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The Effect of Fraction Block-Assisted Project-Based Learning on the Numeracy Ability of Grade IV Students

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Abstract: Numeracy in elementary mathematics involves more than calculating numbers; students also need to interpret information, use mathematical representations, and make decisions based on what they understand. This study examined differences in fourth-grade students' numeracy performance after learning geometry through Project-Based Learning (PjBL) supported by Fraction Blocks and direct instruction. A quasi-experimental study with a posttest-only control-group design was conducted with 64 students at MI Ushuluddin Singkawang, Indonesia. Thirty-two students participated in the PjBL–Fraction Blocks group, while 32 students received direct instruction. Students' numeracy was assessed through three constructed-response items covering the use of mathematical numbers and symbols, analysis of visual information, and interpretation of results. Because the data were not normally distributed, the Mann–Whitney U test was used to compare the two groups. The PjBL–Fraction Blocks group obtained a higher mean score than the control group (89.88 vs. 41.44). The difference was statistically significant ($U = 0.00$, $Z = -6.932$, $p < .001$), with a large effect size ($r = .87$). The findings suggest that combining project-based activities with concrete geometric manipulation can support students in connecting visual experiences with mathematical reasoning. The study also highlights the potential of adapting Fraction Blocks beyond fraction instruction to support geometric composition and decomposition.

Keywords: Elementary Students; Fraction Blocks; Geometry; Numeracy; Project-Based Learning.

INTRODUCTION

Numeracy is increasingly viewed as an essential component of mathematics education because students need to use mathematics not only to obtain correct answers but also to understand information, recognize relationships, interpret representations, and make decisions in everyday situations. These demands are particularly important in elementary school, where students begin to move from informal experiences with quantities and shapes toward more formal mathematical representations. Recent research on mathematical literacy among primary school students suggests that learners may be able to carry out particular mathematical procedures while still experiencing difficulties in communicating, representing, interpreting, and applying mathematical ideas in meaningful situations (Seçgin et al., 2024). This distinction is important because successful mathematics learning cannot be reduced to procedural accuracy alone; students also need opportunities to explain how and why a mathematical solution works.

Geometry provides a particularly relevant context for developing these competencies. Young learners encounter geometric forms in objects, buildings, pictures, patterns, and everyday environments, yet recognizing a shape does not necessarily mean that students understand its mathematical structure. Composition and decomposition of plane figures, for example, require students to identify relationships between parts and wholes, visualize alternative arrangements, and reason about how smaller shapes can be combined or separated to produce a new figure. These processes require students to coordinate visual information with mathematical language and symbols. Research on primary mathematics learning has increasingly emphasized the importance of helping students construct and transform representations rather than simply receiving finished representations from the teacher (Tytler et al., 2023).

The challenge becomes greater when geometry is presented mainly through verbal explanations, textbook

illustrations, or static diagrams. Students may recognize a figure when it is presented in a familiar orientation but struggle when the same figure is rotated, rearranged, or embedded within a composite shape. In such situations, students need opportunities to physically and mentally manipulate representations. Access to manipulatives can provide an intermediate space between an abstract mathematical idea and a representation that students can see and modify. Recent research has shown that manipulatives can support students' mathematical reasoning when they are incorporated into purposeful instructional activities rather than being used simply as additional classroom materials (Leow & Kaur, 2024; Quane, 2025).

The value of manipulatives, however, should not be understood as a consequence of their physical presence alone. Their educational value depends on how students are guided to connect concrete actions with mathematical ideas. Siller and Ahmad (2024), for example, found that instruction incorporating concrete and virtual manipulatives could produce stronger mathematics achievement than conventional instruction among elementary students. At the same time, research on students' use of manipulatives indicates that the teacher's pedagogical decisions remain important. Students need opportunities to discuss what they are doing, compare different configurations, represent their observations, and explain the mathematical relationships underlying their actions (Quane, 2025). Without such connections, manipulating objects can remain an activity rather than becoming a means of mathematical reasoning.

