

The effect of the game-based learning model based on bar diagram board medium on students' mathematical representation ability

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Abstract

Students' ability to represent mathematical concepts verbally, visually, and symbolically is a crucial skill in learning mathematics, as it supports understanding and the meaningful expression of mathematical ideas. Observations and interviews at SDN 2 Ngantru showed that, out of 38 students, only 6 (15.79%) met the minimum competency achievement criteria (KKTP), indicating the need for a learning model capable of fostering student engagement, one of which is Game-Based Learning supported by a bar-diagram board medium. This study aims to determine the effect of the Game-Based Learning model, using a bar-diagram board medium, on the mathematical representation ability of fourth-grade elementary school students. Using a quantitative approach with a quasi-experimental Non-Equivalent Control Group Design, the study involved 50 fourth-grade students at SDN 2 Ngantru, selected through saturated sampling, comprising 25 students from class IV-A (control group) and 25 from class IV-B (experimental group). Data were collected through tests, observation, and questionnaires. The data analysis technique used prerequisite tests (normality and homogeneity), an Analysis of Covariance (ANCOVA) with the pretest score as a covariate to control for initial ability differences between groups, an Independent Samples t-test as a complementary analysis, and an N-Gain effectiveness test. The ANCOVA results showed a statistically significant difference in posttest scores between groups after controlling for the pretest score ($F = 48.156$; $p < 0.001$; partial eta squared = 0.506), consistent with the hypothesis test results (significance value of $0.001 < 0.05$) indicating that the null hypothesis was rejected. The experimental class's average posttest score of 83.36 was higher than the control class's 76.48, with an N-Gain of 60.18% (fairly effective) for the experimental class and 41.83% (less effective) for the control class.

Keywords: Bar Diagram Board Medium; Game Based Learning; Mathematical Representation Ability

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INTRODUCTION

As one of the core subjects in schools, mathematics makes a substantial contribution to training students to think actively, analytically, and logically (Oktaviani et al., 2023). The standard process of mathematics learning ideally comprises five core competencies: problem solving, reasoning and proof, communication, connection, and representation (NCTM, 2000). One competency that receives particular attention is mathematical representation ability, that is, the way students express their understanding of a problem in order to find an appropriate solution, which can be represented through objects, pictures, words, or mathematical symbols (Hafriani, 2021); this ability therefore functions

both as a tool for thinking and as a means of communication in mathematics learning (Sihombing et al., 2024). Mathematical representation ability comprises three main indicators: (1) verbal representation, namely the ability to express a problem through spoken or written explanation; (2) visual representation, namely the ability to depict or present information from a problem in a table or diagram; and (3) symbolic representation, namely the ability to express a problem through symbols, models, or mathematical equations (Saputri & Faiziyah, 2023). These three indicators play an important role when students study data analysis and probability, particularly in presenting data, reading and interpreting information in tables, diagrams, or text, and converting data into various appropriate mathematical forms (Paseh & Firmansyah, 2019).

However, field conditions indicate that students' ability to represent mathematics remains relatively low. The 2022 PISA results recorded that Indonesian students' mathematics scores reached only 366, well below the international average of 472 (Putri et al., 2025). This finding is consistent with Hanifah et al. (2021), who reported that students' mathematical representation ability reached only 11.5% due to the ineffectiveness of the learning models and methods applied. A similar result was reported by Handayani & Juanda (2018), who found that the mathematical representation ability of elementary school students in North Sumedang District reached only 24.9%, categorized as very low, caused by students' tendency to merely imitate the teacher's method of solving problems without being given the opportunity to express their own ideas. This condition was also found in the preliminary study conducted in classes IV-A and IV-B of SDN 2 Ngantru: of 38 students, only 6 (15.79%) met the minimum competency criteria (KKTP), while the remaining 32 (84.21%) did not, as reflected in students' difficulties explaining information shown in diagrams, completing diagrams, presenting data in diagram form, and calculating data values, differences, and totals across categories. Interviews with the classroom teachers from both schools reinforced this finding: although students could already perform calculations, they had not yet been able to explain the information in bar diagrams or construct bar diagrams independently. Teachers had implemented group-based instruction, but had not applied more varied learning models, while the media used remained limited to simple teaching aids such as pictures, PowerPoint, and the whiteboard.

