Mathematics Achievement Before and After Game-Based English-Medium Instruction for Bilingual Elementary Learners

Sri Yulianti[1], Jamshid Husain[2*], Desi Surlitasari Dewi[3]

[1]Universitas Islam Ogan Komering Ilir Kayuagung, Kayuagung, Indonesia
[2]Yuan Ze University, Taoyuan City, Taiwan
[3]Universitas Riau Kepulauan, Batam, Indonesia
*Email: hussainamshid13@gmail.com (corresponding author)

ABSTRACT

Teaching mathematics through English can broaden elementary learners' exposure to academic language, but it can also increase linguistic demands when instruction is insufficiently scaffolded. This study examined whether mathematics achievement differed before and after a six-session game-based English-medium instructional period. A quantitative pre-experimental one-group pretest–posttest design was used with 30 fifth-grade students at a bilingual elementary school in South Sumatra, Indonesia. The intervention, Fraction Mission, comprised six 70-minute fraction lessons that combined board movement, visual fraction models, collaborative challenge cards, immediate feedback, recurring English sentence frames, and limited Indonesian scaffolding. Mathematics achievement was measured with a 25-item test comprising 20 multiple-choice and five short-response items. The posttest mean ($M = 74.33$, $SD = 11.41$) was higher than the pretest mean ($M = 62.37$, $SD = 8.37$). A paired-samples t-test showed a statistically significant difference, $t(29) = 7.36$, $p < .001$, 95% CI (8.65, 15.28), Cohen's $d_z = 1.34$. The results indicate higher mathematics achievement after the instructional period; however, the one-group design does not establish causality. The study offers a low-technology approach for integrating mathematical reasoning and usable academic English in bilingual elementary classrooms.

Keywords: *bilingual elementary education; English-medium instruction; game-based learning; mathematics achievement; paired-samples t-test*

INTRODUCTION

Mathematics in elementary education requires learners to coordinate concepts, symbols, visual representations, procedures, and increasingly specialized language. In bilingual schools, this coordination becomes more demanding because students are expected to develop mathematical understanding while following instructions, discussing strategies, and interpreting word problems through English. English-medium instruction (EMI) may provide meaningful exposure to academic English, yet English proficiency can also shape how easily learners access subject content. Research on bilingual mathematical thinking shows that the language of instruction influences the representation and communication of mathematical ideas, particularly during the first years of bilingual schooling (Bermejo et al., 2021). In Indonesia, primary-school teachers and pupils have likewise reported that EMI offers opportunities for language development but may create difficulties when vocabulary, teacher explanations, or classroom interaction are not sufficiently scaffolded (Ernawati et al., 2021). Therefore, the instructional issue is not simply whether English is used, but how English is integrated with mathematical reasoning in an age-appropriate way.

EMI is commonly distinguished from an English language lesson because the principal learning objective remains disciplinary content. In mathematics, however, content and language are closely connected. Learners must understand relational expressions such as greater than, equivalent to, divided by, and how many remain, as well as the grammatical patterns used to explain procedures and justify answers. Studies of multilingual mathematics classrooms indicate that successful instruction makes mathematical language visible, provides multiple representations, and creates structured opportunities for learners to talk through their reasoning (Sharma & Sharma, 2023). Language-responsive teaching can benefit students with different linguistic backgrounds when teachers deliberately connect symbols, visual models, everyday wording, and formal mathematical expressions (Prediger & Neugebauer, 2022). Translanguaging research also suggests that strategically drawing on learners' full linguistic resources can support participation and conceptual access in English-medium science and mathematics classrooms without abandoning the long-term goal of English development (Tai, 2022).