This issue is particularly relevant to the use of Fraction Blocks. Fraction Blocks are commonly associated with representing fractions and the relationship between parts and a whole. Their physical structure, however, also offers possibilities for other forms of mathematical exploration. When pieces can be moved, combined, separated, and rearranged, students can investigate how different parts form a larger configuration. This feature creates an opportunity to extend the pedagogical function of Fraction Blocks beyond fraction concepts and into geometric composition and decomposition. Such an adaptation is consistent with research showing that manipulatives can function as representations through which learners construct and communicate mathematical relationships, rather than simply as physical aids for demonstrating teacher explanations (Tytler et al., 2023; Vallejo-Vargas & Reid, 2024).

Project-Based Learning (PjBL) offers another potentially useful dimension to this instructional problem. Rather than organizing learning around a sequence of explanations and exercises, PjBL places students in a process of investigating a meaningful task, making decisions, developing a product or solution, and communicating the result. The approach is particularly relevant to mathematics when projects require students to use mathematical concepts as tools for solving problems rather than treating mathematics as a collection of isolated procedures. A quasi-experimental study involving elementary mathematics students found that students participating in project-based instruction achieved higher learning outcomes than those receiving conventional instruction (Lazić et al., 2021). Similarly, research on project-based mathematics has reported positive relationships between project-oriented learning environments and students' academic outcomes, engagement, and perceptions of mathematics learning (Rijken & Fraser, 2024).

The potential of PjBL is also supported by broader reviews of the literature. A systematic review of Scopus-indexed research identified recurring outcomes of PjBL including collaboration, critical thinking, communication, problem-solving, conceptual understanding, motivation, and creativity (Yusri et al., 2024). Research on project-based learning systems further suggests that effective PjBL requires more than assigning students a project. The project needs clear learning goals, meaningful problems, opportunities for inquiry, appropriate scaffolding, and mechanisms that help students connect activities with disciplinary knowledge (He et al., 2023). In mathematics, this point is particularly important because a project can easily become dominated by construction or presentation while the underlying mathematical reasoning receives insufficient attention.

Recent evidence provides further support for examining PjBL specifically in mathematics. A three-level meta-analysis of mathematics PjBL published in 2026 found an overall positive effect on mathematics learning outcomes, although the authors also reported substantial variation across contexts and cautioned that publication bias may inflate the apparent effect (Wang et al., 2026). Another recent meta-analysis focusing on computer-assisted mathematics education integrated into PjBL reported positive effects on Indonesian students' mathematics achievement, suggesting that the learning model can be strengthened when students are given appropriate tools and learning resources (Juandi et al., 2025). These findings suggest that the effectiveness of PjBL should not be considered independently from the learning environment, the mathematical content, and the representations or tools provided to students.

Nevertheless, an important gap remains in the literature. Existing research has generally examined PjBL as a learning model or investigated manipulatives as separate instructional resources. Less attention has been given to how a specific manipulative can be deliberately integrated into the project cycle to support mathematical reasoning. In particular, there is limited empirical evidence on the use of an adapted manipulative to support geometric composition and decomposition while students simultaneously engage in planning, constructing, recording, discussing, and explaining their mathematical ideas. Research involving manipulatives has demonstrated their

potential for supporting problem solving and mathematical argumentation, but much of this work has focused on other mathematical topics or on virtual environments (Leow & Kaur, 2024; Vallejo-Vargas & Reid, 2024).

This gap is important because PjBL and manipulatives address different aspects of learning. PjBL provides a structure for students to investigate, collaborate, make decisions, produce a solution, and reflect on their work. Manipulatives, in contrast, provide representations that students can physically transform while exploring mathematical relationships. Combining the two may therefore create a stronger learning sequence in which students move from action to representation and then to mathematical explanation. Research on representation construction in primary education supports the importance of giving learners active roles in constructing and transforming representations rather than merely interpreting representations prepared by others (Tytler et al., 2023).

The present study responds to this gap by integrating PjBL with adapted Fraction Blocks in the teaching of composition and decomposition of plane figures to fourth-grade students. The Fraction Blocks were not introduced as a new manipulative. Instead, their pedagogical function was deliberately extended from representing fractional relationships to supporting geometric reasoning. During the project, students used the pieces to construct target figures, explore alternative arrangements, document the composition and decomposition process, and explain their decisions. In this way, the physical manipulation of the pieces became part of a broader mathematical process involving visual analysis, symbolic representation, communication, and decision-making.

