



Integrating Science Technology Engineering Mathematics into Project-Based Learning to Develop Students' Mathematical Literacy

Integrasi Science Technology Engineering Mathematics dalam Project Based Learning untuk Mengembangkan Literasi Matematika Siswa

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Abstract

Mathematical literacy encompasses the ability to formulate situations mathematically, employ mathematics, and interpret and evaluate mathematical outcomes in real-world contexts. This classroom action research aimed to improve students' mathematical literacy through STEM-integrated Project-Based Learning (PjBL) and to evaluate the improvement achieved among 27 students of Grade XI Excellent D at SMA Negeri 2 Parepare. The study was conducted in two cycles, each consisting of four instructional meetings followed by one assessment. Test and questionnaire data were analyzed descriptively and using normalized gain (N-Gain). The mean score increased from 52.10 (SD = 26.54) to 70.12 (SD = 19.33), with an N-Gain of 0.36. The greatest improvements were observed in the formulate process and the employ process, while the interpret process remained the lowest. Students' responses were categorized as good. These findings indicate promising development in students' mathematical literacy; however, their ability to interpret results, assess the reasonableness of solutions, and evaluate solutions needs to be further strengthened through validation, argumentation, and evidence-based reflection.

Keywords: Literacy Processes; Mathematical Literacy; Project-Based Learning; STEM.

Abstrak

Literasi matematika mencakup kemampuan merumuskan situasi, menggunakan matematika, serta menafsirkan dan mengevaluasi hasil dalam konteks nyata. Penelitian tindakan kelas ini mengukur perbaikan kemampuan literasi matematika melalui PjBL terintegrasi STEM pada 27 siswa kelas XI Excellent D SMA Negeri 2 Parepare. Penelitian dilaksanakan dalam dua siklus, masing-masing empat pertemuan pembelajaran dan satu tes. Data tes dan angket dianalisis secara deskriptif dan menggunakan N-Gain. Rata-rata skor meningkat dari 52,10 (SD = 26,54) menjadi 70,12 (SD = 19,33), dengan N-Gain 0,36. Peningkatan terbesar terjadi pada formulate dan employ, sedangkan interpret tetap terendah. Respon siswa baik. Temuan ini menunjukkan perkembangan yang menjanjikan, tetapi interpretasi, pemeriksaan kewajaran, dan evaluasi solusi perlu diperkuat melalui validasi, argumentasi, dan refleksi berbasis bukti.

Kata Kunci: Literasi Matematika; Pembelajaran Berbasis Proyek; Proses Literasi; STEM.

Introduction

Mathematical literacy is the capacity to reason mathematically and to formulate, employ, and interpret mathematics when solving problems in a variety of real-world contexts. This competence encompasses the use of mathematical concepts, procedures, facts, and tools to explain and predict phenomena and to make well-reasoned judgments¹. Therefore, mathematical literacy cannot be reduced merely to the speed or fluency with which algorithms are executed. Rather, it requires the ability to identify and formulate the mathematical structure embedded in contextual situations, select and coordinate appropriate representations and strategies, apply mathematical concepts and procedures accurately, and interpret and evaluate results in relation to the original context².

This urgency contrasts with the persistently low performance of Indonesian students. In PISA 2025, Indonesia recorded a mean mathematics score of 364, compared with the OECD average of 463³. These data cannot be used to assess a single class directly because PISA evaluates a sample of students aged approximately 15 years. Nevertheless, this national pattern indicates that students' ability to use mathematics to represent situations, select strategies, and evaluate complex solutions still needs to be strengthened systematically.

A similar problem was identified in mathematics learning at SMA Negeri 2 Parepare. Preliminary interviews indicated that students were generally able to solve routine problems but encountered difficulties when information was presented in narrative form or within authentic contexts. These difficulties were evident in selecting relevant information, translating situations into mathematical models, determining strategies, using symbols and representations, and explaining the reasoning behind and meaning of their answers. Viewed through the PISA framework, these challenges encompass formulate, employ, interpret, and evaluate. Thus, the learning problem involves not merely an inadequate command of formulas but also a

¹ OECD. *PISA 2022 Assessment and Analytical Framework*. Paris: OECD Publishing, 2023. <https://doi.org/10.1787/dfe0bf9c-en>.