This condition illustrates a considerable gap between the level of mathematical representation ability students should ideally possess and the reality observed in the field. Piaget, in his theory of cognitive development, explains that the concrete operational stage occurs between the ages of 6 and 12 (Juwantara, 2019); accordingly, fourth-grade students, generally aged 9-10 years, should be able to represent mathematical ideas reasonably well visually, symbolically, and verbally. Given this problem, an effective learning model is needed, one that offers a meaningful and enjoyable learning experience while encouraging student engagement. Active learning models are considered relevant for classroom implementation because they enable students to construct their own understanding directly (Ramdini et al., 2024). Game based learning is one such relevant option, a model that positions students as the center of learning activity, using game elements to enhance the effectiveness of the learning process, content delivery, concept mastery, and the evaluation of learning outcomes (Indriani et al., 2025). This model is characterized by clear learning objectives, game rules, engaging challenges, and immediate feedback. Optimizing its implementation requires learning media that help students express mathematical ideas in various forms of representation while fostering interest in learning, thereby making learning more appealing (Nurrita, 2018). Media essentially serve as a means of achieving learning objectives, simplifying content delivery, and encouraging instructional innovation, with the aim of increasing students' interest in learning (Amalia et al., 2024). In this study, the medium used was a bar diagram board, chosen because it helps students understand and organize information visually, turning what was once abstract into something more concrete and easier to grasp (Mardhiyana et al., 2025), offering advantages such as: (1) presenting data visually to facilitate students' understanding; (2) helping students convert data into bar diagram form; (3) supporting students' ability to read and interpret data; and (4) increasing student engagement in learning owing to its concrete and user-friendly nature.

Conceptually, game based learning can be understood as a model that integrates game elements into learning activities to boost engagement, motivation, and understanding of the learning material, with the game serving as the primary medium for conveying concepts and training students' thinking skills. Implementing this model makes the classroom atmosphere livelier and more enjoyable, encouraging greater student participation; this is consistent with the view that games, whether online, interactive

activities involving real objects, or group activities, can increase students' interest in learning and motivation (Septiani, 2025). The bar diagram board medium, meanwhile, is a learning tool used to help present and compare data visually, with the data displayed as neatly arranged rectangular or block-shaped bars (Mardhiyana et al., 2025). The presence of this medium encourages students to actively search for, process, and convey information applied directly to the bar diagram board. Thus, the combination of game elements and the concrete, manipulative bar diagram board medium complements one another: the game sustains students' motivation and active involvement, while the medium bridges the abstract concept of data analysis into a visual form that students can observe, construct, and interpret directly, allowing the three indicators of mathematical representation to be trained together within a single learning sequence.

Several previous studies have demonstrated the effectiveness of similar learning models and media in developing students' ability to represent mathematics. Research by Mardhiyana et al. (2025) showed that the use of a bar diagram board medium affected fourth-grade students' mathematics learning outcomes, as reflected in the experimental class's average posttest score of 82.87, which was higher than the control class's 70.09. Research by Indriani et al. (2025) indicated an increase in learning outcomes following the implementation of the GBL model, with the average score rising from 75.37 on the pretest to 87.78 on the posttest. Meanwhile, research by Hanifah et al. (2021) indicated that students' mathematical representation skills improved, from an initial achievement percentage of 11.5% in the pre-cycle stage to 90% by the end of the second cycle.

Compared with these previous studies, the present research differs in several respects. First, it specifically integrates the game-based learning model with a bar-diagram board medium. Second, it embeds this medium in a structured educational game with objectives, rules, challenges, and immediate feedback. Third, the medium is used as a tool to present, compare, and interpret data directly, creating more concrete and contextual learning about data analysis and probability. This research is important because mathematical representation ability at the elementary school level remains relatively low, calling for innovative instruction that actively engages students. Based on the discussion above, this study aims to determine the effect of the game-based learning model based on a bar diagram board medium on the mathematical representation ability of fourth-grade elementary school students, and is expected to contribute an effective,

practical learning option that can be widely applied to the topic of data analysis and probability at the elementary school level.