The need for this intervention was also evident in the research setting. The preliminary assessment conducted with fourth-grade students showed difficulties across the three numeracy indicators examined in the study. Students had difficulty using mathematical numbers and symbols, analyzing information presented visually, and interpreting the results of their analysis to make decisions. Classroom observations further indicated that mathematics learning relied heavily on teacher explanations and practice exercises, while opportunities for students to explore mathematical ideas using concrete objects and discuss alternative solution strategies remained limited. These conditions provided a meaningful basis for examining whether a learning design that combines project work with concrete geometric representations could support students' numeracy performance.

Accordingly, this study examines whether fourth-grade students who learn plane-figure composition and decomposition through PjBL supported by adapted Fraction Blocks demonstrate different numeracy performance from students who receive direct instruction. The study focuses on three aspects of numeracy: the use of mathematical numbers and symbols, the analysis of visual information, and the interpretation of analytical results for decision-making. The study contributes to the existing literature by examining not merely whether PjBL or manipulatives are effective in isolation, but how an established manipulative can be pedagogically repurposed and embedded within a project-based learning process to support numeracy in elementary geometry.

RESEARCH METHODOLOGY

This study uses a quantitative approach with a quasi-experiment method. The design used is Posttest-Only Control Group Design. The two classes that have been available are given different learning treatments, then both classes are given a final test with the same instrument. The experimental class received learning using the Project Based Learning model assisted by Fraction Blocks, while the control class received learning using the Direct Learning model. The design was chosen to compare the results of numeracy skills after the two groups received different learning treatments.

The research was carried out at MI Ushuluddin Singkawang in the even semester of the 2025/2026 academic year, with the research being carried out on May 21-22, 2026. The research population was all students in grade IV of MI Ushuluddin Singkawang. The sample consisted of 64 students, namely 32 students in the experimental class and 32 students in the control class. Learning was carried out in two meetings with composition and decomposition materials of flat buildings. In the experimental class, students worked in groups to complete projects using Fraction Blocks, while the control class followed direct learning through explanations, examples, exercises, and reinforcement from the teacher.

The implementation of learning in the experimental class follows the main stages of PjBL. The activity begins with perception and sparking questions about the shape of the flat building found in the surrounding objects. The teacher introduces the Fraction Blocks and demonstrates how to arrange and decipher the building. Students are then divided into groups and receive a worksheet. Together with the group, students determine the shape to be made, arrange the pieces into certain shapes, record the composition and decomposition processes, and present the results. The teacher acts as a facilitator by providing guidance, monitoring the work process, and providing feedback. At the end of the lesson, students reflect to reinforce the concepts that have been obtained.

The research instrument is a numeracy ability test in the form of a description of three questions. The three questions are arranged based on three indicators, namely: (1) the ability to use various numbers or symbols related

to basic mathematics in solving problems; (2) the ability to analyze information presented in the form of pictures, tables, charts, or other visual forms; and (3) the ability to decipher the results of the analysis to predict and make decisions. Operationally, question 1 asks students to use relevant numerical information and mathematical symbols to solve the problem of composition or decomposition of flat buildings; question 2 asks students to read and analyze the combined building drawings to identify the relationships of the constituent parts; while question 3 asks students to interpret the results of the analysis to determine or predict the appropriate arrangement accompanied by reasons. The maximum score of each item is 12, 12, and 8. Before being used in the research, the instrument was tested on 21 grade IV students of SD Negeri 2 Singkawang. The instrument goes through the stages of content validity, construct validity, reliability, difficulty, and differentiating power.

Data were analyzed using SPSS version 27. Descriptive analysis was performed to obtain the mean, standard deviation, variance, highest value, and lowest value. Next, a Shapiro-Wilk normality test was performed to determine the distribution of posttest data. Because the data were not normally distributed, hypothesis testing used the Mann-Whitney U test for two independent groups. The decision criterion used a significance level of 0.05. If the significance value is less than 0.05, then there is a significant difference between the two groups. The effect size was calculated by dividing the absolute value of the Z statistic from the Mann-Whitney U test by the square root of the total sample size. An effect size value of 0.50 or higher was interpreted as a large effect

RESULTS AND DISCUSSION

Results

The results of the research were obtained through a posttest given after the learning in both classes was completed. Data came from 64 students consisting of 32 students in the experimental class and 32 students in the control class. The test consisted of three description questions that measured three indicators of numeracy ability. The results of the descriptive analysis showed that there was a clear difference in achievement between the two classes.