The need for careful scaffolding is especially important for elementary learners. Integrated mathematics-and-English instruction may be effective when learners possess adequate language expertise, but the additional linguistic processing can produce unnecessary cognitive load for students with lower English proficiency (Jiang et al., 2023). In practical terms, long explanations, unfamiliar word problems, and rapid teacher talk can consume attention that should be directed toward mathematical relationships. Indonesian work on Content and Language Integrated Learning (CLIL) in elementary mathematics similarly emphasizes the importance of selecting appropriate teaching techniques, duration, visual support, and language adjustment (Amiroh et al., 2020). These findings imply that an effective EMI mathematics lesson should reduce avoidable language difficulty while preserving cognitively meaningful mathematical activity. Short commands, repeated sentence frames, demonstrations, manipulatives, peer interaction, and selective first-language clarification can create this balance.

Game-based learning (GBL) offers one possible way to organize such instruction. GBL refers to learning environments in which the rules, goals, challenges, feedback, and actions of a game are meaningfully connected to the intended learning content rather than added as decorative rewards (Plass et al., 2015). Games can provide repeated practice, immediate information about success, visible progress, and opportunities to test strategies in a low-risk setting. Meta-analytic evidence has generally shown positive effects of game-based approaches on mathematics achievement, although outcomes vary according to game design, duration, age, comparison conditions, and the alignment between mechanics and learning goals (Byun & Joung, 2018; Tokac et al., 2019). More recent reviews indicate that mathematics games can affect both cognitive outcomes and affective factors such as enjoyment, motivation, engagement, and willingness to participate (Hui & Mahmud, 2023; Vankúš, 2021).

Primary mathematics studies illustrate several mechanisms behind these outcomes. Adaptive game-based applications can personalize task difficulty and provide frequent opportunities to respond, producing measurable gains among early elementary learners (Bang et al., 2023). Digital games using number lines and rational-number operations can support the development of conceptual connections when game actions embody the mathematical relationships being learned (Kärki et al., 2022; McMullen et al., 2024). Play-based mathematics programs have also improved achievement in resource-constrained elementary settings when teachers were trained to guide purposeful play (Murtagh et al., 2022). At the same time, the presence of a game does not automatically produce learning. Systematic reviews of primary mathematics GBL emphasize that teacher facilitation, suitable challenge, curricular alignment, and opportunities for reflection remain essential (Dan et al., 2024; Debrenti, 2024; Erşen & Ergül, 2022). Teacher scaffolding before, during, and after gameplay can shape students' understanding of the mathematical content and their perceptions of the learning experience (Sun et al., 2021).

Taken together, the literature reveals a three-part gap. Primary mathematics game-based learning studies have mainly examined mathematics outcomes and game design, often without treating the language of instruction as a central instructional variable (Bang et al., 2023; Dan et al., 2024; Tokac et al., 2019). Research on EMI, CLIL, and multilingual mathematics has clarified linguistic demands, language-responsive teaching, cognitive load, and translanguaging, but has less often evaluated a structured game sequence through a mathematics achievement outcome (Amiroh et al., 2020; Ernawati et al., 2021; Jiang et al., 2023; Tai, 2022). In Indonesia, studies have described EMI or CLIL practices and contextual challenges, yet evidence remains limited for low-technology, non-digital games that integrate recurring English commands, visual fraction representations, collaborative reasoning, immediate feedback, and selective Indonesian scaffolding in a bilingual elementary mathematics classroom (Norhasanah & Setiawan, 2023). The present study addresses this instructional and contextual gap through an initial within-group evaluation.

The present study examined a teacher-designed, non-digital game sequence for fifth-grade fraction learning in an Indonesian bilingual elementary classroom. Fraction Mission integrated mathematical actions with recurring English commands, visual models, collaborative explanation, immediate feedback, and limited Indonesian clarification. The research question was: Is there a statistically significant difference between students' mathematics achievement before and after game-based English-medium mathematics instruction? The null hypothesis stated that the mean pretest and posttest scores would not differ significantly, whereas the alternative hypothesis predicted a significant pre-post difference. Because the study used a one-group pretest-posttest design, the analysis identified within-group change and was not intended to establish a definitive causal effect.