² Taufik, A., and N. Zainab. "Mathematical Literacy of Students in Solving PISA-Like Problems Based on Cognitive Styles of Field-Dependent and Field-Independent." *Journal of Physics: Conference Series* 1918 (2021): 042080. <https://doi.org/10.1088/1742-6596/1918/4/042080>; Nurhanurawati, N., C. Caswita, H. Bharata, and W. Widyastuti. "The Analysis of Junior High School Students' Mathematical Literacy: Field Study in Bandar Lampung." *Al-Jabar: Jurnal Pendidikan Matematika* 13, no. 1 (2022). <https://doi.org/10.24042/ajpm.v13i1.11659>; Gustiningsi, T., F. T. Pasaribu, R. Junita, and Z. Ismail. "Investigating Students' Mathematical Literacy: How Students Solve PISA-Like Problems in the Jambi Context." *Jurnal Elemen* (2026). <https://doi.org/10.29408/jel.v12i2.34156>.

³ OECD. (2026). *PISA 2025 Results (Volume I) Future-Ready Students*.

limited ability to use mathematics as a tool for understanding situations and making decisions.

Instruction that emphasizes procedural exercises alone tends to provide students with few opportunities to move through the complete process from context to model and back to context⁴. Kusmaryono and Kusumaningsih⁵ identified a gap between school mathematics teaching practices and the demands of literacy assessments such as PISA. This gap underscores the need for learning experiences that require students to propose assumptions, use data, compare alternatives, justify decisions, and examine model limitations. Contextual tasks alone are insufficient if instruction still ends once a final numerical answer has been obtained.

Project-Based Learning (PjBL) offers a relevant structure because learning is driven by a meaningful problem or question and results in a testable product, model, or solution⁶. Students are required to plan their work, collect information, collaborate, monitor progress, and present their results⁷. A meta-analysis of 66 experimental and quasi-experimental studies showed that PjBL generally contributes positively to academic achievement, thinking skills, and affective outcomes. However, the magnitude of its effects is influenced by subject area, group size, class size, educational level, and intervention duration⁸. This finding suggests that the quality of the project design, rather than the PjBL label alone, determines its pedagogical value.

The integration of science, technology, engineering, and mathematics (STEM) can strengthen the role of projects as a vehicle for developing

⁴ Nguyen, Q. A., and N.-G. Nguyen. "Horizontal and Vertical Mathematization Processes of 10th Grade Students: The Case of Law of Sines." *Journal on Mathematics Education* 15, no. 4 (2024): 1251–1276. <https://doi.org/10.22342/jme.v15i4.pp1251-1276>.

⁵ Kusmaryono, I., and W. Kusumaningsih. "Evaluating the Results of PISA Assessment: Are There Gaps between the Teaching of Mathematical Literacy at Schools and in PISA Assessment?" *European Journal of Educational Research* 12, no. 3 (2023): 1479–1493. <https://doi.org/10.12973/eu-jer.12.3.1479>.

⁶ Zhang, R. "Design of an Authentic Project-Based Learning Course Using Project Management Approach." *International Journal of Fashion Design, Technology and Education* 15 (2021): 57–66. <https://doi.org/10.1080/17543266.2021.1992799>; Li, J., and T.-T. Jiang. "Design and Thinking about Driven Problem in Project-Based Learning." *Advances in Educational Technology and Psychology* (2023). <https://doi.org/10.23977/aetp.2023.071208>.

⁷ Muchson, M. "Application of the Project Based Learning Model to Improve 21st Century Competence 4C." *International Journal of Research and Review* (2023). <https://doi.org/10.52403/ijrr.20230173>; Subagia, I., and R. Sudiatmika. "Project-Based Learning Implementation in Fundamental Chemistry Courses to Meet the 21st Century Learning Target." *Jurnal Pendidikan Kimia Indonesia* 7, no. 2 (2024). <https://doi.org/10.23887/jpki.v7i2.70368>.

⁸ Zhang, L., and Y. Ma. "A Study of the Impact of Project-Based Learning on Student Learning Effects: A Meta-Analysis Study." *Frontiers in Psychology* 14 (2023): 1202728. <https://doi.org/10.3389/fpsyg.2023.1202728>.

mathematical literacy⁹. In integrated STEM, science provides phenomena or constraints that must be explained; technology supports information retrieval, data processing, simulation, and communication; engineering provides a process for designing, creating, testing, and improving solutions; and mathematics is used to measure, model, calculate, analyze, and evaluate¹⁰. The systematic review by Rahman et al.¹¹ also showed that STEM practices in mathematics education are associated with problem solving, critical thinking, communication, collaboration, technology integration, and project-based learning.

Nevertheless, STEM projects do not automatically generate substantive mathematical activity. An analysis of 41 project-based STEAM learning experiences showed that only 25 projects incorporated mathematical content; in some projects, mathematics was limited to basic calculations involving low cognitive demand¹². This finding warns that an appealing product may conceal weak mathematical reasoning when the relationships among objectives, activities, evidence of learning, and assessment are not explicitly designed. Therefore, in this study, mathematics was positioned as the primary tool for constructing and evaluating project decisions.