Table 1. Average Posttest Score of Numeracy Ability

Criteria	Eksperimen	Control
Average	89,88	41,44
Standard deviation	8,19	15,55
Varians	67,03	241,85
Highest score	100	68
Lowest value	75	25
Number of students	32	32

Based on Table 1, the average posttest score of the experimental class reached 89.88, while the control class was 41.44. The average difference between the two classes reached 48.44 points. The experimental class also had a smaller standard deviation than the control class, so the distribution of student scores in the experimental class tended to be more concentrated. Descriptively, the data showed that students who took PjBL with the help of Fraction Blocks had higher numeracy skills after learning than students who participated in direct learning. However, these descriptive differences still need to be tested inferently to ensure their significance.

Table 2. Average Score Recapitulation of Each Numeracy Ability Indicator

Indicator	Eksperimen	Control	Maximum Score
Using basic math numbers or symbols	11,20	4,66	12
Analyze information	10,40	4,25	12
Interpret the results of the analysis	7,10	3,50	8
Quantity	28,70	12,41	32

Table 2 shows that the experimental class had a higher average score on all indicators. In the indicator using basic mathematical numbers or symbols, the experimental class obtained an average of 11.20 out of a maximum score of 12, while the control class obtained 4.66. In the indicator analyzing information, the average experimental class was 10.40 and the control class was 4.25. In the indicator interpreting the results of the analysis, the average experimental class reached 7.10, while the control class was 3.50. The pattern shows that the advantage of the experimental class

does not only occur in the overall score, but is also seen in every aspect of the numeracy ability measured.

The difference in achievement in the three indicators can be attributed to the character of the learning activity. During the project, students repeatedly use the shape, size, and arrangement of Fraction Blocks pieces to determine the completion strategy. They are also asked to record the results of observations on the LKPD so that the concrete experience does not stop at the activity of arranging objects, but is translated into mathematical language and symbols. During the presentation, students must explain the reason for choosing the shape and the process of forming the building. The series of activities provides an opportunity for students to develop the ability to use information, analyze, and interpret results.

The normality test was performed as a prerequisite before hypothesis testing. The test used was Shapiro-Wilk. The test results showed a significance value of 0.01 in the experimental class and less than 0.01 in the control class. Both values were less than 0.05 so that the posttest data of both classes were declared not to be normally distributed. Therefore, the difference test did not use independent samples t-test, but used the Mann-Whitney U nonparametric test.

Table 3. Shapiro-Wilk Normality Test Results

Classes	N	Statistic	Say.	Verdict
Eksperimen	32	0,870	0,01	Abnormal
Control	32	0,857	<0.01	Abnormal

The results of the Mann-Whitney U test showed a U value of 0.00, a Z value of -6.932, and an Asymp value. Sig. (2-tailed) less than 0.001. The significance value was less than 0.05, so H_0 was rejected and H_a was accepted. Thus, there was a significant difference in students' numeracy ability between the experimental class and the control class after being given different learning treatments.

Table 4. Mann-Whitney U Test Results

Statistics	Value
Mann-Whitney U	0,00
Z	-6,932
Asymp. Sig. (2-tailed)	<0.001
Mean Rank Experiment	48,50
Mean Rank Kontrol	16,50

The mean rank value of the experimental class of 48.50 was higher than that of the control class of 16.50. These results reinforce the descriptive finding that the distribution of students' numeracy ability scores in the experimental class was better. Thus, the application of PjBL assisted by Fraction Blocks not only resulted in a higher average score, but also resulted in a statistically confirmed difference in score distribution.

Next, effect size calculations were carried out to find out how much influence the treatment had. The calculation used the absolute value of Z divided by the root of the number of samples. With $Z = -6.932$ and $N = 64$, an effect size value of 0.87 was obtained. This value is greater than 0.50 so it is included in the large category. This result shows that the application of PjBL assisted by Fraction Blocks has a strong influence on students' numeracy ability on flat building materials.