METHODS

This study used a quantitative quasi-experimental approach with a Non-Equivalent Control Group Design, involving an experimental group and a control group whose assignment was not random (Sugiyono, 2013). This design was used to examine the effect of the game based learning model based on a bar diagram board medium on students' mathematical representation ability by comparing pretest and posttest scores. The research was conducted at SDN 2 Ngantru, Trenggalek Regency, involving fourth-grade students in the even semester of the 2025/2026 academic year, with a focus on bar diagrams. All fourth-grade students at SDN 2 Ngantru, totaling 50 students, served as both the population and the sample through saturated sampling, in which the entire population is used as the sample (Fajri et al., 2022). Accordingly, class IV-A (25 students) served as the control group, taught using the expository model, while class IV-B (25 students) served as the experimental group, taught using the game-based learning model based on the bar-diagram board medium. Instruction in the control class was delivered by the same teacher as in the experimental class over two meetings (4 lesson hours), using bar-diagram material identical to that used in the experimental class. The expository model was implemented through the following stages: (1) concept delivery by the teacher through lecture, assisted by a whiteboard; (2) the teacher providing worked examples; (3) collaborative re-definition of the concept with students; (4) independent completion of the Student Worksheet; and (5) reinforcement of the material at the end of the lesson.

In contrast to the experimental class, which used the bar diagram board medium as a concrete, manipulable tool in group-based game activities, the control class did not use this concrete medium; its instruction was individual in nature and free of game elements. Both classes received the same time allocation, number of meetings, teaching materials, and pretest and posttest instruments, so that the resulting difference in learning outcomes can more confidently be attributed to differences in the learning model and medium applied, rather than to differences in teacher, materials, or time allocation. The learning model served as the independent variable, while students' mathematical representation

ability, comprising the verbal, visual, and symbolic indicators, served as the dependent variable.

Data were collected through observation, questionnaires, and pretest and posttest scores. The test instrument was developed to measure three indicators of mathematical representation ability, namely verbal, visual, and symbolic representation, with the number of items mapped to each indicator presented in Table 1.

Table 1. Test Instrument Blueprint

Indicator	Multiple-Choice Item Number	Essay Item Number	Total
Verbal Representation	1, 5, 6, 8	2	5
Visual Representation	7, 11, 12, 13, 14, 15	1, 4, 5	9
Symbolic Representation	2, 3, 4, 9, 10	3	6
Total	15	5	20

The test instrument was first piloted on 27 students outside the research sample, comprising 20 multiple-choice items and 10 essay items. Instrument feasibility was determined through a validity test using the Pearson Product-Moment correlation technique, with an item deemed valid if its *r*-value exceeded the *r*-table value (0.381) at the 0.05 significance level. The pilot test results showed that 15 of the 20 multiple-choice items were valid, while 6 of the 10 essay items were valid. The five invalid multiple-choice items were subsequently discarded and not used further. Of the 6 valid essay items, 5 items that were most representative of the distribution of mathematical representation indicators were selected for use in the final instrument. The final instrument used for data collection therefore comprised 20 items (15 multiple-choice and 5 essay), as presented in Table 1, which was then tested for reliability, difficulty level, and discriminating power before being used for data collection.

The data analysis began with prerequisite testing, comprising a normality test (Shapiro-Wilk) and a homogeneity test (Levene's test) applied to the posttest scores of the control and experimental groups, to ensure that the pretest and posttest data were normally distributed and homogeneous. Given that the assignment of the experimental and control groups was not carried out randomly, the main hypothesis test in this study used Analysis of Covariance (ANCOVA), with the posttest score as the dependent variable, the learning model as the independent variable, and the pretest score as the covariate to control for possible initial ability differences between groups. As a

complementary analysis, an independent samples t-test was also conducted on the posttest scores, as reported in the Results and Discussion section. Effect size was calculated using partial eta squared to determine the magnitude of the difference between groups. Subsequently, an N-Gain effectiveness test was conducted using the formula $N\ Gain = \frac{Posttest\ Score - Pretest\ Score}{Ideal\ Score - Pretest}$ (Wahab et al., 2021). The N-Gain effectiveness categories used were: ineffective (<40%), less effective (40-55%), fairly effective (56-76%), and effective (>76%) (Febrinita, 2022: 5). The N-Gain was calculated for each student and then averaged to measure the magnitude of the improvement that occurred. All calculations were performed using SPSS version 25.