Several recent studies have demonstrated the potential of similar approaches. Hadiyanti et al.¹³ developed a STEM-collaborative PjBL mathematics e-module for vocational high school students and reported that the product had adequate quality. Pramasdyahsari et al.¹⁴ developed a

⁹ Kartini, F. S., A. Widodo, and N. Winarno. "STEM Project-Based Learning on Student's STEM Literacy: The Case of Teaching Earth Layer and Disaster." *Journal of Physics: Conference Series* 1806 (2021): 012221. <https://doi.org/10.1088/1742-6596/1806/1/012221>.; Rachmani, N., and N. Farah. "The Development of STEM-Nuanced Mathematics Teaching Materials to Enhance Students' Mathematical Literacy Ability through Information and Communication Technology-Assisted Preprospec Learning Model." *International Journal of Educational Methodology* 9, no. 2 (2023): 409–421. <https://doi.org/10.12973/ijem.9.2.409>.

¹⁰ Hallström, J., and P. Ankiewicz. "Design as the Basis for Integrated STEM Education: A Philosophical Framework." *Frontiers in Education* 8 (2023): 1078313. <https://doi.org/10.3389/educ.2023.1078313>.

¹¹ Rahman, N. A., R. Rosli, A. S. Rambely, and L. Halim. "Mathematics Teachers' Practices of STEM Education: A Systematic Literature Review." *European Journal of Educational Research* 10, no. 3 (2021): 1541–1559. <https://doi.org/10.12973/eu-jer.10.3.1541>.

¹² Diego-Mantecon, J. M., T. Prodromou, Z. Lavicza, T. F. Blanco, and Z. Ortiz-Laso. "An Attempt to Evaluate STEAM Project-Based Instruction from a School Mathematics Perspective." *ZDM-Mathematics Education* 53, no. 5 (2021): 1137–1148. <https://doi.org/10.1007/s11858-021-01303-9>.

¹³ Hadiyanti, N. F. D., Hobri, A. C. Prihandoko, Susanto, R. P. Murtikusuma, N. Khasanah, and P. Maharani. "Development of Mathematics E-Module with STEM-Collaborative Project Based Learning to Improve Mathematical Literacy Ability of Vocational High School Students." *Journal of Physics: Conference Series* 1839, no. 1 (2021): 012031. <https://doi.org/10.1088/1742-6596/1839/1/012031>.

¹⁴ Pramasdyahsari, A. S., R. D. Setyawati, S. N. Aini, J. P. Arum, W. Widodo, I. D. Astutik, U. Nusuki, U. Salamah, and N. Zuliah. "Design Digital Book STEM-PjBL Using Context of Kota

contextual STEM-PjBL digital book to stimulate junior high school students' mathematical literacy. In an intervention study, Supianti et al.¹⁵ found that STEAM-PjBL supported secondary school students' mathematical literacy as well as character traits such as cooperation and responsibility. Susanta et al.¹⁶ also showed that the form of interaction in STEM learning can influence literacy achievement, indicating that technology integration should be viewed as part of the learning design rather than merely as an additional medium.

However, this body of literature leaves two needs unaddressed. First, the intervention components, educational levels, and research outcomes remain diverse: some studies focus on media development, some employ STEAM, and others compare forms of STEM without PjBL. Second, an increase in the total score often does not explain whether formulate, employ, and interpret develop proportionally. Students may successfully construct and process a model yet still fail to interpret the results, examine assumptions, or evaluate the reasonableness of a decision. Cevikbas et al.¹⁷ showed that modeling competence consists of several subcompetencies that do not necessarily develop simultaneously.

Based on these gaps, this study aimed to analyze the development of Grade 11 students' mathematical literacy during the implementation of STEM-integrated PjBL through classroom action research. The contribution of this study lies in aligning the project stages with the formulate, employ, and interpret processes and analyzing achievement in each process rather than considering only the total score. This study aimed to improve students' mathematical literacy through PjBL-STEM instruction and, specifically, to: (1) examine the improvement in students' mathematical literacy achievement from Cycle 1 to Cycle 2; (2) analyze the development patterns of the formulate, employ, and interpret processes; and (3) describe students' responses to PjBL-STEM instruction.

Semarang: Learning Media for Stimulating Students' Mathematical Literacy." *AIP Conference Proceedings* 3046, no. 1 (2024): 020044. <https://doi.org/10.1063/5.0194574>.