Table 5. Effect Size Calculation Results

Components	Value
Z	-6,932
N	64
$\sqrt{N}$	7,48
Effect Size	0,87
Category	Large

Discussion

The findings of this study show a clear difference in numeracy performance between students who learned through Project-Based Learning (PjBL) assisted by Fraction Blocks and those who experienced direct instruction. The experimental group obtained a mean posttest score of 89.88, compared with 41.44 in the control group. The Mann-Whitney U test also indicated a statistically significant difference between the two groups ($U = 0$, $p < .001$), with an effect size of $r = .87$. These results suggest that the learning experience provided in the experimental class was associated with substantially stronger numeracy performance in the context of composing and decomposing plane figures. Similar evidence has been reported in elementary mathematics research, where project-based instruction produced better achievement than more conventional classroom approaches (Lazić et al., 2021). Recent meta-analytic

evidence also indicates a generally positive relationship between PjBL and mathematics learning outcomes, although the magnitude of the effect varies across contexts and study characteristics (Wang et al., 2026).

One possible explanation for this result is the way PjBL changed the nature of students' mathematical activity. In the experimental class, students were not only asked to identify geometric shapes or follow examples provided by the teacher. They had to decide how different pieces could be arranged, test their ideas, examine whether the resulting shape matched the target, and explain their decisions. In this sense, mathematics became part of the process of completing the project rather than an activity that occurred only after the teacher had explained a procedure. This interpretation is consistent with the broader literature describing PjBL as a learning environment in which students apply knowledge while planning, investigating, producing, and communicating solutions (He et al., 2023; Yusri et al., 2024). Research in mathematics classrooms has similarly shown that project-based approaches can support achievement while also creating a more active learning environment (Rijken & Fraser, 2024).

The role of Fraction Blocks is particularly important in interpreting the findings. The results should not be understood simply as evidence that providing students with a physical teaching aid automatically improves numeracy. Rather, the manipulative was embedded in a sequence of mathematical actions. Students moved, combined, separated, and compared pieces while working on a specific geometric problem. These actions gave students an opportunity to see relationships between parts and wholes before expressing those relationships through drawings, numbers, and mathematical symbols. This interpretation is supported by recent work on representation construction, which emphasizes that students' mathematical understanding can develop through activities that require them to construct, transform, and connect different forms of representation (Tytler et al., 2023).

The findings are also consistent with recent research on mathematical manipulatives. Siller and Ahmad (2024) found that instruction supported by concrete and virtual manipulatives produced higher mathematical achievement than conventional instruction among elementary students. Ahmad and Siller (2024) likewise reported positive effects of manipulative-supported instruction across different achievement levels. Leow and Kaur (2024), meanwhile, showed that access to manipulatives can become part of how young learners approach non-routine mathematical problems. Taken together, these studies suggest that the value of manipulatives lies not merely in their physical presence but in how they support students in exploring mathematical relationships.

This point is relevant to the present study because Fraction Blocks were used beyond their more familiar function of representing fractions. In this study, their pieces were repurposed as geometric components for composing and decomposing plane figures. The contribution, therefore, is better understood as a pedagogical adaptation rather than the introduction of a new manipulative. The blocks provided a physical representation of geometric parts, while PjBL created a reason for students to manipulate those parts, compare alternatives, and justify their decisions. This combination may explain why the intervention was particularly effective for tasks requiring students to connect visual information with mathematical representations.

The differences across the three numeracy indicators provide further insight. The experimental group performed strongly in using mathematical numbers or symbols, with a mean of 11.20 out of 12, and in analyzing information, with a mean of 10.40 out of 12. The interpretation indicator had a lower mean of 7.10 out of 8, although it remained substantially higher than the control group's 3.50. This pattern is meaningful because interpretation requires more than identifying information or representing it mathematically. Students must integrate the available information, consider possible arrangements, and use that information to support a decision. Research on mathematical literacy similarly emphasizes that students need to move beyond obtaining an answer toward interpreting mathematical information and using it to reason about a situation (Seçgin et al., 2024).

The relatively lower performance on interpretation also suggests an area that should not be overlooked. Manipulating concrete objects can make relationships visible, but visibility does not automatically lead to mathematical reasoning. Students still need questions that ask them to explain why a particular arrangement works, what would happen if one component were changed, or why one solution is more appropriate than another. Vallejo-Vargas and Reid (2024) illustrate a related point: manipulatives can support mathematical argumentation when students are encouraged to use the representation as evidence for their reasoning. Thus, future implementation of Fraction Blocks should place greater emphasis on explanation, justification, comparison of strategies, and reflection rather than treating construction of a shape as the final learning objective.