RESULTS AND DISCUSSION

The pretest and posttest data on the mathematical representation ability of the control and experimental classes obtained in this study are presented in Table 2.

Table 2. Pretest and Posttest Data

Group	Average Pretest	Pretest Standard Deviation	Average Posttest	Posttest Standard Deviation
Control Class (IV-A)	59.76	10.81	76.48	7.23
Experimental Class (IV-B)	58.72	9.28	83.36	6.04

Based on Table 2, both groups had relatively similar pretest means. The pretest standard deviations for the control group (SD = 10.81) and the experimental group (SD = 9.28) likewise indicate a comparable spread of data, suggesting that students' initial ability was relatively similar between the two groups before treatment. Following treatment, the posttest means of both groups increased, but the increase in the experimental class (from 58.72 to 83.36, a gain of 24.64 points) was considerably larger than that in the control class (from 59.76 to 76.48, a gain of 16.72 points).

Before proceeding to hypothesis testing, the pretest and posttest data for both groups were first subjected to a normality test to determine whether the data were normally distributed, using the Shapiro-Wilk test in SPSS version 25, with the criterion that the data are considered normally distributed if the significance value exceeds 0.05. The results are presented in Table 3.

Table 3. Normality Test Results

<i>Shapiro-Wilk</i>			
Class	Statistic	Df	Sig.
Control Class Pretest	.929	25	.084
Control Class Posttest	.939	25	.140
Experimental Class Pretest	.931	25	.094
Experimental Class Posttest	.940	25	.148

Based on Table 3, all significance values were above 0.05, so there is insufficient evidence to reject the assumption of normality for the pretest and posttest scores of both groups.

The next step was a homogeneity test on the posttest scores to examine whether the variances of the data in the control and experimental classes were equal, with the criterion that the data are considered homogeneous if the significance value is above 0.05. The results are shown in Table 4.

Table 4. Homogeneity Test Results

<i>Test of Homogeneity of Variance</i>				
Basis	<i>Levene Statistic</i>	df1	df2	Sig.
Based on Mean	.620	1	48	.435
Based on Median	.674	1	48	.416
Based on Median and with adjusted df	.674	1	47.556	.416
Based on trimmed mean	.685	1	48	.412

As shown in Table 4, the significance value of 0.435 exceeds 0.05, meaning the data are homogeneous.

As these prerequisites were met, parametric statistics served as the basis for hypothesis testing. As a complementary analysis to the ANCOVA, which serves as the primary analysis (results presented in Table 6), an independent samples t-test was used to examine whether there was a significant difference between the average posttest scores of the experimental and control classes, with the criterion that the null hypothesis is rejected if the significance value (2-tailed) is below 0.05. The results are shown in Table 5.

Table 5. Hypothesis Test Results

t-test for Equality of Means				
Basis	t	df	Sig. (2-tailed)	Mean Difference
<i>Equal Variances Assumed</i>	-3.652	48	.001	-6.880
<i>Equal Variances Not Assumed</i>	-3.652	46.531	.001	-6.880

Based on Table 5, the experimental class's average posttest score exceeded that of the control class by 6.88 points, and the significance value of 0.001 (< 0.05) indicates that the null hypothesis is rejected, indicating a statistically significant difference in posttest scores between the experimental and control groups.

Since the assignment of the experimental and control groups in this study was not randomized, a further analysis was conducted using Analysis of Covariance (ANCOVA), with the pretest score as a covariate to control for potential initial ability differences between groups. The ANCOVA results are presented in Table 6.

