \frac{8+18}{24} = \frac{26}{24} = 1 \frac{1}{6} \checkmark$$

$$6.) \frac{3}{4} : \frac{1}{3} = \frac{3}{4} \times \frac{3}{1} = \frac{9}{4} \checkmark$$

Post-Test

$$5.) \frac{1}{2} \times \frac{2}{3} = \frac{1}{3}$$

$$\frac{1}{3} + \frac{2}{6} = \frac{2}{6} + \frac{2}{6} = \frac{4}{6} = \frac{2}{3}$$

$$\frac{2}{3} + \frac{3}{4} = \frac{8}{12} + \frac{9}{12} = \frac{17}{12} = 1 \frac{5}{12} \checkmark$$

$$6.) \frac{3}{4} : \frac{1}{3} = \frac{3}{4} \times \frac{3}{1} = \frac{9}{4} \checkmark$$

Figure 7. Example of student work, inference indicator (pretest and posttest)

DISCUSSION

The mean N-Gain varied across indicators, with interpretation in the moderate category and analysis, evaluation, and inference in the low category. The following discussion relates these findings to previous research and considers their implications. Given the single-group design and ten participants, the interpretations remain tentative.

Interpretation

Interpretation was the indicator with the largest gain, with a mean N-Gain of 0.35 and eight of ten students in the moderate category. The work sample of a student who answered directly in the pretest and wrote systematic steps in the posttest illustrates this change. Interpretation concerns identifying and representing the information given in a problem, and a possible explanation is that the learning activities directed students' attention to the problem statement before solving. Points and leaderboard rankings gave students a reason to attempt each task carefully, and explaining solution procedures to peers required them to state what the problem asked. This explanation remains inferential, since student behavior during the activities was not recorded.

The pattern is compatible with evidence on gamification at the primary level. Romero-Rodríguez et al. (2024) reported positive effects of gamification on engagement, motivation, and self-efficacy in primary education, and Dehghanzadeh et al. (2024) described motivation, engagement, and competitiveness as the main routes through which gamification supports K-12 learning outcomes. Higher engagement could be associated with more attentive reading of problem statements. Fraga-Varela et al. (2021) observed significant improvement in mathematics fluency among 284 primary students who used serious games, and Kärki et al. (2022) observed a small positive effect of a digital game on rational number conceptual knowledge among fifth and sixth graders. These studies examined different outcomes, designs, and tools, so the comparison indicates only that gains in mathematical performance after game-based learning have been reported at this educational level. Alternative explanations remain plausible for the present result. Marsden and Torgerson (2012) discussed regression to the mean, maturation, history, and test effects as sources of change in single-group designs, and the similarity of the pretest and posttest forms may have contributed to the gain. For classroom practice, teachers who use gamified tasks in fraction lessons could ask students to restate the given information and the question before points are awarded, which gives the interpretation step explicit attention.

Analysis

Analysis had a mean N-Gain of 0.24 in the low category, and four of ten students reached the moderate category. Student work showed corrected conversion of mixed fractions in the posttest, which indicates improvement in a specific solution step. Analysis as

measured in this study also involves examining relationships among the parts of a problem. Siegler et al. (2013) reported that learning fractions requires recognizing that properties of whole numbers do not always apply, and Siegler et al. (2011) placed understanding of numerical magnitudes at the center of whole number and fraction development. Conceptual relationships of this kind may need sustained instruction, and a short gamified sequence may provide limited time for it.

Different patterns have been reported for learning outcomes in gamification research. Romero-Rodríguez et al. (2024) described mixed outcomes for learning results in primary education, and Sailer and Homner (2020) found that the effect on cognitive outcomes was stable in high-rigor studies, with effects on motivational and behavioral outcomes less stable. These findings should be interpreted in relation to differences in outcome definitions, because the cognitive outcomes in those syntheses were broader than indicator-level critical thinking. Kärki et al. (2022) observed a small effect on rational number conceptual knowledge, which is in the same direction as the low analysis gain observed here, although the outcome measures differ. The pattern suggests that gamified practice may support procedural steps in the short term, while gains in analysis may require longer or more targeted instruction. This interpretation cannot be tested with the present design. In practice, gamified activities could be combined with tasks that ask students to map the components of a problem and to represent fraction magnitudes, which Siegler et al. (2013) discussed as central to fraction understanding. Whether such combinations raise analysis gains requires empirical testing.