¹⁵ Supianti, I. I., P. Yaniawati, E. Bonyah, A. W. Hasbiah, and N. Rozalini. "STEAM Approach in Project-Based Learning to Develop Mathematical Literacy and Students' Character." *Infinity Journal* 14, no. 2 (2025): 283–302. <https://doi.org/10.22460/infinity.v14i2.p283-302>.

¹⁶ Susanta, A., E. Susanto, E. Stiadi, and Rusnilawati. "Mathematical Literacy Skills for Elementary School Students: A Comparative Study between Interactive STEM Learning and Paper-and-Pencil STEM Learning." *European Journal of Educational Research* 12, no. 4 (2023): 1569–1582. <https://doi.org/10.12973/eu-jer.12.4.1569>.

¹⁷ Cevikbas, M., G. Kaiser, and S. Schukajlow. "A Systematic Literature Review of the Current Discussion on Mathematical Modelling Competencies: State-of-the-Art Developments in Conceptualizing, Measuring, and Fostering." *Educational Studies in Mathematics* 109, no. 2 (2022): 205–236. <https://doi.org/10.1007/s10649-021-10104-6>.

Methods

1. Research Design and Participants

This study employed classroom action research (CAR) involving a cyclical process of planning, action, observation, and reflection to design improvements for the subsequent cycle¹⁸. This design was selected because the study aimed to improve instructional practice in a single class while documenting the development of students' mathematical literacy throughout the intervention. The researcher acted as the implementing teacher. The study was conducted at SMA Negeri 2 Parepare during the first semester of the 2025/2026 academic year and involved 27 students from Grade XI Excellent D.

The study was conducted in two cycles. Each cycle consisted of five meetings: four project-based learning sessions and one mathematical literacy test session, resulting in a total of ten meetings throughout the intervention. The study was concluded after Cycle II because the predetermined indicators of research success had been achieved, making a further cycle unnecessary. Thus, the reflection conducted at the end of Cycle II indicated that the implemented instructional intervention had met the established success criteria.

2. PjBL-STEM Intervention Design

The alignment presented in Table X was developed by integrating the principles of Project-Based Learning, STEM engineering design, and the PISA mathematical literacy framework. PjBL provides an authentic problem-oriented learning structure in which students investigate a driving question, develop solutions, and produce tangible outcomes¹⁹. Within STEM-integrated PjBL, engineering design serves as a connecting mechanism among science, technology, engineering, and mathematics through problem scoping, planning, construction, testing, evaluation, and redesign²⁰. These activities provide opportunities for students to engage in the three mathematical literacy processes defined by PISA: formulating situations mathematically, employing

¹⁸ Kemmis, S., R. McTaggart, and R. Nixon. *The Action Research Planner: Doing Critical Participatory Action Research*. Singapore: Springer, 2014. <https://doi.org/10.1007/978-981-4560-67-2>.

¹⁹ Krajcik, J. S., & Shin, N. (2022). Project-Based Learning. In *The Cambridge Handbook of the Learning Sciences* (pp. 72–92). Cambridge University Press. <https://doi.org/10.1017/978110888295.006>

²⁰ English, L. D., & King, D. T. (2015). STEM learning through engineering design: fourth-grade students' investigations in aerospace. *International Journal of STEM Education*, 2(1), 14. <https://doi.org/10.1186/s40594-015-0027-7>. Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1), 11. <https://doi.org/10.1186/s40594-016-0046-z>

mathematical concepts, facts, and procedures, and interpreting and evaluating mathematical outcomes²¹.

Table 1. Alignment of PjBL, STEM, and Mathematical Literacy Processes

PjBL Stage	STEM Function	Primary Mathematical Activity	Dominant Literacy Process
Problem orientation	Science provides phenomena; technology supports initial exploration	Identifying information, quantities, constraints, and problem objectives	Formulate
Project planning	Engineering guides the design; technology supports representation	Determining assumptions, variables, models, strategies, and a measurement plan	Formulate and employ
Investigation and development	Measurement, data processing, and product creation or simulation	Using concepts, procedures, symbols, tables, graphs, and calculations	Employ
Testing and improvement	The design is tested against data, criteria, or constraints	Comparing predictions with results and checking units, errors, and reasonableness	Employ and interpret
Presentation and reflection	Technology communicates the results; engineering supports revision	Explaining the meaning of results, assessing assumptions and limitations, and drawing conclusions	Interpret

Sumber: Sintesis penulis berdasarkan English and etc²²

3. Instruments and Data Collection

The primary data were obtained through a mathematical literacy test and a student-response questionnaire. The test was designed to generate a total score on a 0–100 scale and scores for the three mathematical literacy processes. Formulate assessed the ability to identify the mathematical structure of a problem and determine an appropriate model or strategy; employ assessed the use of concepts, procedures, reasoning, and representations; and interpret assessed the ability to explain results, relate

²¹ OECD. (2026). *PISA 2025 Results (Volume I) Future-Ready Students*.