METHOD

Research Design

The study employed a quantitative pre-experimental one-group pretest–posttest design. One intact class completed a mathematics achievement pretest, participated in six game-based EMI lessons, and completed a parallel posttest. This design was selected as an initial classroom evaluation because the school could provide only one bilingual class at the relevant grade level during the implementation period. The design permitted examination of score change within the same participants, but it did not control for history, maturation, testing, or other alternative explanations. Accordingly, the statistical findings were interpreted as evidence of improvement associated with the instructional period rather than proof that the intervention alone caused the improvement (Creswell & Creswell, 2018).

Participants and Setting

The study involved 30 fifth-grade students enrolled in one bilingual elementary class in South Sumatra, Indonesia. In this study, bilingual refers to a school program in which English was used in classroom routines and selected content subjects, while Indonesian remained the dominant language for everyday communication. The students were approximately 10–11 years old and had received English exposure through classroom routines and selected content subjects since the lower grades. The class was selected through convenience sampling because it was accessible to the researchers and was scheduled to study fractions during the research period. All enrolled students completed the pretest, intervention, and posttest and were included in the paired analysis.

Table 1

Participant characteristics

Characteristic	Category	n (%)
Gender	Girls	16 (53.3)
	Boys	14 (46.7)
Age	10 years	18 (60.0)
	11 years	12 (40.0)

Note. Percentages are based on N = 30.

Instructional Intervention

The intervention was titled Fraction Mission and was designed as a sequence of face-to-face, non-digital games. Non-digital materials were selected so that interaction, mathematical explanation, and teacher observation remained central and so that the approach could be implemented without one device per student. The learning objectives covered recognizing fraction representations, generating equivalent fractions, comparing fractions, adding and subtracting fractions with related denominators, and solving short contextual problems. English was the principal language for opening routines, rules, challenge cards, feedback phrases, and student sentence frames. Indonesian was used briefly when a key misconception or rule could not be resolved through demonstration, visuals, repetition, or peer explanation. This flexible support was intended to preserve access to mathematical meaning while maintaining substantial English use, consistent with inclusive translanguaging principles in EMI classrooms (Tai, 2022).

Students worked in six teams of five. Each team used a board with numbered spaces, fraction tiles, number-line strips, English challenge cards, a die, counters, and a score sheet. To move, a team drew a card, solved the task collaboratively, and presented an answer using a sentence frame such as "The fractions are equivalent because ...," "___ is greater than ___," or "First, we make the denominators the same." Correct solutions allowed the team to move and collect a mission badge; partially correct answers triggered a hint or visual model; and incorrect answers returned the card to the deck for later retrieval. The mechanics were aligned with the learning objectives: movement depended on mathematical decisions, visual tools represented fraction magnitude, and rewards followed accurate reasoning rather than speed alone (Plass et al., 2015).

Table 2
Sequence of the game-based EMI mathematics intervention

Session	Mathematics focus	Core game activity	Target English language
1	Fraction representations	Match cards to fraction tiles and shaded models	numerator, denominator, part, whole
2	Equivalent fractions	Build equivalent pairs to unlock board routes	equivalent to; multiply both by
3	Comparing fractions	Place cards on a number line and defend the order	greater than; less than; closer to
4	Addition of fractions	Combine visual pieces and complete mission cards	add; common denominator; sum
5	Subtraction of fractions	Solve "remaining part" challenges	subtract; difference; remaining
6	Word problems and review	Team quest integrating all skills	first, next, because, therefore

Each 70-minute lesson followed a stable structure: a 10-minute language-and-concept warm-up, a 10-minute teacher demonstration, 35 minutes of gameplay, a 10-minute whole-class debrief, and a 5-minute exit task. Stable routines reduced the need to learn new rules in every meeting and allowed students to focus increasingly on mathematics and English explanation. During gameplay, the teacher circulated, asked short probing questions, modeled pronunciation only when it affected comprehensibility, and redirected teams from guessing toward the visual models. The debrief connected game experiences to formal notation so that successful moves were not left as isolated play. The sequence followed evidence that primary GBL is most productive when teacher guidance, reflection, and curricular consolidation accompany the game (Dan et al., 2024; Sun et al., 2021).