Evaluation

Evaluation had a mean N-Gain of 0.26 in the low category. Six of ten students individually reached the moderate category, and the standard deviation of 0.14 indicates variation among students. In the posttest work sample, the student calculated more carefully, and the checking remained limited to the accuracy of the final result. Peer teaching and peer feedback were intended to give students occasions to check answers and reasons. The quality of peer feedback was not assessed, and the variation among students may be associated with differences in the feedback they gave and received.

Hattie and Timperley (2007) concluded that feedback is among the major influences on learning, that its effect can be positive or negative, and that the type of feedback and the way it is given matter. Abrami et al. (2015) associated dialogue and

mentoring with positive effects on critical thinking skills, and Alegre et al. (2019) synthesized research on peer tutoring in primary mathematics, which shows that this format has been studied at the level examined here. Findings on rewards provide additional context. Hanus and Fox (2015) reported negative effects of gamification elements on motivation and satisfaction in a university course, and Deci et al. (1999) reported across 128 studies that tangible rewards undermined intrinsic motivation, that this effect tended to be stronger for children than for college students, and that positive feedback enhanced interest. These studies involve different populations and designs, so they inform the careful design of rewards without directly predicting the present results. If rankings and rewards attract attention to the final answer, students may check mainly the accuracy of the result, although the data do not allow this to be determined. Peer feedback could therefore be structured with criteria that ask for evidence, such as a checklist for verifying each step, and simple rewards could be accompanied by informational verbal feedback.

Inference

Inference had the lowest mean N-Gain (0.15), and three students (S2, S4, and S9) had an N-Gain of 0.0. Student work showed solution steps arranged sequentially in the posttest with conclusions that remained simple. Inference requires combining information and formulating a conclusion about the problem, and arranging steps in order can lead to a correct final result without an explicit conclusion. The intervention description includes no activity directed specifically at formulating written conclusions, which may be associated with the small gain.

Abrami et al. (2015) include explanations of the considerations behind a judgment in their description of critical thinking, which links inference to the justification of conclusions. Hamari et al. (2016) found that game challenge was a strong predictor of learning outcomes and recommended that challenge keep pace with learners' growing abilities, so the level of demand in the gamified tasks may be associated with the low inference gain. Wang and Tahir (2020) concluded that Kahoot! can have positive effects on learning performance while some studies reported little or no effect, which indicates that outcomes depend on task design and context. Task demand and reflection time were not measured here, so these explanations remain tentative. Tasks could include prompts

that ask students to write a concluding statement linking the answer to the problem context, and the lesson schedule could allow time for this step.

Overall Interpretation

The combined mean N-Gain of 0.25 falls in the low category, and gains were distributed unevenly across indicators. N-Gain values cannot be compared directly with the Hedges' g values reported in meta-analyses (Bai et al., 2020; Li et al., 2023; Sailer & Homner, 2020), because the metrics differ and the present study had no comparison group. From the perspective of self-determination theory, Ryan and Deci (2000) identified competence, autonomy, and relatedness as psychological needs that support self-motivation. Feedback within gamified tasks and peer activities could relate to competence and relatedness, although motivation was not measured in this study. Taken together, the results suggest that gamified fraction lessons may need complementary activities such as reflective discussion, problem mapping, and written conclusions to support analysis, evaluation, and inference.

Limitations and Directions for Future Research

The design had one group, so changes cannot be attributed to the intervention. The sample comprised ten students from one school, which limits generalization, and no inferential test was applied. Only four of Facione's six indicators were measured, so the findings say nothing about explanation and self-regulation. Using equivalent test forms may have contributed to test effects. Future studies should include comparison groups, larger and more diverse samples, validated instruments with reported reliability, and measures of motivation and peer feedback quality. Designs that add reflection and conclusion-drawing activities to gamified fraction lessons can then be compared with gamification alone.

CONCLUSION

This study described changes in the mathematical critical thinking ability of ten sixth-grade students on fraction material following gamification-based learning. The combined mean N-Gain was 0.25 (low category). Interpretation showed the highest gain (0.35, moderate), and evaluation (0.26), analysis (0.24), and inference (0.15) remained in the low category. These results describe uneven gains across indicators. Because the design had no comparison group and a small sample, the findings are exploratory and indicate where gamification-based fraction lessons may need additional support, particularly for

analysis, evaluation, and inference. Teachers may consider combining gamified tasks with structured peer feedback criteria, problem-mapping tasks, and prompts for written conclusions. Comparative studies with larger samples are needed to test whether these combinations strengthen the indicators that showed smaller gains.

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