²² English, L. D., & King, D. T. (2015). STEM learning through engineering design: fourth-grade students' investigations in aerospace. *International Journal of STEM Education*, 2(1), 14. <https://doi.org/10.1186/s40594-015-0027-7>. Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1), 11. <https://doi.org/10.1186/s40594-016-0046-z> Krajcik, J. S., & Shin, N. (2022). Project-Based Learning. In *The Cambridge Handbook of the Learning Sciences* (pp. 72–92). Cambridge University Press. <https://doi.org/10.1017/9781108888295.006> OECD. (2026). *PISA 2025 Results (Volume I) Future-Ready Students*. Robert M. Capraro. (2013). *STEM Project-Based Learning* (R. M. Capraro, M. M. Capraro, & J. R. Morgan, Eds.). SensePublishers. <https://doi.org/10.1007/978-94-6209-143-6>

them to the context, and evaluate the reasonableness of solutions. The operational focus of each process is presented in Table 2.

Table 2. Measurement Focus of the Mathematical Literacy Processes

Process	Operational Focus	Evidence in Students' Responses
Formulate	Translating a real-world problem into mathematical form and determining a strategy	Relevant information, assumptions, variables, models, diagrams, or solution plans
Employ	Using concepts, facts, procedures, reasoning, and representations	Calculations, manipulations, tables, graphs, symbols, and reasons for selecting procedures
Interpret	Interpreting, applying, and evaluating results in relation to the context	Meaning of results, units, reasonableness, limitations, decisions, and conclusions

*PISA 2025 (OECD, 2026)*²³.

The student-response questionnaire was used to obtain data on students' acceptance of the implementation of PjBL-STEM instruction. The instrument consisted of 15 statements rated on a four-point Likert scale.

4. Data Analysis

The total score and the score for each process were analyzed descriptively using the number of participants, minimum, maximum, mean, and standard deviation. The score categories used in this study were low (0–65), moderate (66–75), and high (76–100). These were local interpretive categories for the research instrument rather than PISA proficiency levels. Change across cycles was calculated as the difference between the Cycle 2 and Cycle 1 means. Individual normalized gain was calculated using $g = (\text{Cycle 2} - \text{Cycle 1}) / (100 - \text{Cycle 1})$ and then averaged; $g < 0.30$ was categorized as low, $0.30 \leq g < 0.70$ as moderate, and $g \geq 0.70$ as high²⁴. In this analysis, the Cycle 1 score served as the initial score for calculating development toward Cycle 2, not as a pretest administered before the entire intervention.

Student responses were analyzed using the mean percentage and the predetermined categories. Questionnaire scores were converted into percentages: scores of 0–43 were categorized as very poor, 44–62 as poor, 63–81 as good, and 82–100 as very good, in accordance with the guidelines used in this study²⁵. Because responses and cognitive ability are distinct constructs,

²³ OECD. (2026). *PISA 2025 Results (Volume I) Future-Ready Students*.

²⁴ Mandur, K., et al. "Improving University Students' Mathematics Achievement through the Development of Web Blog-Based Integral Calculus Teaching Materials." *Aksioma: Jurnal Program Studi Pendidikan Matematika* 14, no. 4 (2025): 1349–1366. <https://doi.org/10.24127/ajpm.v14i4.14001>.

²⁵ Putra, A. R. "Penerapan Modul Project Based Learning (PjBL) pada Mata Pelajaran Teknik Pemesinan CNC di SMK Antartika 1 Sidoarjo." *JPTM* 14, no. 1 (2025): 1–6.

response scores were not treated as evidence of improvement in mathematical literacy.

Results and Discussion

1. Overall Development of Mathematical Literacy

The descriptive statistics in Table 3 show that the mean mathematical literacy score increased by 18.02 points, from 52.10 in Cycle 1 to 70.12 in Cycle 2. Based on the categories used in this study, the class means moved from the low to the moderate category. The mean N-Gain was 0.36, which was categorized as moderate. The minimum score increased by 13.63 points, whereas the maximum score increased by 2.28 points. The standard deviation decreased from 26.54 to 19.33, indicating that the Cycle 2 scores were more concentrated around the mean than the Cycle 1 scores.