Implementation Fidelity

Implementation fidelity was monitored through a checklist covering six planned components: the language-and-concept warm-up, teacher modelling, use of target English routines, use of visual or manipulative supports, completion of the core game mechanics with feedback, and the whole-class debrief. The checklist documented whether these components were implemented during the six-session instructional sequence and provided a structured record of the intervention procedures.

Instrument

Mathematics achievement was measured with a 25-item test comprising 20 multiple-choice items and five short-response items. Items represented fraction identification, equivalence, comparison, operations, and contextual problem solving. The two forms followed the same blueprint, while item order and numerical values were changed to reduce direct recall. Directions were written in concise English and supported by familiar symbols or diagrams; a short English–Indonesian glossary was available for non-target procedural terms. Each multiple-choice item was worth 3 points, giving a total of 60 points. Each short-response item was worth 4 points: 2 points for a correct mathematical answer and 2 points for an acceptable representation or explanation, giving a total of 20 points. Raw scores therefore ranged from 0 to 80 and were converted to a percentage using (raw score / 80) × 100.

Content validity was evaluated by two elementary mathematics educators and one English education specialist. The validators examined curriculum alignment, mathematical accuracy, clarity of English, age appropriateness, and equivalence of the pretest and posttest forms. The overall Aiken's V coefficient was .89. A pilot administration with 28 students outside the research class yielded a KR-20 reliability coefficient of .84 for the objective items, while agreement between two raters on the short-response scoring reached .90. These results indicated acceptable content validity and reliability for classroom achievement measurement.

Data Collection Procedures

Data collection proceeded chronologically. Before data collection, authorization was obtained from the participating school, and written parental or guardian consent and student assent were secured. Participation was voluntary, students could withdraw without academic penalty, and research scores did not affect school grades. The pretest was administered for 45 minutes under standardized classroom conditions. The classroom teacher then implemented six Fraction Mission lessons over three weeks using lesson plans and materials prepared with the researchers. The posttest was administered within three school days after the final session. Test sheets were coded with participant numbers so that pretest and posttest scores could be paired without using students' names in the analysis.

Data Analysis Techniques

The analysis used descriptive statistics and a paired-samples t-test. Means, standard deviations, minima, maxima, and paired score differences described achievement before and after the instructional period. Before hypothesis testing, the distribution of difference scores was assessed with the Shapiro-Wilk test and visual inspection for extreme outliers. Statistical significance was evaluated at alpha = .05 using a two-tailed test. The mean difference was reported with a 95% confidence interval. Cohen's dz was calculated by dividing the mean paired difference by the standard deviation of the difference scores and was interpreted as a standardized within-participant difference (Lakens, 2013).

RESULTS

All 30 students had complete paired scores. Table 3 presents the descriptive statistics. The pretest mean was 62.37 (SD = 8.37), the posttest mean was 74.33 (SD = 11.41), and the mean increase was 11.97 points. Because the study focused on paired change, the inferential analysis used each student's posttest–pretest difference rather than treating the two score distributions as independent samples.

Table 3

Descriptive statistics for mathematics achievement scores

Measure	n	Minimum	Maximum	M	SD
Pretest	30	41	80	62.37	8.37
Posttest	30	53	100	74.33	11.41
Difference	30	−3	30	11.97	8.91

Note. Scores are reported on a 0–100 scale.

The Shapiro–Wilk test of the 30 difference scores was non-significant, W = .971, p = .570, and visual inspection did not identify an extreme outlier. The normality assumption was therefore considered acceptable, and the paired-samples t-test was retained. The estimated mean difference was 11.97 points, with a 95% confidence interval from 8.65 to 15.28 points.

Table 4

Paired-samples t-test for pretest and posttest mathematics achievement

Comparison	Mean difference	SD difference	95% CI	t(df)	p	Cohen's dz
Posttest - pretest	11.97	8.91	[8.65, 15.28]	7.36 (29)	< .001	1.34

Note. CI = confidence interval; dz = standardized mean paired difference.