Table 6. ANCOVA Test Results

Source of Variance	Sum of Squares	df	F	Sig.	Partial Eta Squared
Pretest (covariate)	1455.040	1	101.320	0.000	0.683
Learning Model	691.559	1	48.156	0.000	0.506
Error	674.960	47	-	-	-

Table 7. Corrected Posttest Means (Estimated Marginal Means)

Learning Group	Mean	Std. Error	95% CI Lower	95% CI Upper
Expository	76.196	0.758	74.670	77.722
Game-Based Learning	83.644	0.758	82.118	85.170

The ANCOVA results show that the pretest score was a significant covariate ($F(1,47) = 101.320$; $p < 0.001$; partial eta squared = 0.683), indicating that its inclusion in the model as a statistical control was appropriate. After controlling for the effect of the pretest score, a statistically significant difference remained in posttest scores between the group taught using the game-based learning model based on a board medium and the group taught using the expository model ($F(1,47) = 48.156$; $p < 0.001$), with a large effect

size (partial eta squared = 0.506). As shown in Table 7, the corrected (adjusted) mean posttest score of the experimental group was 83.64 (SE = 0.758), higher than that of the control group at 76.20 (SE = 0.758), with a corrected mean difference of 7.448 points. These results indicate that the statistically significant difference in posttest scores persisted even after controlling for potential initial ability differences between groups, providing stronger grounds for interpreting the learning model's contribution to the difference in students' mathematical representation achievement.

An N-Gain effectiveness test was also conducted to measure the magnitude of the improvement in students' mathematical representation ability following treatment, with the complete results presented in Table 8.

Table 8. N-Gain Effectiveness Test Results

Class	Average N-Gain	Category
Control Class	41.83	Less effective
Experimental Class	60.18	Fairly effective

Table 8 shows that the experimental class achieved an average N-Gain of 60.18% (fairly effective), while the control class achieved only 41.83% (less effective), a difference of 18.35 percentage points. Descriptively, the experimental class showed a higher average N-Gain than the control class. This difference is descriptive in nature and was not tested inferentially; however, its direction is consistent with the ANCOVA results, which showed a statistically significant difference in the corrected posttest scores between the two groups.

To obtain a more detailed picture of the development of students' mathematical representation ability, an analysis of scores was also conducted based on each indicator, namely verbal, visual, and symbolic representation, as presented in Table 9.

Table 9. Mathematical Representation Ability Scores by Indicator

Indicator	Group	Pretest (%)	Posttest (%)	Increase (Points)
Verbal Representation	Control	59.11	79.11	20.00
	Experimental	66.67	88.00	21.33
Visual Representation	Control	57.14	73.71	16.57
	Experimental	54.67	79.24	24.57

Indicator	Group	Pretest (%)	Posttest (%)	Increase (Points)
Symbolic	Control	66.80	81.20	14.40
Representation	Experimental	61.20	88.80	27.60

Table 9 shows that the experimental group experienced a greater increase than the control group across all three indicators. The most pronounced increase occurred in the symbolic indicator (61.20% to 88.80%, a gain of 27.60 points) and the visual indicator (54.67% to 79.24%, a gain of 24.57 points), while the increase in the verbal indicator was comparatively smaller (66.67% to 88.00%, a gain of 21.33 points), although still higher than that of the control group. This pattern is consistent with the concrete, visual nature of the bar diagram board medium, which specifically trains students to construct and interpret data in diagrammatic form (the visual indicator) and to convert such data into numerical form through arithmetic operations (the symbolic indicator). Meanwhile, the increase in the verbal indicator, although still significant, was comparatively more modest, as the ability to explain information orally or in writing was not directly trained through manipulation of the concrete medium.

The difference in results between the two classes cannot be separated from the difference in treatment. The game-based learning model was designed with a systematic, student-centered structure, so that students were involved in finding, processing, and presenting information through structured game activities, while also being encouraged to actively discuss, collaborate, and solve problems within the context of the game. This active involvement was reinforced by the bar diagram board medium as a concrete learning tool, which allowed students to directly arrange bars on the board, complete incomplete diagrams, read information from constructed diagrams, and visually and concretely compare data across categories.