Table 3. Descriptive Statistics for Mathematical Literacy Across Two Cycles

Measure	N	Minimum	Maximum	Mean	SD
Mathematical literacy, Cycle 1	27	13.64	95.45	52.10	26.54
Mathematical literacy, Cycle 2	27	27.27	97.73	70.12	19.33
Individual N-Gain	27	0.00	0.84	0.36	0.20

Changes in the mean and score dispersion should be interpreted together. The lower standard deviation and higher minimum score indicate that development was not confined to students with high scores. However, the minimum N-Gain of 0.00 shows that at least one student demonstrated no measurable development. Because the source document did not provide category distributions for individual students or paired data, the proportions of students whose scores increased, remained unchanged, or decreased could not be reported.

2. Development of Formulate, Employ, and Interpret

The process-level analysis revealed an uneven pattern of development (Table 4). Formulate showed the largest increase, at 20.68 points, followed by employ at 19.60 points. Both reached the high category in Cycle 2. By contrast, interpretation increased by only 9.26 points and remained in the low category. Thus, the increase in the total score was primarily supported by students' ability to formulate problems and employ mathematics, whereas returning mathematical results to the original context remained the main challenge.

Table 4. Score Development by Mathematical Literacy Process

Process	Cycle 1	Category	Cycle 2	Category	Change
Formulate	59.57	Low	80.25	High	+20.68
Employ	56.79	Low	76.39	High	+19.60
Interpret	26.85	Low	36.11	Low	+9.26

3. Student Responses

The mean student response to PjBL-STEM was 79.14 and was categorized as good. This result indicates generally positive acceptance of the project-based learning experience. However, the source document provided only a single mean score without a standard deviation, category distribution, or item-level summary. Therefore, the response results cannot identify which aspects of the instruction students found most engaging, most helpful, or most challenging.

4. Development of Mathematical Literacy During PjBL-STEM

The results showed a substantial development in mathematical literacy, from 52.10 to 70.12. The mean increase of 18.02 points and the N-Gain of 0.36 indicate a moderate level of change, while the decrease in the standard deviation indicates a narrower dispersion of scores. This pattern is consistent with the argument that authentic projects provide students with a functional reason to use mathematics. When numbers, representations, and procedures are needed to create or evaluate a design, mathematical concepts are no longer positioned as abstract objectives detached from their application.

The increase in the mean mathematical literacy score indicates that integrating the PjBL syntax with the STEM approach can strengthen students' conceptual and applied understanding. In STEM learning, mathematics is not studied in isolation; instead, it serves as a tool for analysis and modeling to solve scientific and technological engineering problems²⁶. Project-based learning allows students to explore mathematical concepts more meaningfully, thereby fostering sustained cognitive engagement and deep understanding²⁷.

²⁶ Sulaiman, F., Jeffry Juan Rosales, and Jae Kyung Lee. "The effectiveness of integrated science, technology, engineering and mathematics project-based learning module." *International Journal of Evaluation and Research in Education (IJERE)* (2024). <https://doi.org/10.11591/ijere.v13i3.26676>.

²⁷ Siskawati, F. S., S. A. Ayubi, A. Mt, E. Wahyuni, and M. Maswar. "Development of Project-Based Learning Using Mathematical Aquaponics with a Deep Learning Approach." *Alifmatika: Jurnal Pendidikan dan Pembelajaran Matematika* 8, no. 1 (2026): 121-134. <https://doi.org/10.35316/alifmatika.2026.v8i1.121-134>; S. Prajoko, I. Sukmawati, A. F. Maris, and A. N. Wulanjani, "Project Based Learning (PjBL) Model with STEM Approach on Students' Conceptual Understanding and Creativity," *Jurnal Pendidikan IPA Indonesia* 12, no. 3 (2023): 401, <https://doi.org/10.15294/jpii.v12i3.42973>

This finding is consistent with the meta-analysis by Zhang and Ma²⁸, which demonstrated the positive contribution of PjBL to academic achievement, thinking skills, and affective outcomes. However, consistency between the findings does not mean that the increase observed in this study can be attributed exclusively to PjBL-STEM. Classroom action research combines an intervention with improvements in facilitation across cycles. In addition to students' growing experience, the changes may have been influenced by clearer instructions, group management, scaffolding, feedback, and familiarity with the test format. Therefore, the most appropriate term is development during the intervention rather than an isolated causal effect.

From a pedagogical perspective, STEM integration can explain why projects support more meaningful uses of mathematics. Science provides phenomena and constraints that must be understood; technology expands the ways in which information can be obtained, processed, and represented; engineering requires students to design and test solutions; and mathematics provides the language for measuring, modeling, comparing, and making decisions. This framework is consistent with Maass et al.²⁹, who identified interdisciplinary integration and authentic contexts as important features of STEM. The review by Rahman et al.³⁰ also showed that problem solving, communication, collaboration, technology, and projects are dominant practices in STEM-based mathematics instruction.