The paired-samples t-test showed a statistically significant pretest–posttest difference, t(29) = 7.36, p < .001, mean difference = 11.97, 95% CI (8.65, 15.28), Cohen's dz = 1.34. The positive confidence interval indicates that the mean posttest score was higher than the mean pretest score. The result supports a pretest–posttest association after the game-based English-medium instructional period. However, the absence of a comparison group prevents the analysis from separating the instructional contribution from maturation, repeated testing, ordinary classroom progress, or other concurrent influences.

DISCUSSION

The study examined whether bilingual elementary students' mathematics achievement differed before and after six game-based lessons delivered primarily through English. The paired analysis indicated higher posttest achievement and a large standardized within-participant difference. This pretest–posttest pattern is consistent with broader evidence that well-designed game-based mathematics instruction can support learning outcomes when challenge, feedback, repeated action, and game mechanics are aligned with mathematical ideas (Bang et al., 2023; Byun & Joung, 2018; Dan et al., 2024; Debrenti, 2024; Tokac et al., 2019). The distinctive contribution of the present design is its combination of these features with an EMI context in which English functioned as the main instructional language rather than as a separate subject.

A plausible instructional explanation is the density of meaningful mathematical practice built into the game cycle. Each move required teams to interpret a task, inspect or manipulate a representation, agree on a solution, state a response, and receive immediate feedback. Incorrect or incomplete cards returned to the deck, creating repeated retrieval within a lesson. Because the study measured achievement rather than learning processes, this mechanism should be understood as an intended design feature and a possible explanation, not as an empirically tested mediator. Similar design principles appear in rational-number games in which number-line movement and arithmetic choices are embedded in game actions rather than presented as unrelated exercises (Kärki et al., 2022; McMullen et al., 2024).

The collaborative structure may also have reduced individual speaking pressure and created opportunities to rehearse short mathematical explanations with peers before a public response. Recurrent sentence frames such as "___ is greater than ___ because ..." narrowed the language demand while preserving reasoning. This interpretation is consistent with language-responsive mathematics instruction, which coordinates academic language, multiple representations, and structured discourse (Prediger & Neugebauer, 2022; Sharma & Sharma, 2023). However, participation, speaking pressure, collaboration quality, and English hesitation were not measured in this study. They therefore remain plausible mechanisms for future observation rather than demonstrated outcomes of the achievement analysis.

Visual and material supports may have reduced some of the additional processing demands associated with EMI. Fraction tiles, shaded models, and number lines provided non-verbal access to magnitude and equivalence while the instructional sequence recycled English terms such as denominator, equivalent, and greater than. This multimodal alignment was intended to prevent unfamiliar English from blocking access to a challenging mathematical concept. The interpretation is consistent with evidence that the language of instruction shapes mathematical meaning-making and that integrated language-and-mathematics learning interacts with learners' existing language expertise (Bermejo et al., 2021; Jiang et al., 2023). Because process measures were not collected, the present study cannot quantify how strongly each support contributed to the score change.

The instructional protocol permitted brief Indonesian clarification when visual demonstration, peer explanation, and simplified English did not resolve a key misconception or rule. The teacher then returned to English and elicited the final response through the target sentence frames. This procedure reflects translanguaging as a temporary resource for conceptual access rather than a rejection of EMI (Tai, 2022). Because the achievement analysis did not measure the frequency, timing, or direct effect of Indonesian use, selective first-language support is interpreted as part of the intervention design rather than as a measured causal mechanism.

The design also responds to Indonesian evidence that EMI and CLIL implementation depends on teacher strategies and contextual adaptation. Primary-school participants have valued English-medium learning while also reporting comprehension and interaction difficulties (Ernawati et al., 2021), and Indonesian CLIL research has emphasized the importance of locally appropriate teaching practices (Norhasanah & Setiawan, 2023). Fraction Mission represents one possible adaptation: predictable rules recycle a limited language set, cards make commands visible, visual models connect words with quantities, and feedback is attached to mathematical action. The pedagogical contribution is therefore not merely that the activity is entertaining, but that the game structure can organize content and language demands around purposeful mathematical tasks.