The group-work component of PjBL may also have contributed to the observed pattern. During the project, students had opportunities to compare arrangements and discuss possible solutions with peers. Such interaction can make mathematical thinking more visible because students have to communicate what they are doing and respond to alternative ideas. The systematic review by Yusri et al. (2024) identified collaboration, communication, critical thinking, problem-solving, and concept understanding among the important elements associated with PjBL. Diego-Mantecon et al. (2021) similarly demonstrated the potential of project-based approaches to connect mathematics with more active and interdisciplinary classroom practices. In the present study, collaboration was not an additional

activity separated from mathematics; it was part of the process through which students negotiated geometric solutions.

The magnitude of the observed group difference is noteworthy, but it should be interpreted carefully. An effect size of .87 indicates a large separation between the two groups under the conditions of this study. However, the result should not be interpreted as evidence that the same magnitude would necessarily occur in other schools or with longer interventions. The study involved 64 students from one school, the intervention lasted only two meetings, and numeracy was measured through three constructed-response items. In addition, the posttest-only design does not allow direct estimation of individual change from pre-intervention to post-intervention. These limitations are important because recent reviews have shown that although PjBL generally has positive effects, the magnitude of those effects depends on intervention duration, educational context, and other design characteristics (Wang et al., 2026). Farshad and Fortin (2026) similarly found a consistently positive direction for PjBL across meta-analyses but cautioned that the strength of the evidence and reported effect sizes vary considerably.

The findings therefore have a practical implication for elementary mathematics teachers. The central lesson is not simply to “use Fraction Blocks” or “use PjBL,” but to design a coherent relationship between the learning model, the manipulative, and the mathematical objective. A concrete object becomes more valuable when students must use it to investigate a mathematical question, record their observations, represent their thinking, and justify a conclusion. Likewise, a project becomes more meaningful when its product requires genuine mathematical decisions rather than merely producing a physical object. The present findings support this principle and suggest that PjBL combined with carefully structured manipulative-based activities can provide a promising approach to numeracy-oriented geometry instruction.

Overall, this study extends previous research by bringing together two instructional resources that are often examined separately: project-based learning and mathematical manipulatives. The distinctive contribution lies in using Fraction Blocks as tools for geometric composition and decomposition while embedding their use within a project structure. The large difference between the two groups suggests that this integration is worthy of further investigation. Future studies should use pretest–posttest or randomized designs, involve more schools and diverse student populations, extend the intervention beyond two meetings, and include richer measures of mathematical reasoning and interpretation. Such research would help determine whether the benefits observed here represent a short-term instructional advantage or a more sustained improvement in students’ mathematical understanding and numeracy.

CONCLUSION

This study found a substantial difference in the numeracy performance of Grade IV students who learned through Project-Based Learning (PjBL) assisted by Fraction Blocks and those who received direct instruction in composing and decomposing plane figures. The experimental group achieved a higher mean posttest score (89.88) than the control group (41.44), with a difference of 48.44 points. The Mann–Whitney U test confirmed a statistically significant difference between the two groups ($U = 0$, $p < .001$), while the effect size ($r = .87$) indicated a large effect under the conditions of this study.

The findings suggest that combining a project-based learning structure with concrete manipulation can provide students with meaningful opportunities to explore geometric relationships, analyze visual information, use mathematical symbols, and explain the results of their reasoning. The use of Fraction Blocks was particularly useful when the pieces were treated not simply as teaching aids, but as objects that students could arrange, compare, combine, and decompose while working on a mathematical task. The project structure also encouraged students to discuss strategies and communicate their reasoning.

However, these findings should be interpreted within the scope of the study. The research involved 64 students from one school, used a two-meeting intervention, and measured numeracy through three constructed-response questions using a posttest-only design. Future research should involve more diverse schools and samples, longer interventions, broader assessment instruments, and pretest–posttest or experimental designs to examine whether the observed benefits are sustained over time.