Implementing this framework still requires coherence among the driving question, mathematical objectives, activities, product, and assessment. Markula and Aksela³¹ showed that successful PjBL is supported by a driving problem, collaboration, artifacts, technology use, presentation, and reflection, although these characteristics are not always easy to implement consistently. In the context of the present study, the increase in Cycle 2 may reflect the benefits of a reflective cycle that enabled the teacher to improve the quality of instructional support. This proposed mechanism should be confirmed using structured observation records in the final manuscript.

The increase in the minimum score and the decrease in the standard deviation suggest that class development involved more than a shift in the mean. Nevertheless, a smaller standard deviation does not establish homogeneity of ability, and the minimum N-Gain of 0.00 indicates that some

²⁸ Zhang and Ma, "Impact of Project-Based Learning."

²⁹ Maass, K., V. Geiger, M. Romero Ariza, and M. Goos. "The Role of Mathematics in Interdisciplinary STEM Education." *ZDM-Mathematics Education* 51, no. 6 (2019): 869–884. <https://doi.org/10.1007/s11858-019-01100-5>.

³⁰ Rahman et al., "Mathematics Teachers' Practices of STEM Education."

³¹ Markula, A., and M. Aksela. "The Key Characteristics of Project-Based Learning: How Teachers Implement Projects in K–12 Science Education." *Disciplinary and Interdisciplinary Science Education Research* 4 (2022): article 2. <https://doi.org/10.1186/s43031-021-00042-x>.

students still require targeted support. In practice, PjBL-STEM should therefore incorporate differentiation, including guiding questions for selecting information, tables showing relationships among variables, examples of how to use representations, feedback on the rationale for selected strategies, and brief conferences with groups or individual students who encounter difficulties. Such support should be gradually reduced so that it does not replace students' reasoning.

5. *Development Across the Mathematical Literacy Processes*

The most important contribution of this study concerns the uneven development across components. The gains in formulate and employ were nearly twice the gain in interpret. This finding demonstrates that a total score may conceal weaknesses at the final stage of the literacy cycle. According to the OECD³², formulate, employ, and interpret are interconnected processes: a real-world situation is translated into the mathematical world, solved mathematically, and then the results are returned to the real world. Literacy remains incomplete when students can obtain a numerical answer but cannot explain whether it is reasonable or useful for making decisions in the original context.

The scores for *Formulate* (80.25) and *Employ* (76.39) reached the high category in Cycle 2, supported by *engineering design* activities such as identifying constraints, creating sketches, and performing measurements and calculations. These activities helped students formulate problems and apply mathematics in developing design solutions³³. This process trained students to use variables, algebraic symbols, tables, and graphs flexibly (employ) as forms of contextual mathematical representation³⁴. The study by Masjudin et al.³⁵ also confirmed that students' engagement in interdisciplinary STEM projects consistently improves mathematical problem-solving performance and mathematical computation skills.

The improvement in the formulate process can be explained by the characteristics of the initial project stages. Before performing calculations, students needed to identify needs, select relevant information, determine

³² OECD, *PISA 2022 Assessment and Analytical Framework*.

³³ English, Lyn D., and D. King. "STEM learning through engineering design: fourth-grade students' investigations in aerospace." *International Journal of STEM Education* 2 (2015): 1-18. <https://doi.org/10.1186/s40594-015-0027-7>.

³⁴ Tika Siswanti and Djamilah Bondan Widjajanti, "Exploration Influence Problem-Based Learning STEM-Based towards Ability Literacy Mathematics Middle School Students," *International Journal of Multicultural and Multireligious Understanding* 11, no. 8 (2024): 858, <https://doi.org/10.18415/ijmmu.v11i8.6142>

³⁵ Masjudin, M., A. Muliadi, A. Kurniawan, F. Fatwini, I. C. Nissa, and A. Adaminata. "Development of STEM-Integrated Problem-Based Learning Instructional Materials to Enhance Science Students' Problem-Solving Ability." *Jurnal Penelitian Pendidikan IPA* 8, no. 5 (2022). <https://doi.org/10.29303/jppipa.v8i5.13075>.

quantities, make assumptions, and formulate design constraints. These activities slowed the tendency to search for a formula immediately and directed attention to the structure of the problem. Improvement in the employ process subsequently emerged when students used concepts, procedures, tables, graphs, symbols, or technology to process data and test their designs. The findings of Susanta et al.³⁶ support the importance of interaction design in STEM learning; technology becomes meaningful when it helps students construct and test representations rather than merely enhancing the appearance of a product.