The effect size should nevertheless be interpreted cautiously. Controlled and large-sample studies sometimes report smaller effects than the Cohen's dz value found in this study. Differences may reflect initial achievement, intervention length, test similarity, sample size, and whether an effect is estimated within one group or between treatment and comparison groups (Bang et al., 2023; Kärki et al., 2022). A one-group standardized difference may include repeated-testing effects, normal classroom progress, and measurement error. It should therefore not be treated as an estimate of the intervention's causal impact.

A further implementation issue is the possibility of unequal participation within teams. Confident students may dominate calculations or English explanations unless roles and individual accountability are deliberately structured. Future implementations should document role allocation and rotation, monitor whether every learner manipulates representations and speaks, and collect process evidence such as observation ratings, turn counts, or brief interaction samples. This recommendation is consistent with evidence that teacher scaffolding and alignment among objectives, process, resources, teacher capacity, and evaluation shape game-based learning experiences (Pan et al., 2021; Sun et al., 2021).

The study has practical implications for bilingual elementary schools. First, teachers can use game-based EMI without expensive technology. A board, cards, counters, and reusable manipulatives can support repeated language and mathematics practice. Second, English demands should be planned as carefully as mathematical difficulty. Teachers should identify a small set of target terms and sentence frames for each lesson, demonstrate them through visuals, and recycle them during the game and debrief. Third, rewards should follow mathematical reasoning, collaboration, and explanation rather than speed alone. Speed-based competition may disadvantage learners who need more time to process English. Fourth, post-game reflection is essential. Students should translate game actions into formal notation, compare strategies, and explain errors so that play develops transferable knowledge rather than context-bound success.

Rather than empirically demonstrating a content-language mechanism, the study offers a design proposition at the intersection of game-based learning and language-responsive mathematics instruction. GBL frameworks explain how challenge, feedback, representation, and goal-directed action can structure learning (Plass et al., 2015), whereas EMI and multilingual mathematics research explains how language mediates access to disciplinary concepts (Macaro et al., 2018; Sharma & Sharma, 2023). The resulting proposition is that game mechanics in bilingual mathematics should simultaneously require mathematical reasoning and make a limited set of academic English usable. Future studies can test this proposition by measuring English participation, representation use, feedback uptake, role distribution, mathematics achievement, and language development together.

Several limitations restrict the conclusions. The pre-experimental design lacked a comparison group and random assignment, so causal claims are not warranted. The small convenience sample from one class limits generalizability. The intervention lasted only six lessons and did not include a delayed posttest, so retention is unknown. Mathematics achievement was the only measured outcome; English mathematical vocabulary, speaking confidence, motivation, anxiety, participation, and implementation processes were not assessed directly. The classroom teacher implemented the intervention, which may introduce expectancy effects. Future research should include comparable classes, implementation-fidelity evidence, parallel test forms, baseline language information, delayed measurement, and complementary process data.

CONCLUSION

This study examined mathematics achievement before and after a six-session game-based English-medium mathematics sequence for bilingual fifth-grade learners. The paired analysis indicated higher achievement after the instructional period, but the one-group design does not establish that Fraction Mission caused the difference. The intervention offers a practical, low-technology model in which mathematical actions, visual representations, recurring English sentence frames, collaborative problem solving, and limited first-language scaffolding are integrated within the game rules. The findings are limited by the small single-class sample, short duration, absence of a comparison group, and lack of separate language and process measures. Controlled studies with delayed posttests and combined mathematics-language outcomes are needed.

ACKNOWLEDGEMENTS

The authors thank the participating school, classroom teacher, students, and expert validators for their contributions to the study.

FUNDING STATEMENT

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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