REFERENCES

- Ahmad, S., & Siller, H.-S. (2024). Investigating the effect of manipulatives on mathematics achievement: The role of concrete and virtual manipulatives for diverse achievement level groups. *Journal on Mathematics Education*, 15(3), 979–1002.
- Diego-Mantecon, J.-M., Prodromou, T., Lavicza, Z., Blanco, T. F., et al. (2021). An attempt to evaluate STEAM project-based instruction from a school mathematics perspective. *ZDM–Mathematics Education*, 53, 1137–1148.

<https://doi.org/10.1007/s11858-021-01303-9> Springer Link

- Farshad, S., & Fortin, C. (2026). An umbrella review of meta-analyses on project-based learning: Effects on academic achievement, higher-order thinking, and 21st-century skills. *Educational Research Review*, 52, 100809. <https://doi.org/10.1016/j.edurev.2026.100809>
- He, P., Krajcik, J., & Schneider, B. (2023). Transforming standards into classrooms for knowledge-in-use: An effective and coherent project-based learning system. *Disciplinary and Interdisciplinary Science Education Research*, 5, 22. <https://doi.org/10.1186/s43031-023-00088-z> Springer Link
- Juandi, D., Suparman, Putri, A. D., Dahlan, J. A., & Dasari, D. (2025). The utilization of computer-assisted mathematics education integrated into project-based learning to optimize Indonesian students' mathematics achievement: A systematic review and meta-analysis. *International Electronic Journal of Mathematics Education*, 20(4), em0853. <https://doi.org/10.29333/iejme/16899> DOI
- Lazić, B. D., Knežević, J. B., & Maričić, S. M. (2021). The influence of project-based learning on student achievement in elementary mathematics education. *South African Journal of Education*, 41(3), 1–10. <https://doi.org/10.15700/saje.v41n3a1909> African Journals Online
- Leow, S. H., & Kaur, B. (2024). A study of Grade Two students solving a non-routine problem with access to manipulatives. *International Journal of Science and Mathematics Education*, 22, 1457–1478. <https://doi.org/10.1007/s10763-024-10443-9>
- Quane, K. (2025). The confluence of attitudes towards mathematics and pedagogical practice: Evaluating the use of mathematical manipulatives. *Mathematics Education Research Journal*, 37, 369–398. <https://doi.org/10.1007/s13394-024-00494-0> Springer Link
- Rijken, P. E., & Fraser, B. J. (2024). Effectiveness of project-based mathematics in first-year high school in terms of learning environment and student outcomes. *Learning Environments Research*, 27, 241–263. <https://doi.org/10.1007/s10984-023-09477-7>
- Seçgin, M. G., Başkurt, İ., & Güner, P. (2024). Mathematical literacy of primary school students in the context of mathematical modeling. *Journal of Pedagogical Sociology and Psychology*, 6(3), 149–175. <https://doi.org/10.33902/jpsp.202430538>. (Scopus-indexed) Avesis
- Siller, H.-S., & Ahmad, S. (2024). The effect of concrete and virtual manipulative blended instruction on mathematical achievement for elementary school students. *Canadian Journal of Science, Mathematics and Technology Education*, 24, 229–266. <https://doi.org/10.1007/s42330-024-00336-y> Springer Link
- Tytler, R., Prain, V., Kirk, M., et al. (2023). Characterising a representation construction pedagogy for integrating science and mathematics in the primary school. *International Journal of Science and Mathematics Education*, 21, 1153–1175. <https://doi.org/10.1007/s10763-022-10284-4> Springer Link
- Vallejo-Vargas, E. A., & Reid, D. A. (2024). Influences of a virtual manipulatives context on argumentation about integers. *International Journal of Science and Mathematics Education*, 22, 585–608. <https://doi.org/10.1007/s10763-023-10386-7>
- Wang, C., Zhang, W., & Cheng, J. (2026). Can project-based learning improve students' mathematics learning outcomes: A three-level meta-analysis. *Frontiers in Psychology*, 17, 1868415. <https://doi.org/10.3389/fpsyg.2026.1868415>
- Yusri, R., Yusof, A. M., & Sharina, A. (2024). A systematic literature review of project-based learning: Research trends, methods, elements, and frameworks. *International Journal of Evaluation and Research in Education*, 13(5), 3345–3359. <https://doi.org/10.11591/ijere.v13i5.27875>