A crucial finding of this study was the relatively low achievement in interpret (36.11 in Cycle 2). This phenomenon indicates that students experienced cognitive overload when they were asked to evaluate the limitations of mathematical models, communicate theoretical reasoning, and reflect on calculation results in relation to real-world constraints. The low interpret score is consistent with global and national PISA assessment findings³⁷. Indonesian students are generally accustomed to procedural-algebraic thinking, as reflected in the formulate and employ processes, but remain weak in critical argumentation, reflective evaluation, and the formulation of qualitative judgments based on mathematical data. For subsequent interventions, the instructional syntax should be strengthened during the reflection and evaluation stages through mathematical argumentation discussions and evaluative presentations.

The interpret process requires a different cognitive transition. Students must relate results to units and context, examine magnitudes, compare results with data or product performance, assess assumptions, recognize model limitations, and formulate evidence-based conclusions. The review by Cevikbas et al.³⁸ showed that modeling competence consists of multiple subcompetencies; success in carrying out procedures does not guarantee success in validating or evaluating a model. This gap emerges when instruction treats a task as complete once a product has been created or a numerical answer obtained.

The low interpret score may also indicate the dominance of a product orientation. Diego-Mantecon et al.³⁹ found that mathematics in STEAM projects is sometimes limited to basic calculations and does not always involve strong cognitive demand. If project assessment places greater emphasis on neatness, visual creativity, or the physical success of a product, students may achieve

³⁶ Susanta et al., "Mathematical Literacy Skills for Elementary School Students."

³⁷ Stacey, K. "The PISA View of Mathematical Literacy in Indonesia." *Journal on Mathematics Education* 2, no. 2 (2011): 95–126. <https://doi.org/10.22342/jme.2.2.746.95-126>.

³⁸ Cevikbas, Kaiser, and Schukajlow, "Systematic Literature Review."

³⁹ Diego-Mantecon et al., "Attempt to Evaluate STEAM Project-Based Instruction."

good results without being accountable for the quality of their mathematical decisions. Therefore, project presentations should require answers to the following questions: What does this result mean? Are the units and magnitude reasonable? What assumptions were used? How do the data support the decision? Under what conditions does the model no longer apply? What needs to be revised?

This finding is consistent with the report by Supianti et al.⁴⁰ on the potential of STEAM-PjBL to support mathematical literacy, while extending the discussion by showing that literacy components can develop asymmetrically. In other words, the success of the approach cannot be evaluated solely from a total score or the project product. Evaluation must identify where development and difficulties occur throughout the modeling cycle so that teachers can design targeted interventions.

6. Student Responses and the Quality of the Learning Experience

The student-response score of 79.14 indicates good acceptance of PjBL-STEM. This positive response may have been encouraged by concrete project objectives, opportunities for collaboration, the use of technology, varied representations, and the creation of a presentable product. This finding is consistent with Zhang and Ma⁴¹, who demonstrated the contribution of PjBL to affective outcomes, and Supianti et al.⁴², who reported that STEAM-PjBL supported cooperation, communication, and responsibility.

Nevertheless, a positive response is not equivalent to cognitive development. Students may enjoy a project because of its novelty, technology, or group interaction, even when the demands of interpretation have not been adequately addressed. The gap between the positive response and the persistently low interpret score instead demonstrates the need to distinguish evidence of the learning experience from evidence of mastery of mathematical processes.

Moreover, group work can generate positive responses while obscuring differences in individual contributions. Certain students may dominate the project product, while other members participate primarily in nonmathematical aspects. To maintain assessment validity, group assessment should be combined with individual evidence, such as decision logs, brief reflections, oral questions, or transfer tests that require students to explain a model and evaluate a new solution independently.

⁴⁰ Supianti et al., "STEAM Approach in Project-Based Learning."

⁴¹ Zhang and Ma, "Impact of Project-Based Learning."

⁴² Supianti et al., "STEAM Approach in Project-Based Learning."

Conclusion

The implementation of STEM-integrated PjBL across two cycles was accompanied by the descriptive development of mathematical literacy among students in Grade 11 Excellent D. The mean score increased from 52.10 to 70.12, with an N-Gain of 0.36. Student responses, meanwhile, fell within the good category. This development was uneven: formulate and employ reached the high category in Cycle 2, whereas interpret remained in the low category. Thus, the primary contribution of the intervention was evident in students' ability to formulate problems and employ mathematics, while the interpretation and evaluation of results remained critical challenges.

Future research is recommended to involve a larger sample and place greater emphasis on strengthening the *interpret* process, particularly in interpreting results, checking the reasonableness of solutions, and relating mathematical outcomes back to the problem context. A longer duration of instruction may also be considered to provide a more comprehensive picture of students' mathematical literacy development.

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