This series of activities allowed students to construct their own understanding through direct learning experience. During instruction, students not only received information from the teacher but also analyzed data, constructed bar diagrams, engaged in discussions, and presented their work. This process fostered students' ability to represent mathematics, as they learned to convert information into visual form, explain their observations verbally, and solve problems using mathematical symbols or calculations. The concrete nature of the bar diagram board medium also made it easier for students to understand data presentation, as they could directly observe, construct, and

interpret the diagrams. This is consistent with Piaget's theory of cognitive development, which places fourth-grade students (aged 9-10) in the concrete operational stage, where learning occurs most effectively through direct experience with concrete objects (Juwantara, 2019).

The findings of this study are consistent with those of various prior studies. The use of the bar diagram board medium integrated into the game based learning model was shown to be effective in improving the mathematical representation ability of fourth-grade students on the topic of data presentation, in line with the study by Mardhiyana et al. (2025), which demonstrated that the bar diagram board medium affected fourth-grade students' mathematics learning outcomes. The combination of the GBL model and the bar diagram board medium applied in the experimental class was also shown to foster an active, enjoyable, and challenging learning environment through game elements such as clear rules, challenges, competition, collaboration, and immediate feedback, elements likewise found to contribute to improved learning outcomes in the study by Indriani et al. (2025), which applied the game based learning model. This is further consistent with the findings of Hanifah et al. (2021), which showed that Project-Based Learning, grounded in active student engagement, significantly improved fourth-grade students' mathematical representation skills. Although the learning models employed differed across these studies, all three converge on a mutually reinforcing conclusion: innovative learning models that position students as active subjects are more effective in improving mathematical representation ability than conventional instruction.

Nevertheless, implementing game-based learning on a bar-diagram board requires careful preparation, from ensuring the medium's readiness to developing varied questions so that learning proceeds effectively and in a focused manner. The success of this model also depends on teachers' skill in managing what is often an active classroom, since an enjoyable learning atmosphere can create noise that disrupts the learning process if not properly managed. Despite these challenges, implementing GBL using this medium proved not only to improve learning outcomes but also to provide an active, collaborative, and meaningful learning experience, enabling students' ability to represent mathematics to develop more effectively. Given that these two components were implemented simultaneously as a single, unified treatment, their relative contributions to the

improvement in students' mathematical representation ability cannot be empirically disentangled in this study.

CONCLUSION

This study concludes that integrating a game-based learning (GBL) model with a bar-diagram board medium significantly enhances fourth-grade students' mathematical representation abilities compared to a traditional expository model. The experimental approach not only yielded higher learning achievements and N-Gain improvements but also demonstrated a large effect size, confirming its pedagogical efficacy. The success of this intervention lies in its unified approach: structured game elements combined with concrete, manipulative media position students at the center of the learning process. This synergy enables students to physically construct, read, and interpret data in a tangible visual form. Furthermore, positive responses from both students and teachers confirm that this integration fosters an active, engaging, and enjoyable learning environment.

Despite the positive outcomes, this study acknowledges several limitations that should be considered when interpreting the results. First, the GBL model and the physical bar-diagram board were administered as a single, combined intervention. Consequently, the relative contribution of each individual component to the enhancement of students' mathematical representation abilities cannot be distinctly isolated. Second, the study was conducted with a limited sample size, specifically fourth-grade students at SDN 2 Ngantru, obtained through saturated sampling. This localized demographic and specific context constrain the generalizability of the findings to broader educational populations. To address these limitations and advance the field, several avenues for future research are recommended. Future experimental studies should consider isolating the GBL model from the physical medium (e.g., using a factorial design) to evaluate the relative contributions of the GBL model and the physical medium. Furthermore, subsequent research should replicate this study across diverse demographics, larger sample sizes, and different grade levels to establish broader generalizability. Beyond expanding the sample, researchers are encouraged to integrate the GBL approach with modern digital tools or computer-assisted educational technologies. Finally, broadening the scope of investigation to measure other complex cognitive domains, such as mathematical

problem-solving and mathematical reasoning, will provide a more comprehensive understanding of the model's overall impact on mathematics education.

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